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Leaders in what's now. Innovators of what's next.

Enhanced Loran

Resilient Timing and UTC in the United States

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This document does not contain critical or sensitive information and there are no risks with the public release of the information.

Motivation For a Resilient Timing & UTC Service

GPS / GNSS *Vulnerabilities*

- ✓ **Antenna needs clear view of the sky**
- ✓ **Performance Degradation**
  - ✓ **Natural**
  - ✓ **Human**
- ✓ **Spectrum Competition**
- ✓ **Radio Frequency Interference**
- ✓ **System Anomalies & Failures**
- ✓ **Jamming**
- ✓ **Spoofing & Counterfeit Signals**
- ✓ **Proliferation of Satellite Systems**
- ✓ ***Satellite Launch Problems***
- ✓ ***Ground Segment Problems***
- ✓ ***Onboard Technology Problems***
- ✓ ***Program Delays***
- ✓ ***Funding Issues***

“ Of the 16 Critical Infrastructure / Key Resource sectors in the U.S., 15 use GPS for **timing**.

GPS **timing** is deemed **essential** for 11 of the sectors. ”

Source: U.S. DHS

Why should you care?

Banking | Finance MiFID | FINRA | SEC | NYSE
Regulations are evolving from millisecond time stamping to tens of microseconds, or even single microsecond levels. Synchronization moving from ***relative*** to ***absolute*** time.

Telecommunications No need for an external antenna and a long run of conduit to connect the antenna to the PTP servers.

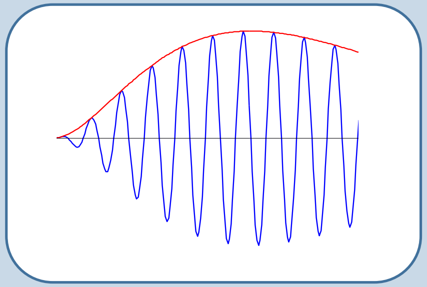
Electrical Power Utility Without electricity, most other things don't matter. Which one can you do without for one day, one week, or one month: GPS, telecommunications, electricity?

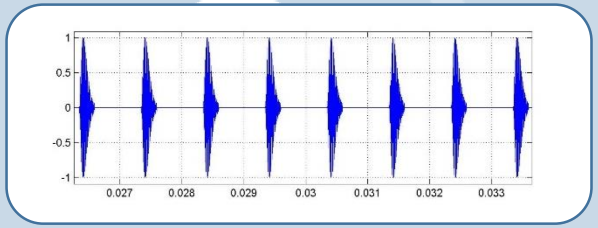
Aviation Ground Segment Synchronization
NextGen | ADS-B Constructing an event timeline requires information from many systems in many locations. The time stamps of the system logs of all these systems need to be synchronized accurately within a few microseconds.

What is Loran-C?

Loran-C:

- Developed by DOD
- Global PNT standard: 1957-2010+
- Radio Frequency (RF) system
- 90 – 110 kHz internationally protected spectrum
- **Ground wave** signal
- Very high power
- Pulsed
- Stratum-1e frequency standard
- Positioning, Navigation, Timing





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What is *Enhanced* Loran?

eLoran-21

Enhanced **Loran:**

All the good stuff from Loran-C, plus:

- Time-of-Transmission control
- Differential corrections (dLoran and/or DGPS)
- Receivers can use all-in-view signals
- Loran Data Channel (LDC)
- Additional integrity
- Transmissions synchronized to UTC

***New* Infrastructure & Technology**

- 21st century solid state transmitters
- Three cesium-based PRS per station
- Precision time & frequency equipment
- Whole-station UPS
- Secure telecommunications

***New* Operations Paradigms**

- Unmanned and/or autonomous operation
- Sites v. Stations
- Time-of-Emission v. System Area Monitor
- Terrain effects (ASF) modeling and/or measurement

GPS (GNSS) & (e)Loran

How are they *similar?*

- Developed by the DOD (GOV)
- Get time from the USNO (UTC)
- Provide PNT
- Better with augmentations
- Stratum-1e
- Hyperbolic
- Global standard
- Free (when Government provided)
- Azimuth / Compass
- Ground infrastructure

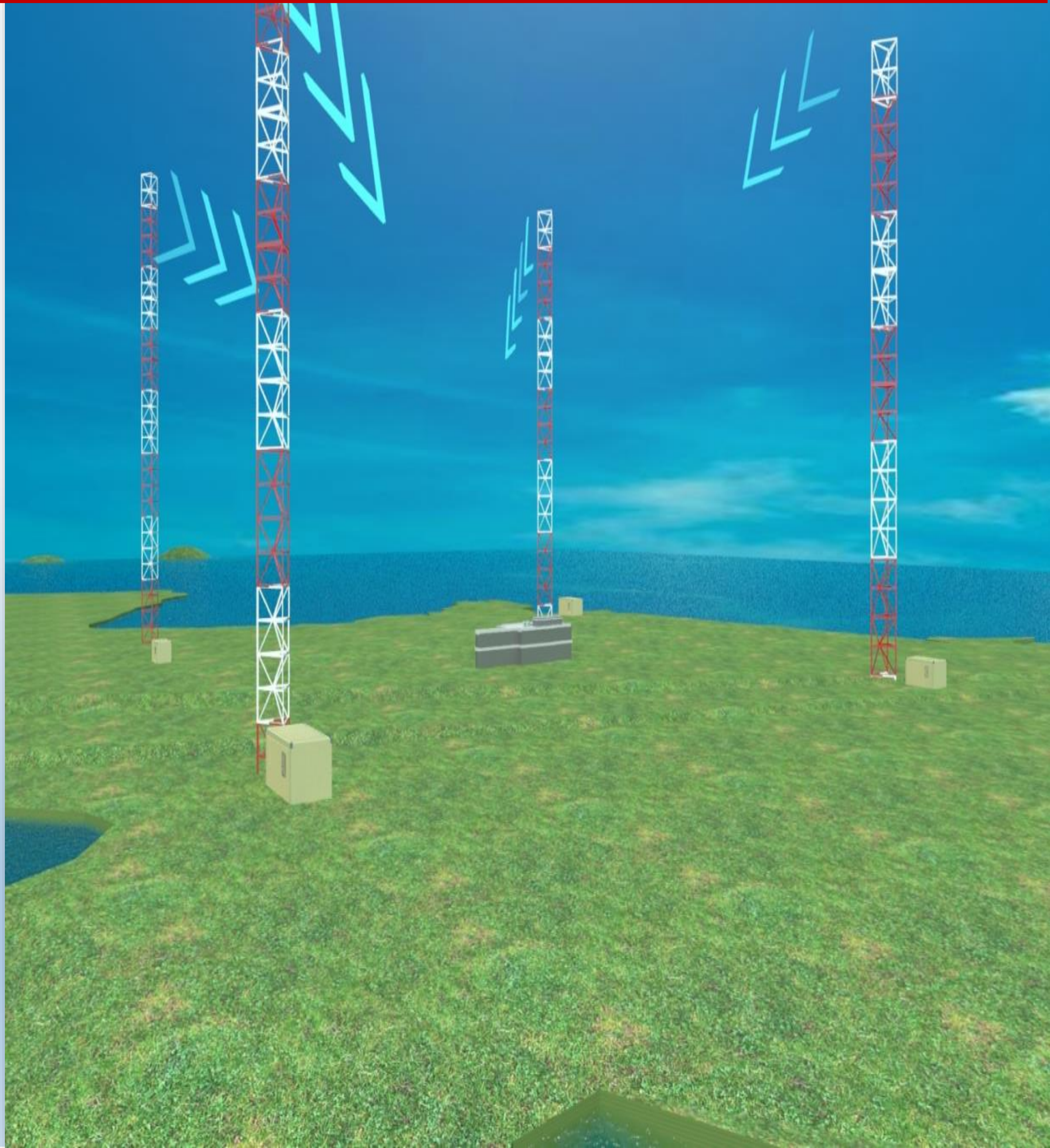
Old / antiquated technology?

TV: 1925 → Radar: 1934 → Loran-A: 1940 → Loran-C: 1957 → SatNav: 1959 → ARPANet: 1963

How are they *different*?

	GPS	eLoran
System:	GPS	eLoran
Frequency:	Very High	Very Low
Power:	Very Low	Very High
Transmissions:	Space	Terrestrial
Jamming:	Easy	Very Hard
Spoofing:	Becoming Easier	Very Hard
Integrity:	None	Built In
Data Channel:	None	At least one
Reach:	Global	Continental
Accuracy:	Best	Good
Positioning:	3D	2D*
Propagation:	Atmosphere	Ground
View Required:	Clear	Obstructed OK

*3D with altimeter



eLoran Generation 21 Technology

eLoran-21

User Receivers

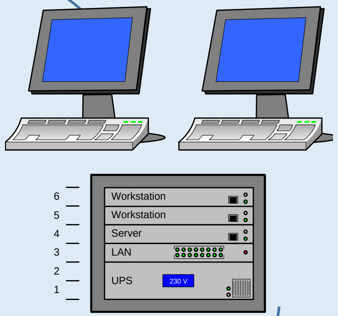
Differential Reference Site

Remote Time Scale
GNSS (GPS)
TWSTT
TWLFTT
Microwave
Dedicated fiber
"Hot Clock"

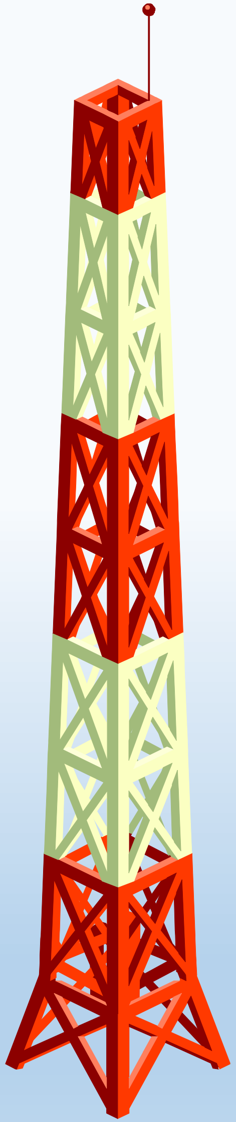
Local Time Scale
PRS
PRS
PRS

Transmitting Site

Can operate 70-90 days without remote reference.



"Control" & Monitor Site



What good is it to me?

eLoran provides "proof of time" and "proof of location".

eLoran reaches inside buildings, even without windows.

eLoran is not hold-over. It is a co-primary source of time.

With eLoran inside, no antenna on the roof.

eLoran is an enabler, and extends and enhances other technologies.

eLoran provides timing at the cabinet on the edge of the network.

eLoran has built-in integrity, and provides integrity to GPS.

eLoran can provide synchronization simultaneously over very large areas.

eLoran is a multi-modal solution: timing/frequency, aviation, maritime, handheld, land-mobile.

Complement, backup, alternative, co-primary.

Evaluating eLoran as a Wide Area Timing Source

- Transmissions from former USCG Loran Support Unit site at Wildwood, NJ
  - 360 KW Effective Radiated Power
  - Two Way Satellite Time Transfer (TWSTT) UTC reference from the US Naval Observatory

- Receivers and Distance from Transmitting Site
  - Washington, DC (USNO) (120 Miles)
  - Leesburg, VA (140 Miles)
  - N. Billerica, MA (310 Miles)
  - Columbus, OH (440 Miles)
  - Bangor, ME (500 Miles)
  - Ocala, FL (790 Miles)

- Technology
  - Outdoor E-Field antenna
  - Outdoor Loop antenna
  - Indoor | Outdoor H-Field antenna
  - Loran Data Channel (LDC) demodulation available
  - GPS and/or Primary Reference Standard used as comparison

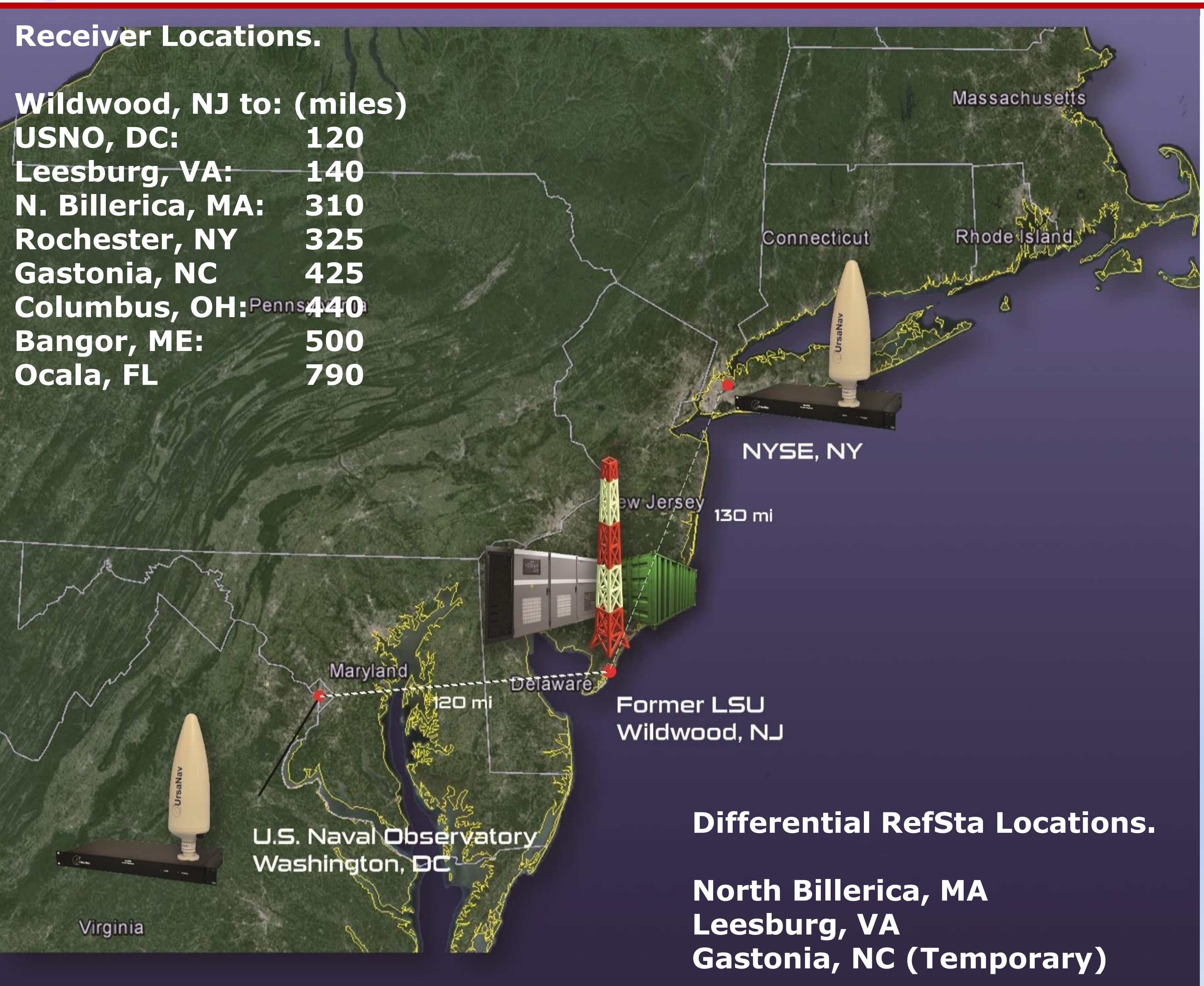
- Criteria
  - Meet one microsecond 2014 FRP timing user requirement

eLoran Timing Evaluation Technology Laydown

Receiver Locations.

Wildwood, NJ to: (miles)

USNO, DC:	**120**
Leesburg, VA:	**140**
N. Billerica, MA:	**310**
Rochester, NY	**325**
Gastonia, NC	**425**
Columbus, OH:	**440**
Bangor, ME:	**500**
Ocala, FL	**790**



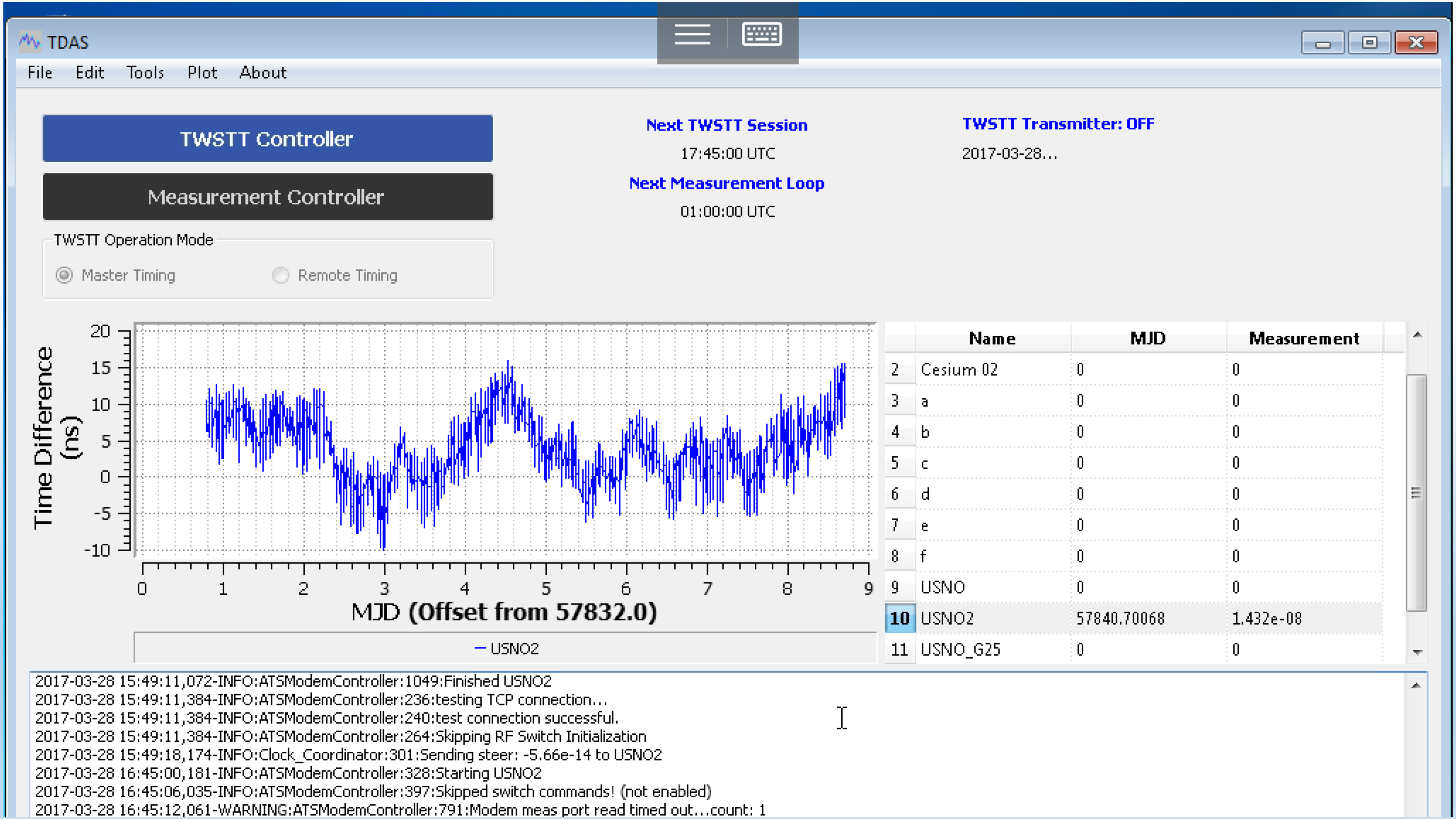
Differential RefSta Locations.

North Billerica, MA
Leesburg, VA
Gastonia, NC (Temporary)

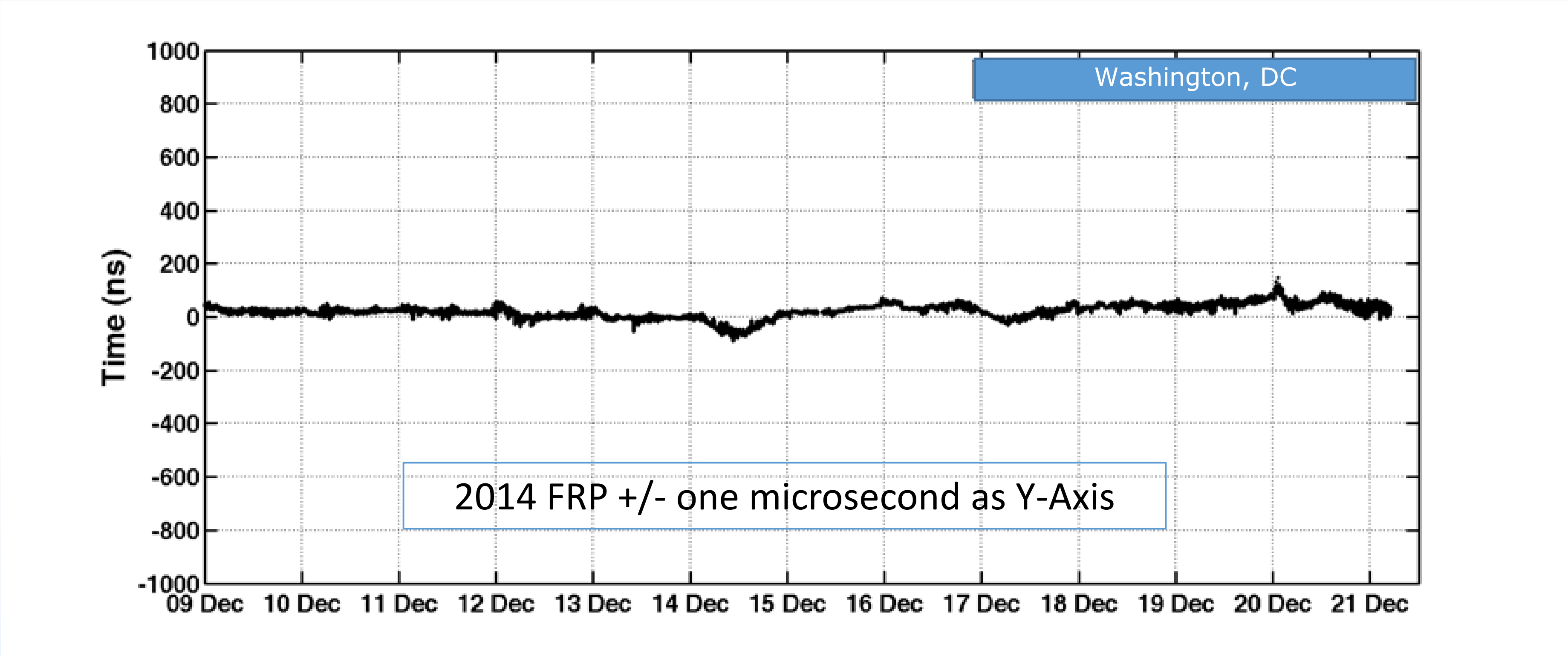
eLoran Transmissions from former USCG Loran Support Unit Wildwood, NJ

- Synchronized to UTC via Two Way Satellite Time Transfer **(TWSTT)** provided by US Naval Observatory
- **360 kW** of Effective Radiated Power
- Broadcasting dual rated as 8970 Master and Secondary
- Data sent via **LDC** only on Secondary rate at raw data rate of 56 bps and effective data rate of 21 bps

Master UTC @ USNO <- TWSTT -> PRS @ Wildwood, NJ Transmitting Site
PRS Steered by USNO

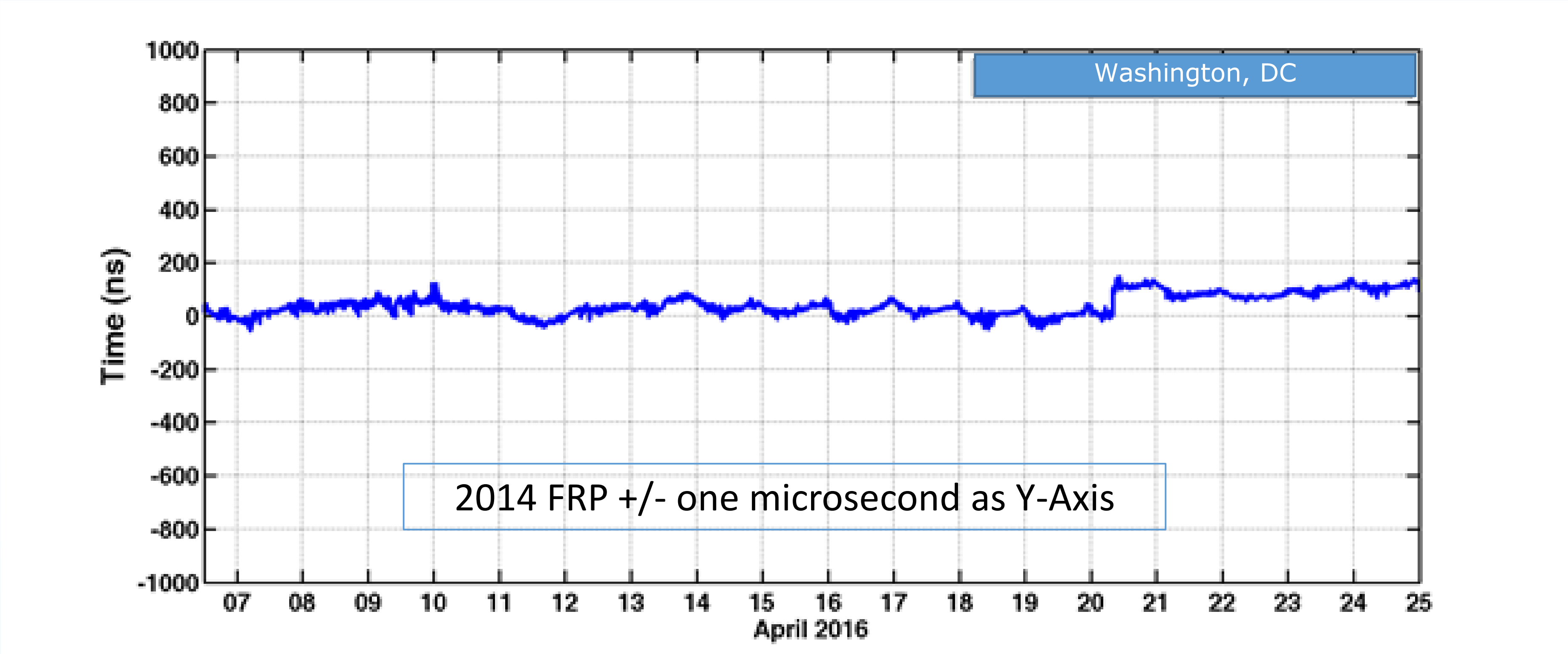


Wildwood, NJ to Washington, DC (USNO) User Receiver



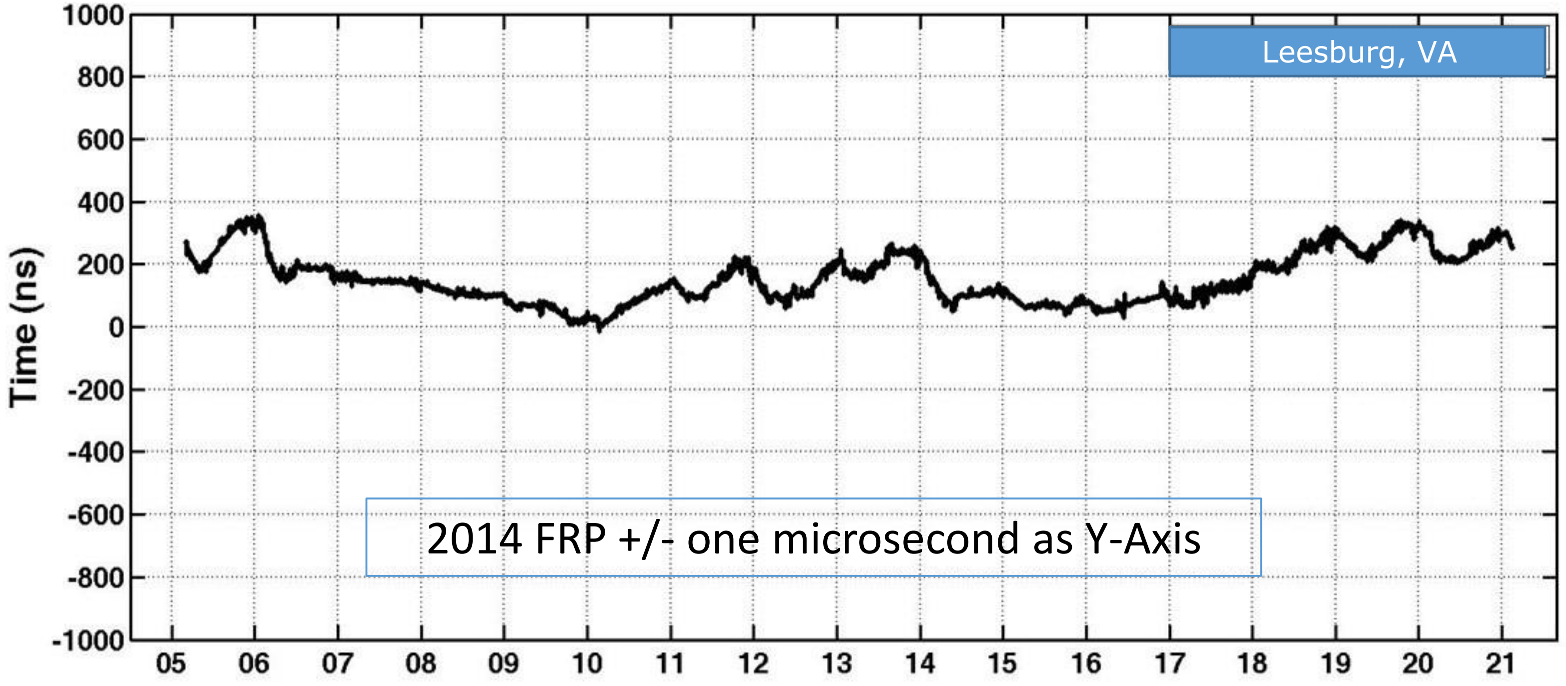
Period: December 2015
Distance to XMTR: 120 miles
Mean: 22.9 ns
STD: 26.1 ns
Max: 147.0 ns
Min: -90.0 ns

Wildwood, NJ to Washington, DC (USNO) User Receiver



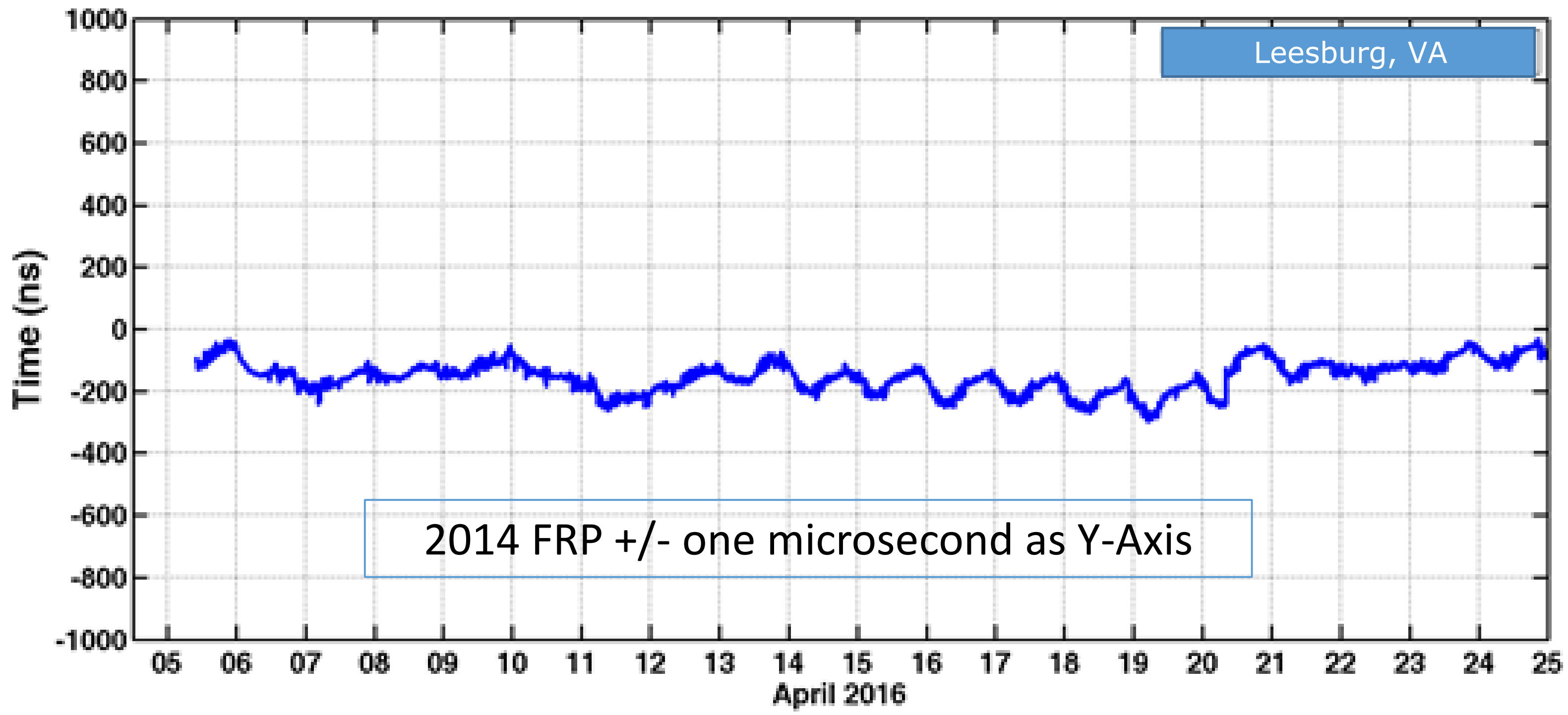
Period: April 2016
Distance to XMTR: 120 miles
Mean: 41.3 ns
STD: 39.4 ns
Max: 147.0 ns
Min: -57.0 ns

Wildwood, NJ to Leesburg, VA User Receiver



Period: January 2016
Distance to XMTR: 140 miles
Mean: 153.6 ns
STD: 79.9 ns
Max: 358.0 ns
Min: -16.0 ns

Wildwood, NJ to Leesburg, VA User Receiver



Period: April 2016

Distance to XMTR: 140 miles

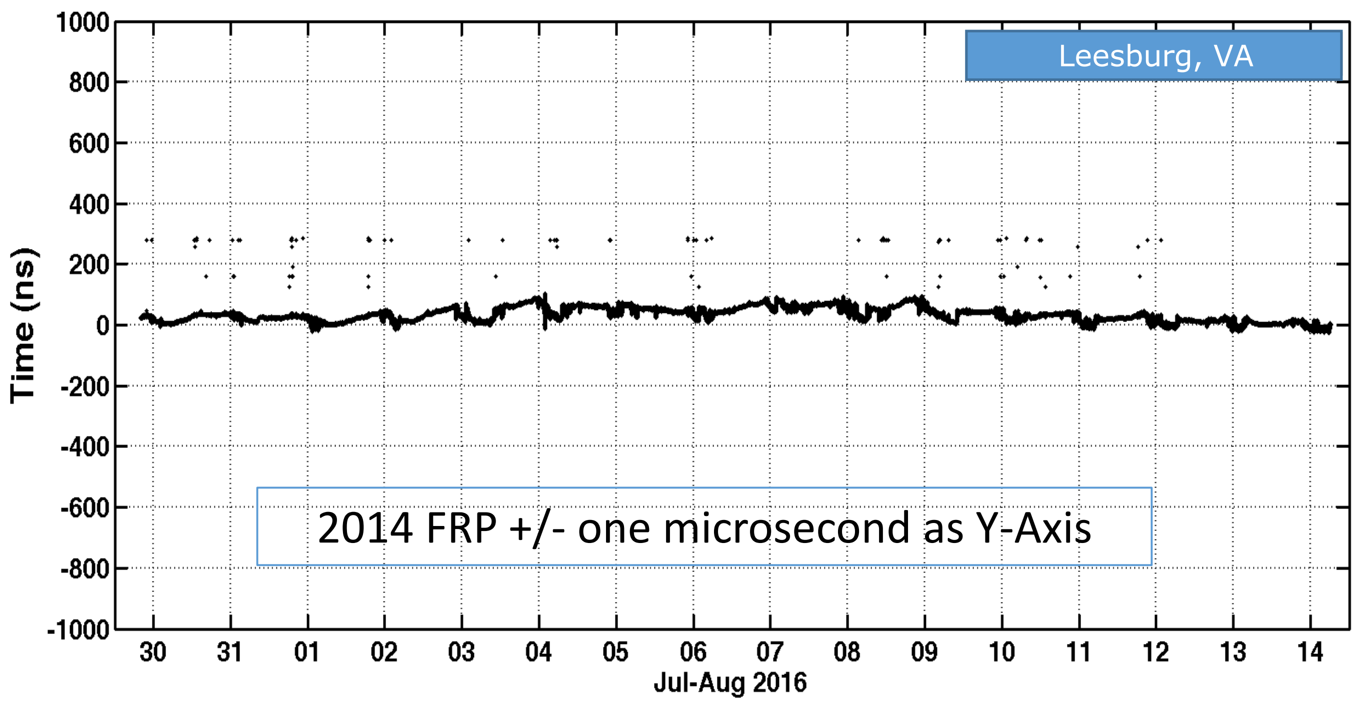
Mean: -153.0 ns

STD: 49.1 ns

Max: -31.0 ns

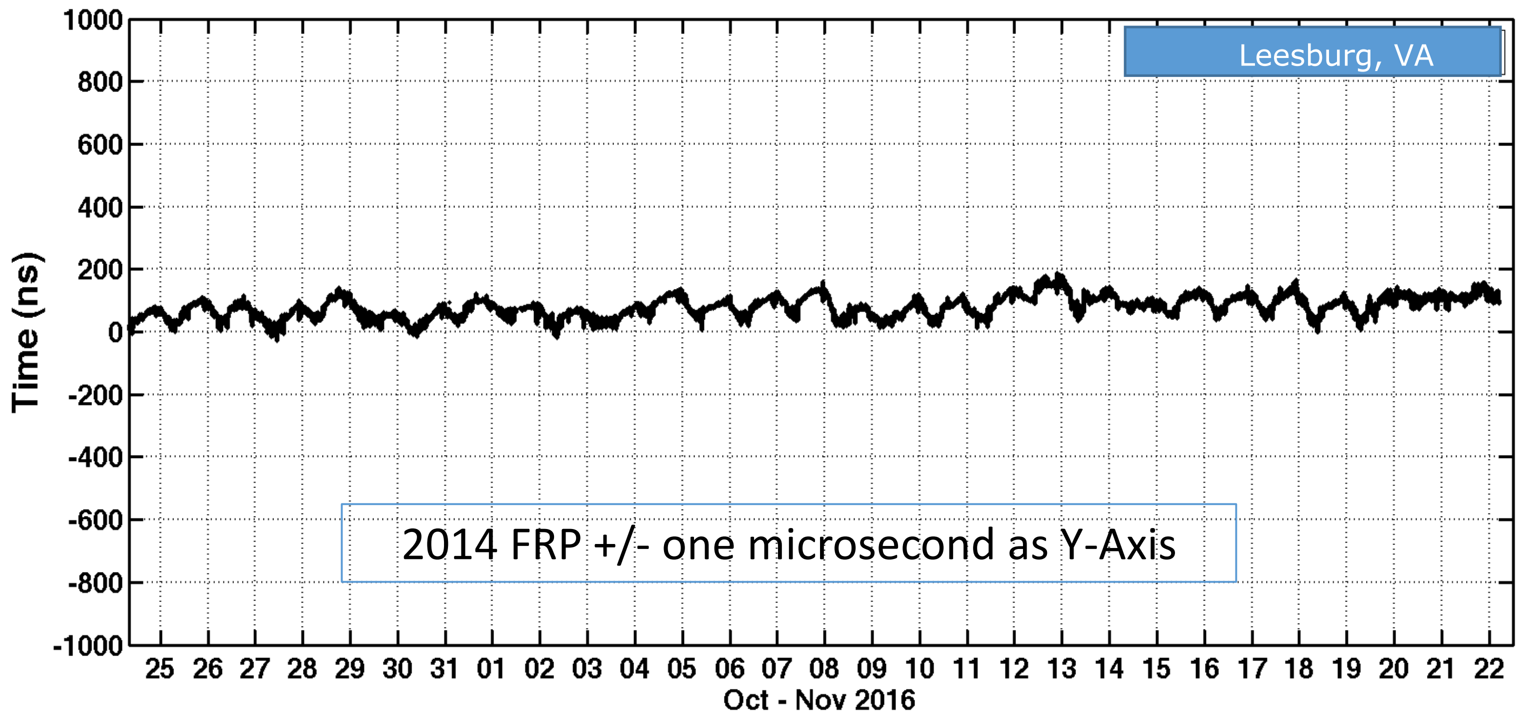
Min: -298.0 ns

Wildwood, NJ to Leesburg, VA User Receiver



Period July – August 2016
Distance to XMTR: 140 miles
Mean: 33.3 ns
Std: 23.2 ns
Max: 287.0 ns
Min: -25.0 ns

Wildwood, NJ to Leesburg, VA User Receiver



Period: October – November 2016

Distance to XMTR: 140 miles

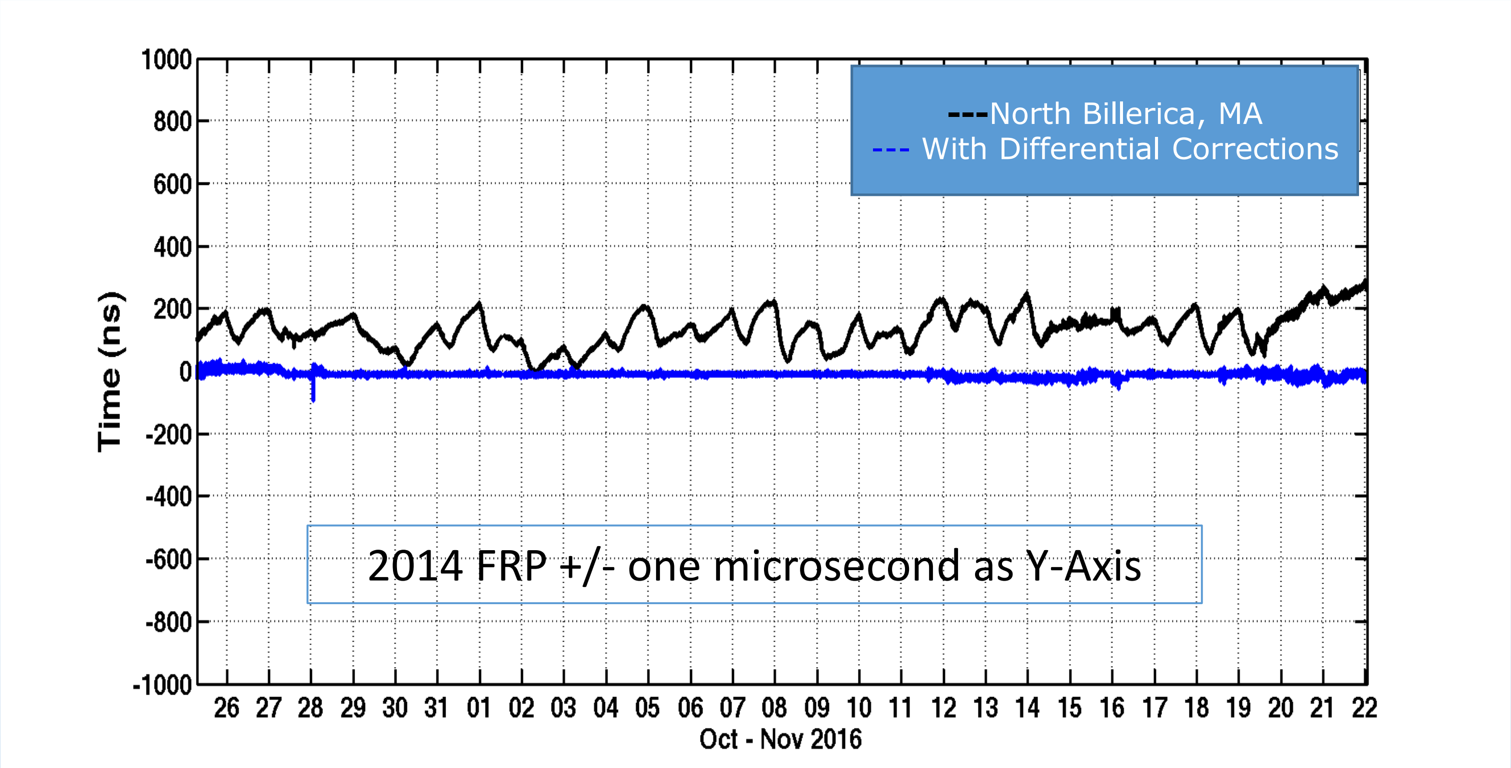
Mean: 79.1 ns

Std: 33.1 ns

Max: 188.0 ns

Min: -29.0 ns

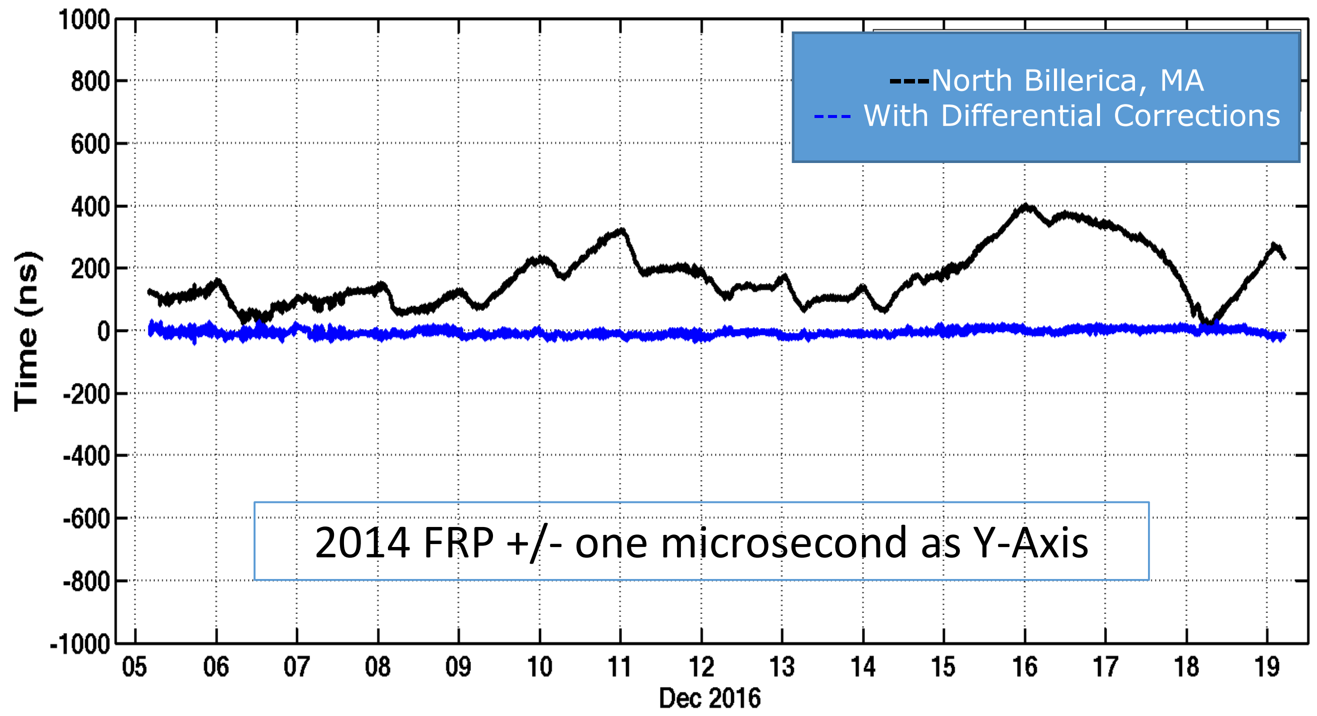
Wildwood, NJ to N. Billerica, MA with & without Differential Corrections



Period: October – November 2016
Distance to XMTR: 310 miles
Without Differential corrections
Mean: 134.1 ns
Std: 54.6 ns
Max: 292.0 ns
Min: -12.0 ns

Period: October – November 2016
Distance to XMTR: 310 miles
With Differential corrections
Mean: -10.5 ns
Std: 8.1 ns
Max: 38.0 ns
Min: -95.0 ns

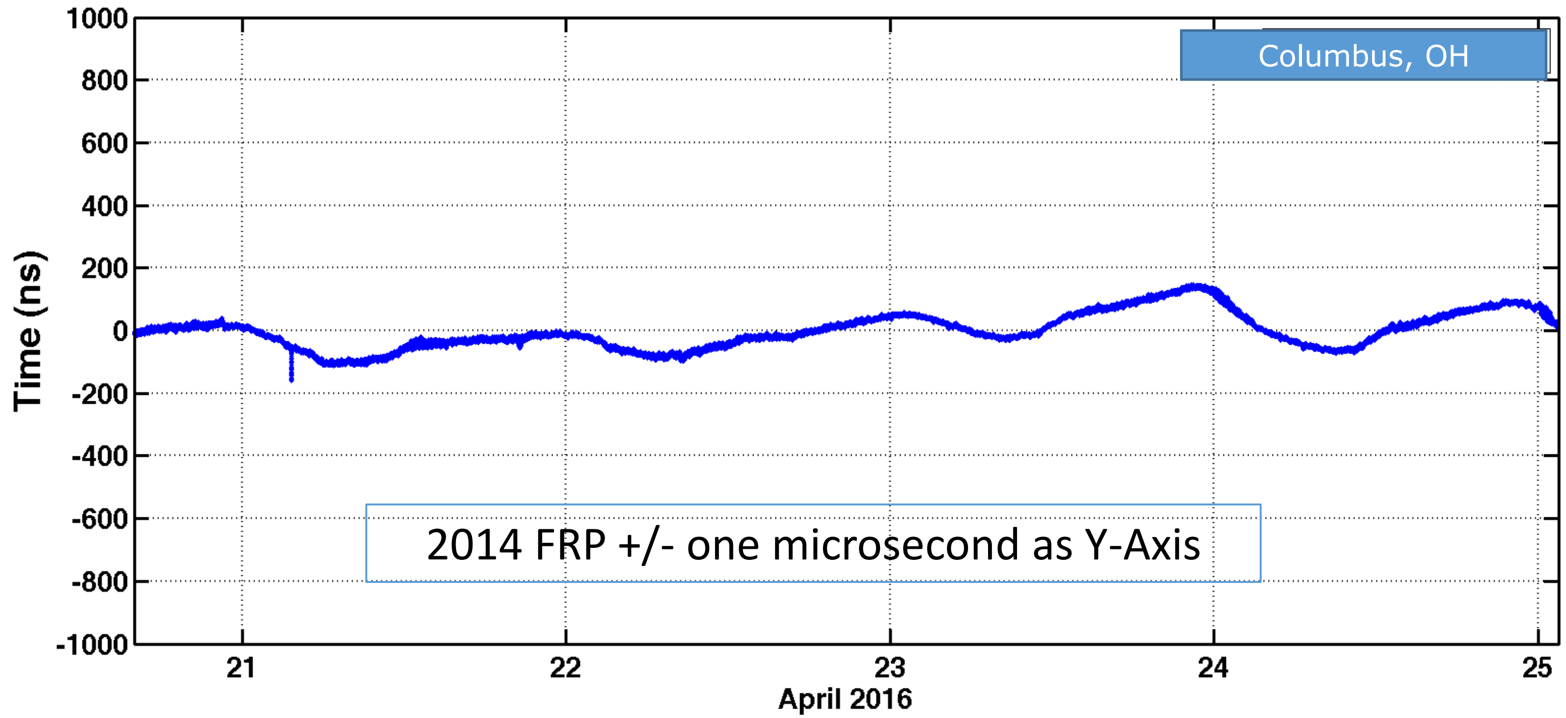
Wildwood, NJ to N. Billerica, MA with & without Differential Corrections



Period: December 2016
Distance to XMTR: 310 miles
Without Differential corrections
Mean: 171.7 ns
Std: 92.8 ns
Max: 404.0 ns
Min: 12.0 ns

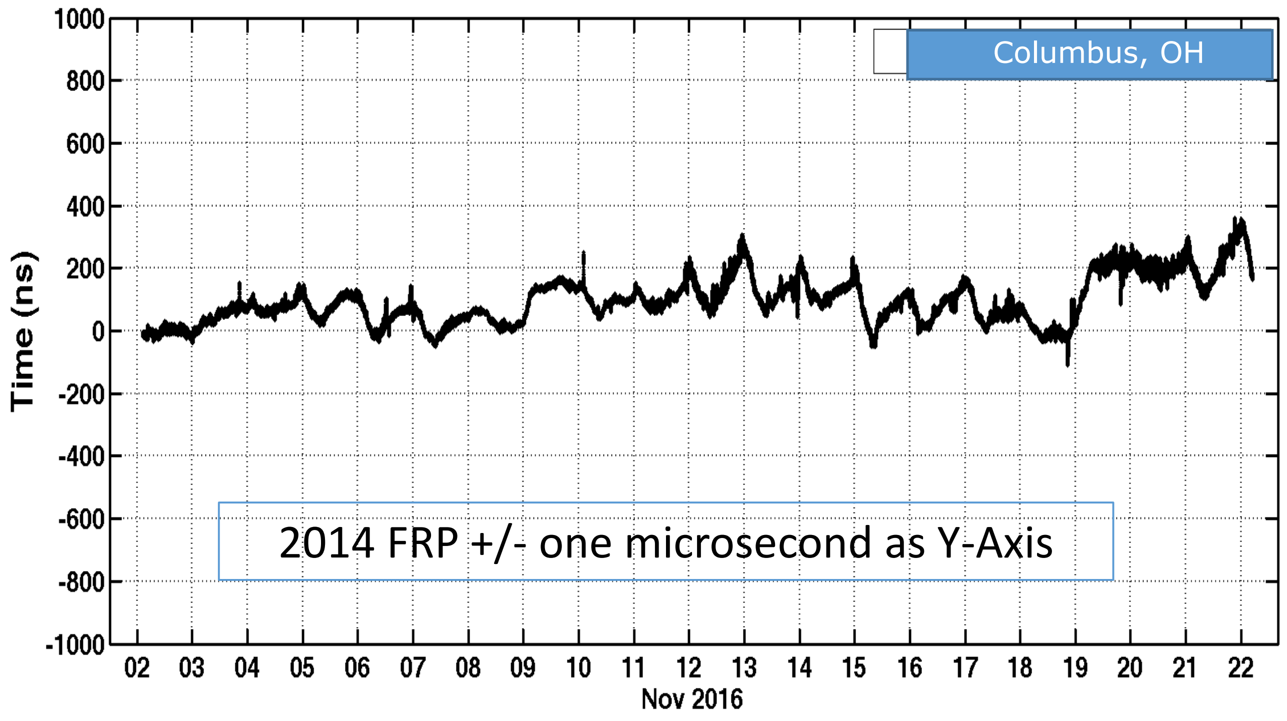
Period: December 2016
Distance to XMTR: 310 miles
With Differential corrections
Mean: -5.1 ns
Std: 9.7 ns
Max: 32.0 ns
Min: -40.0 ns

Wildwood, NJ to Columbus, OH User Receiver



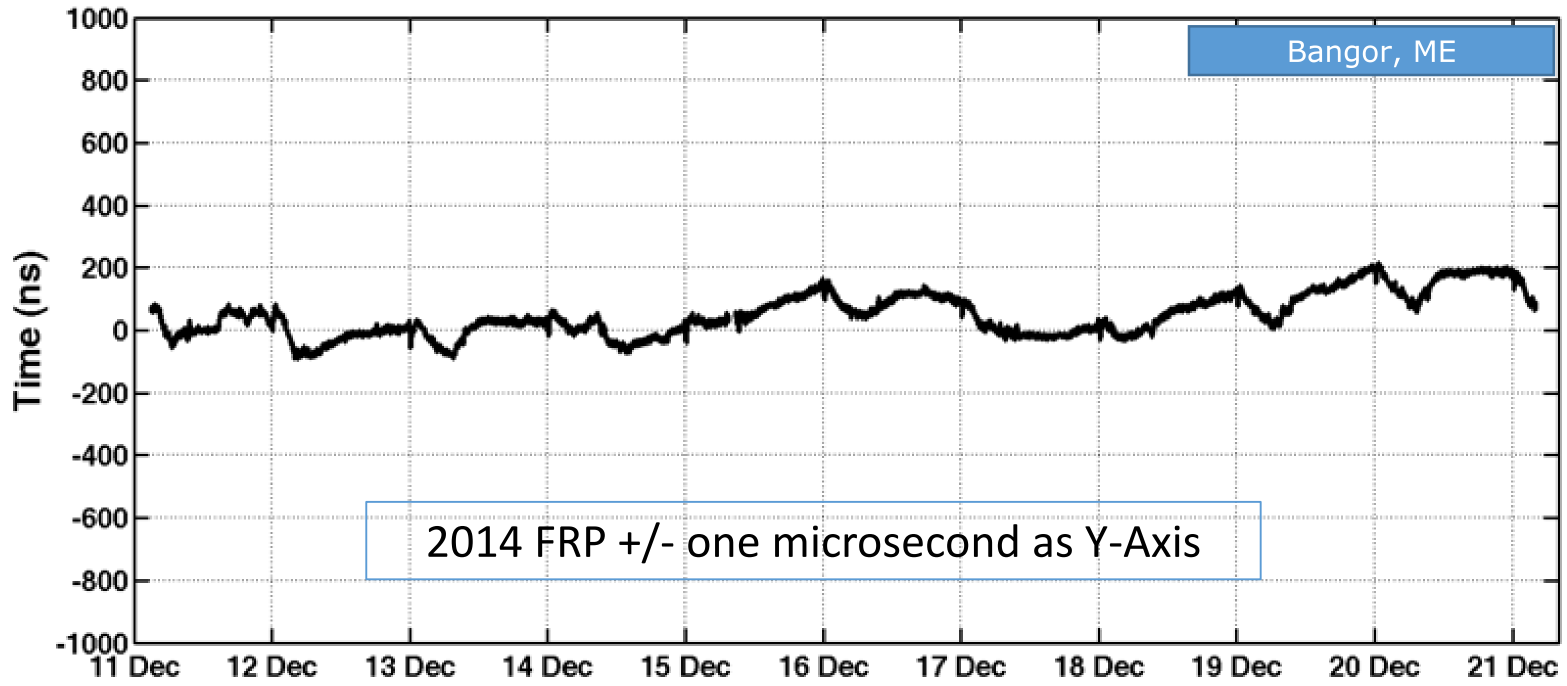
Period: April 2016
Distance to XMTR: 440 miles
Mean: 170.4 ns
STD: 56.4 ns
Max: 148.6 ns
Min: -159.4 ns

Wildwood, NJ to Columbus, OH User Receiver



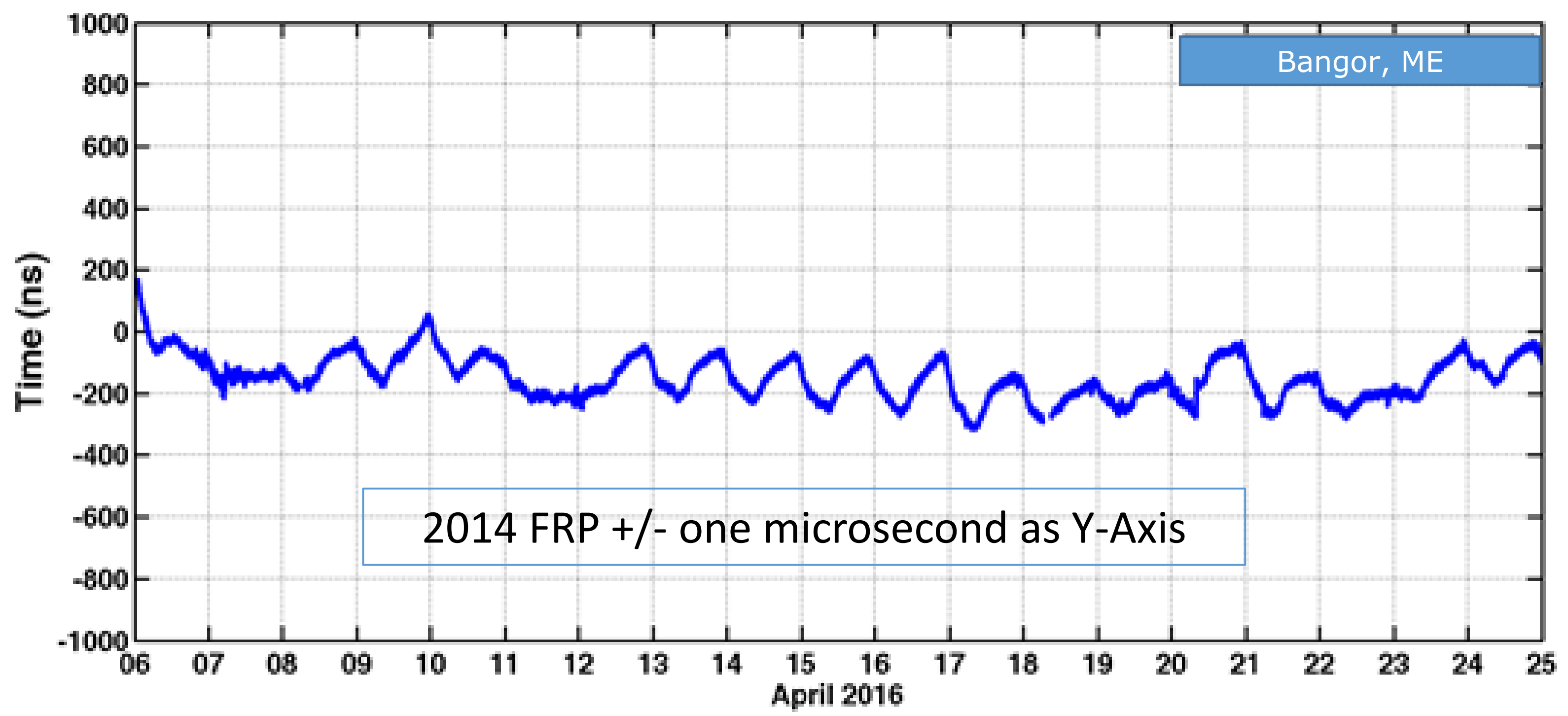
Period: November 2016
Distance to XMTR: 440 miles
Mean: 93.8 ns
Std: 74.1 ns
Max: 361.0 ns
Min: -109.0 ns

Wildwood, NJ to Bangor, ME User Receiver



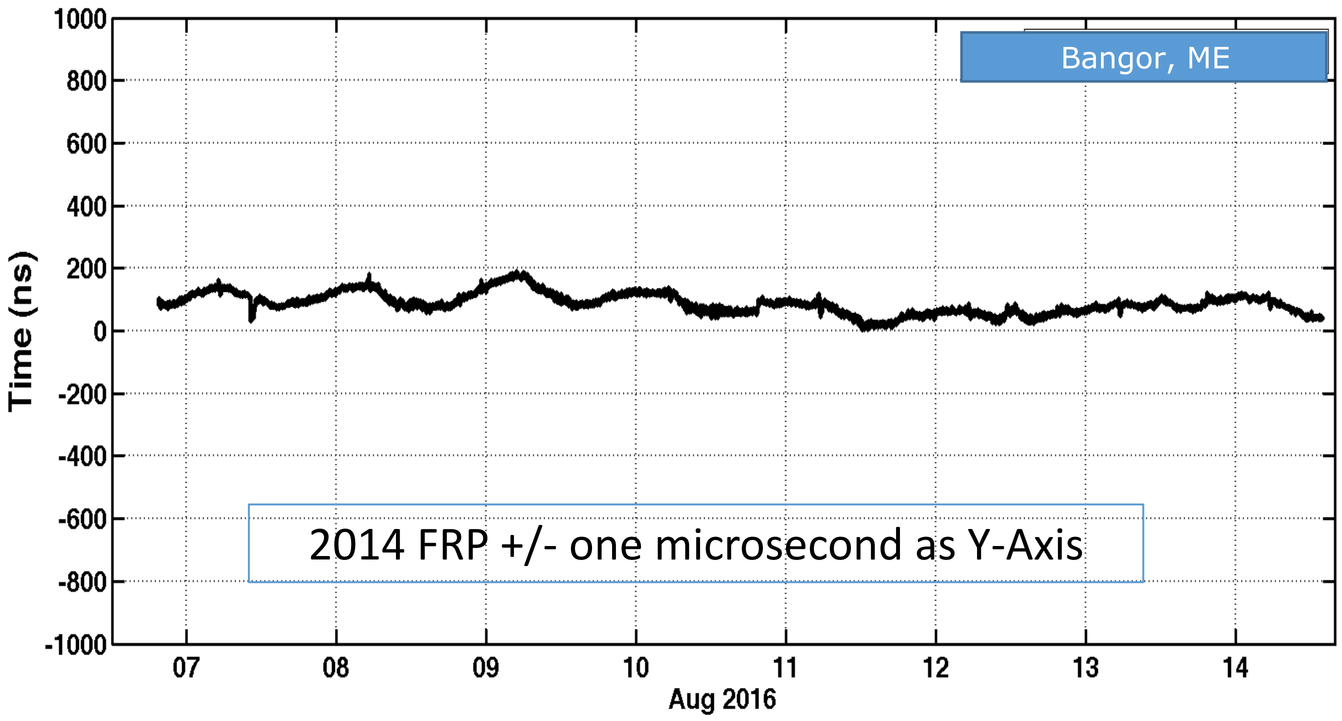
Period: December 2015
Distance to XMTR: 500 miles
Mean: 49.7 ns
STD: 68.6 ns
Max: 216.0 ns
Min: -91.0 ns

Wildwood, NJ to Bangor, ME User Receiver



Period: April 2016
Distance to XMTR: 500 miles
Mean: -149.1 ns
STD: 69.7 ns
Max: 171.0 ns
Min: -318.0 ns

Wildwood, NJ to Bangor, ME User Receiver



Period: August 2016

Distance to XMTR: 500 miles

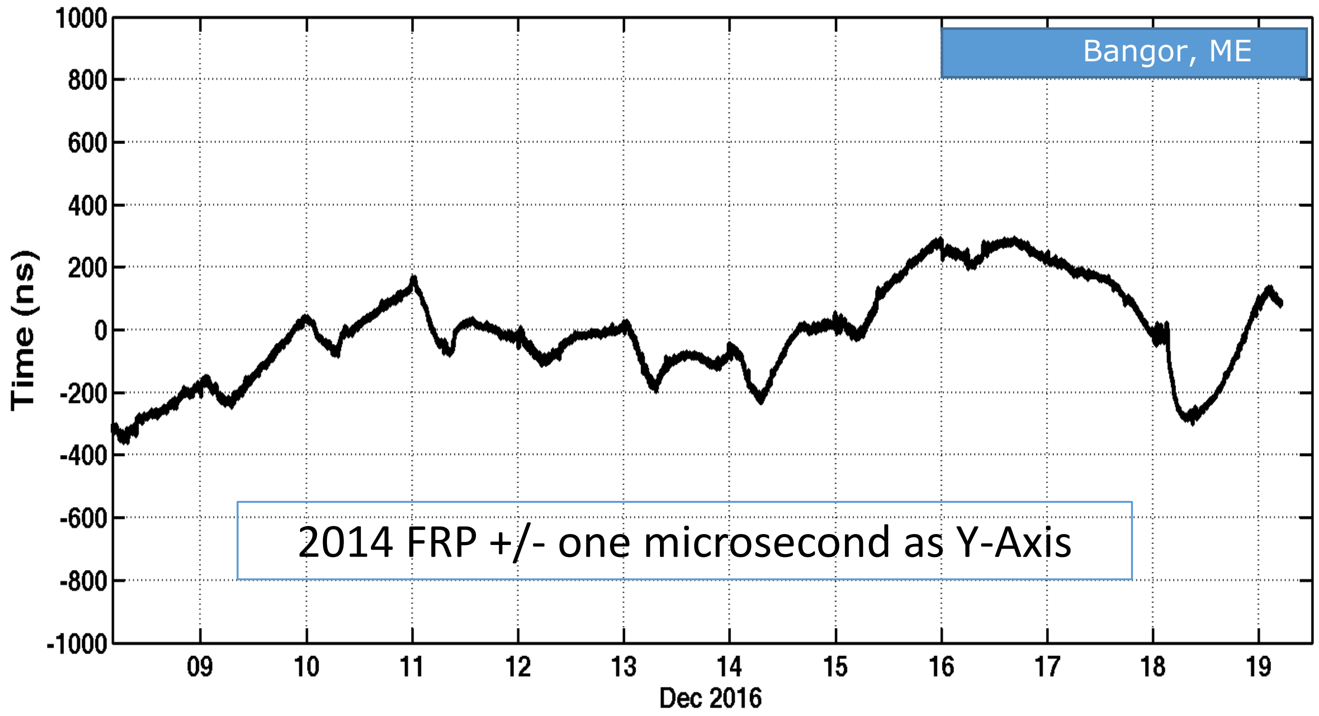
Mean: 87.6 ns

Std: 32.9 ns

Max: 191.0 ns

Min: 2.0 ns

Wildwood, NJ to Bangor, ME User Receiver



Period: December 2016

Distance to XMTR: 500 miles

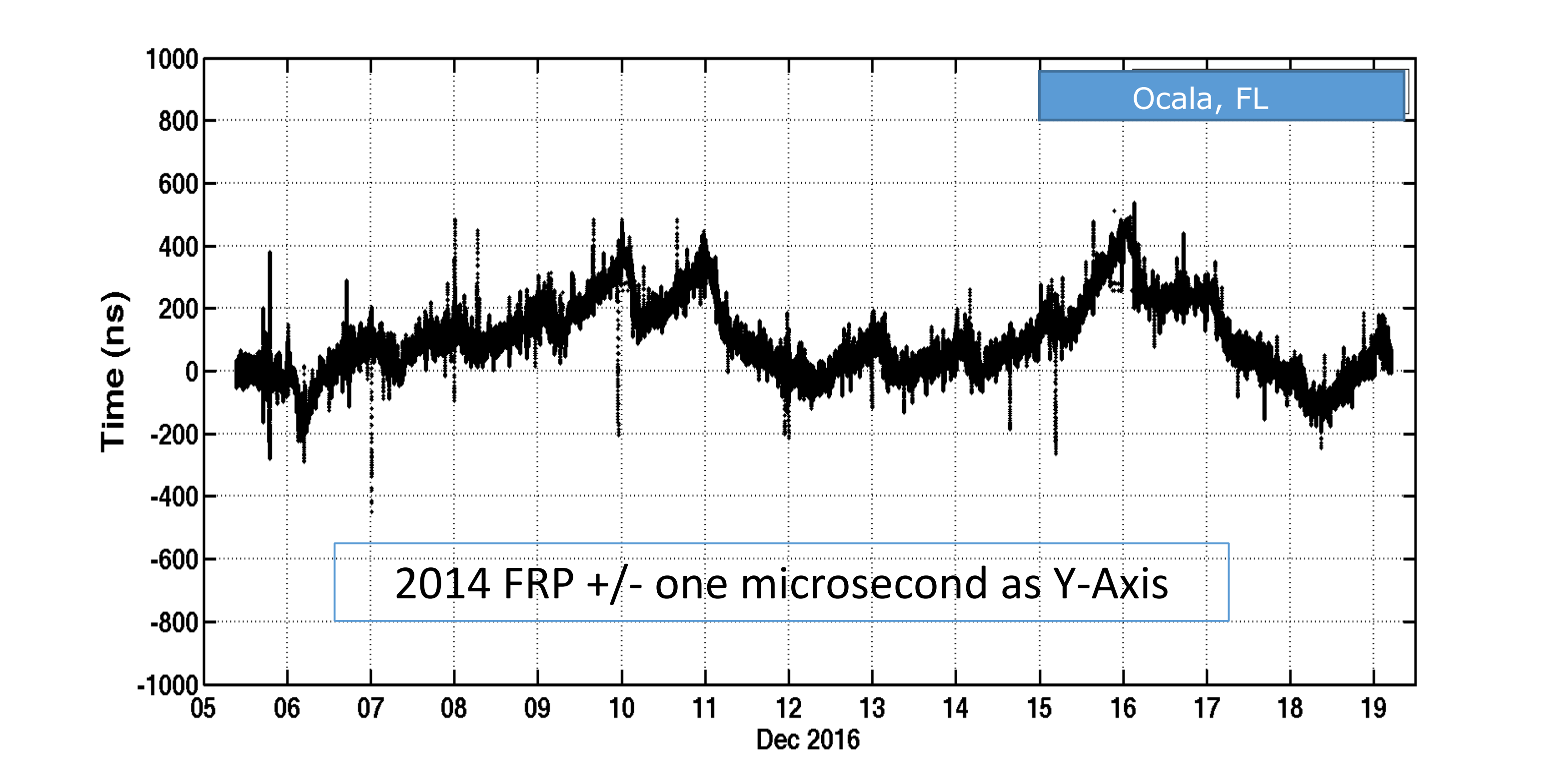
Mean: -9.1 ns

Std: 154.2 ns

Max: 294.0 ns

Min: -361.0 ns

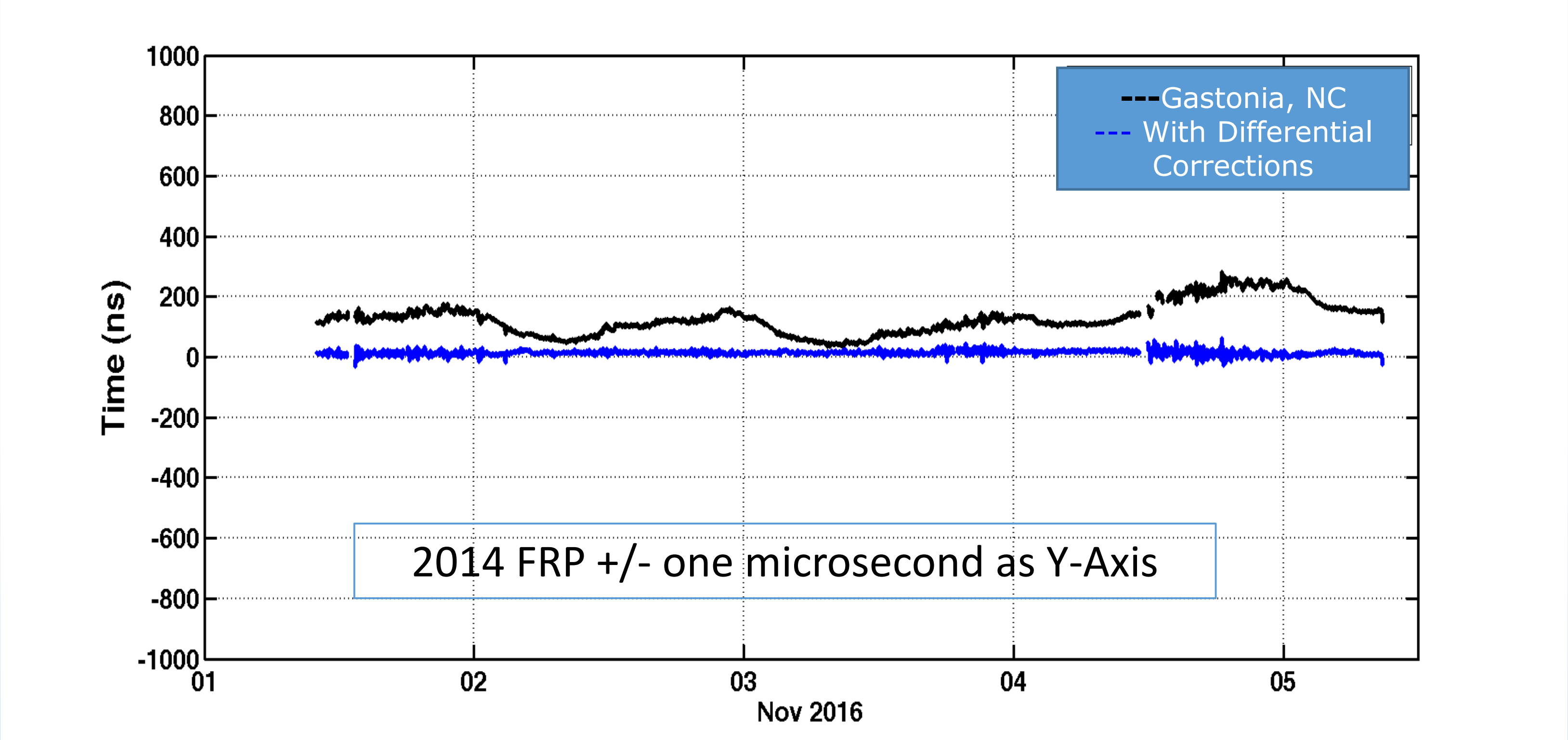
Wildwood, NJ to Ocala, FL User Receiver



Period: December 2016
Distance to XMTR: 790 miles
Mean: 93.0 ns
Std: 114.7 ns
Max: 536.0 ns
Min: -448.0 ns

Wide Area Multilateration (WAM) Test Results
Wildwood, NJ to Gastonia, NC

Requirement: +/- 30 ns, 95%



Period: November 2016
Distance to XMTR: 425 miles
Without Differential corrections
Mean: 127.8 ns
Std: 52.5 ns
Max: 283.0 ns
Min: 35.0 ns

Period: November 2016
Distance to XMTR: 425 miles
With Differential corrections
Mean: 14.7 ns
Std: 7.5 ns
Max: 64.0 ns
Min: -30.0 ns

Validation that eLoran Timing meets WAM Requirements

- Real-world test using WAM equipment
- The Proof-of-Concept WAM radio using Differential eLoran as the time reference performed equally as well as the WAM radios using GPS as the time reference
- The Proof-of-Concept WAM radio Using Differential eLoran did not cause the system to alarm, nor were any thresholds exceeded
- The MLAT Server produced accurate position solutions with eLoran more than 96 hours after loss of GPS

eLoran To-Date CRADA Summary

- ***Without*** differential … easily demonstrated the ability to meet the (+/ … ent proposed in the 2014 Federal Radionavigatio …

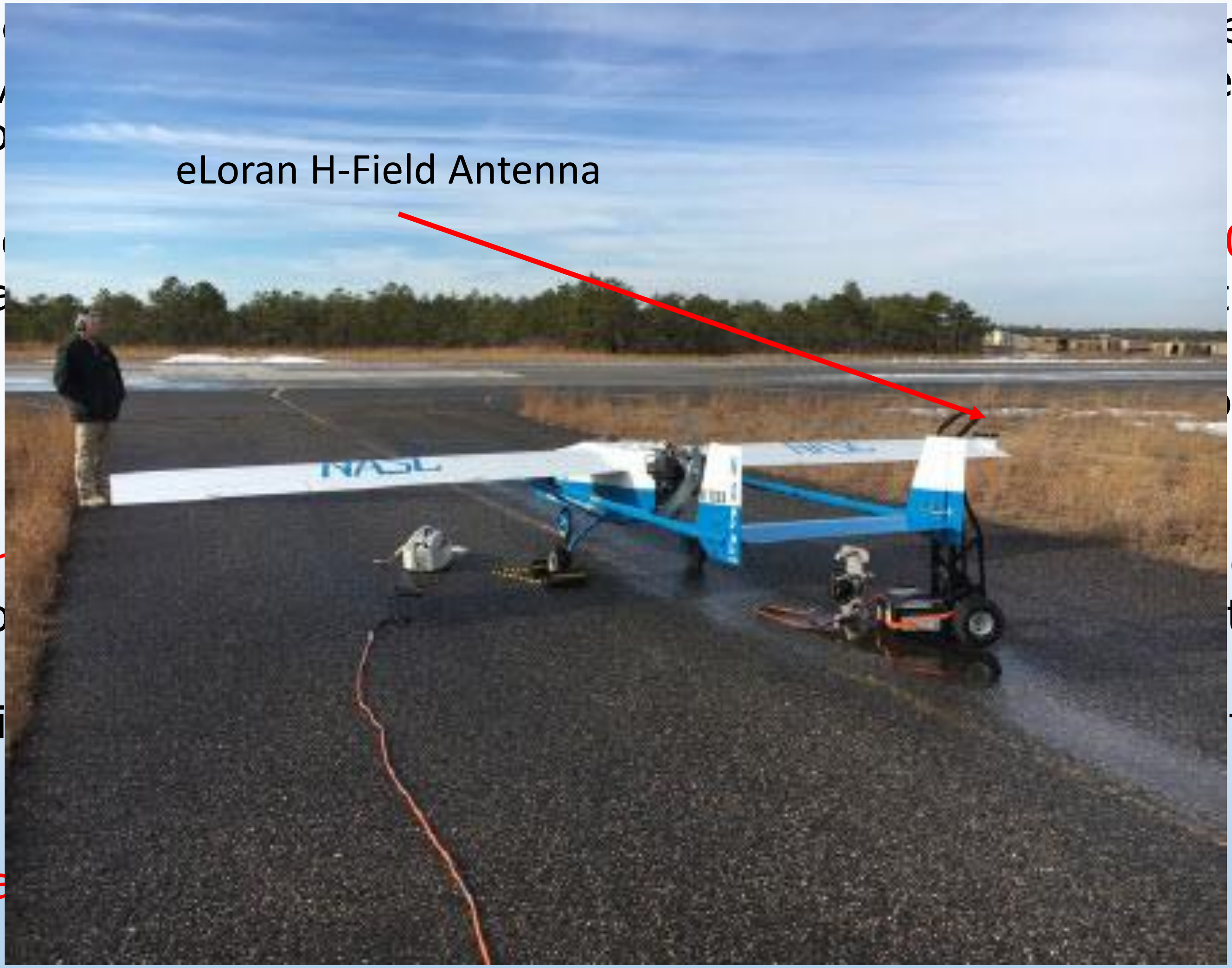
- ***Without*** differential c … 00 mile range of the test transmitter location ha … tion to UTC

- ***Without*** differential … llected was within 200 nanoseconds of UTC

- ***With*** differential corr … of a Differential eLoran Reference Station, eLo … thin 100 nanoseconds

- eLoran was proven i … timing in a Wide Area Multilateration (WAM) … to GPS

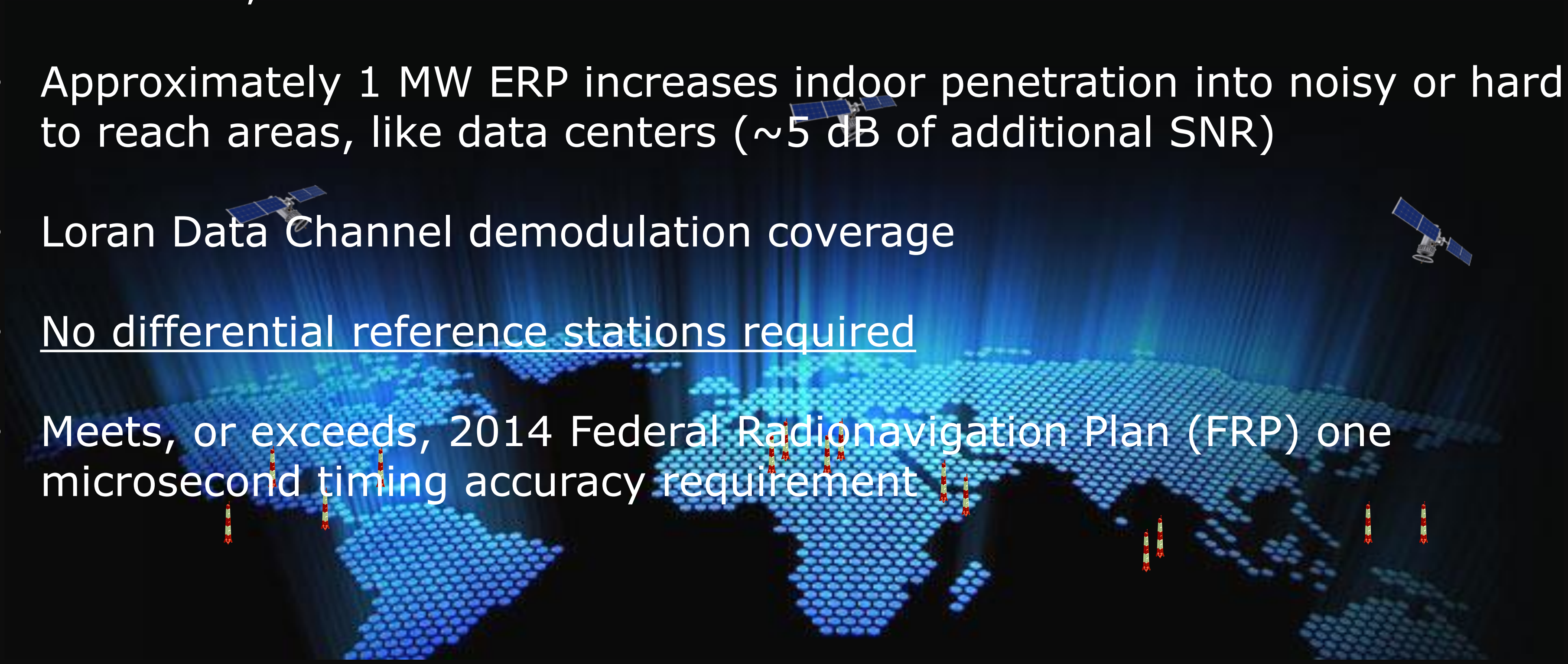
- eLoran in Smart Grid a … year



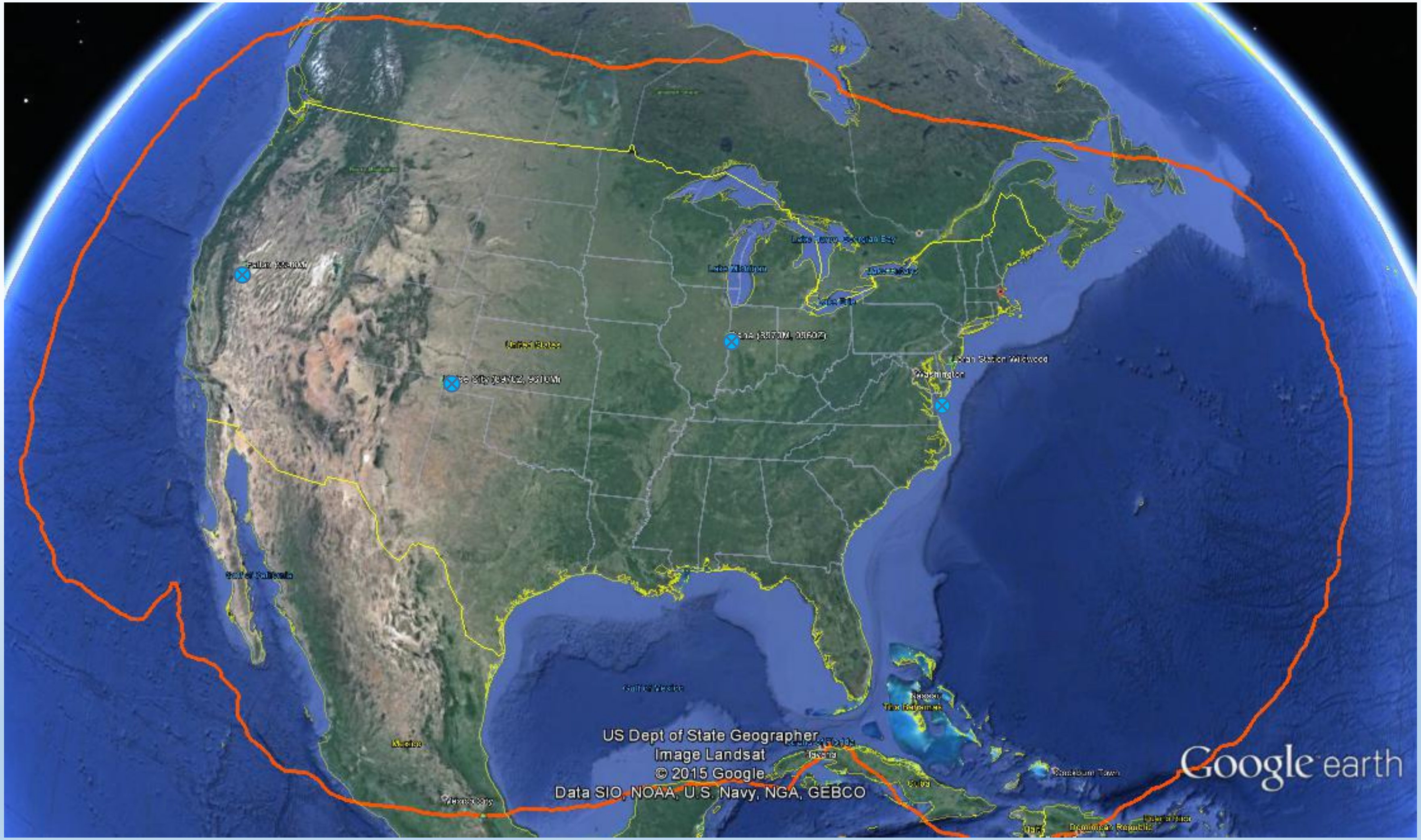
- Additional aviation testing is ongoing, with plans underway to demonstrate precise time synchronization, Loran Data Channel (LDC) communication, and compass (heading) applications in Unmanned Aerial Vehicles and General Aviation aircraft this year

Postulate: Wide Area *Basic eLoran Timing Service*

- Contiguous 48 States
- Initial Operating Capability (IOC) with four transmitting stations
  - ✓ Former Loran Support Unit site at Wildwood, NJ
  - ✓ Former Loran-C transmitting station sites: Dana, IN; Boise City, OK; Fallon, NV
- Approximately 1 MW ERP increases indoor penetration into noisy or hard to reach areas, like data centers (~5 dB of additional SNR)
- Loran Data Channel demodulation coverage
- <u>No differential reference stations required</u>
- Meets, or exceeds, 2014 Federal Radionavigation Plan (FRP) one microsecond timing accuracy requirement



Coverage From Initial Four eLoran Transmitting Sites



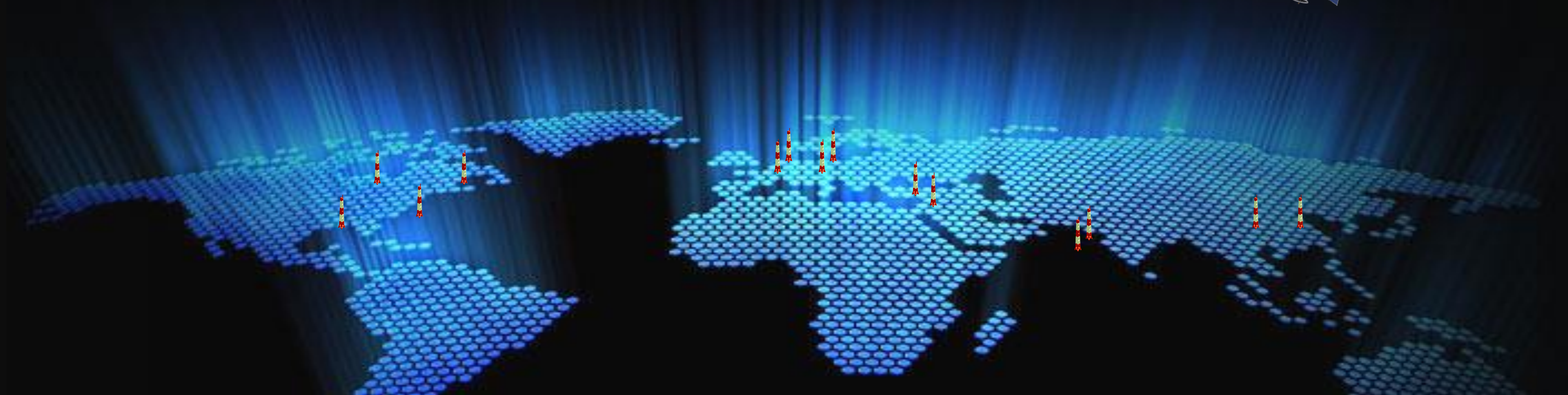
2014 FRP Coverage Area With 1 MW Transmitting Stations

Postulate: Local Area *Precision eLoran Timing Service*

- Metropolitan or other high priority locations

- Coverage and accuracy
  - ✓ Expected differential timing coverage of 35 miles radius
  - ✓ Expected accuracy within +/- 100 nanoseconds WRT UTC (USNO)

- Representative Differential Reference Station laydown initially consists of 71 locations
  - ✓ Covers top 50 major metropolitan areas
  - ✓ Covers top 50 ports / harbors
  - ✓ Covers top 50 airports



Representative Higher Accuracy Locations Within Lower 48

+/- 1 µS boundary

Notional Location of Differential eLoran Reference Station Site

Underlying Magic: Enhanced Loran (eLoran)

- NOT Loran-C!
- Exceptionally hard to disrupt, jam, or spoof
- Very wide area coverage (i.e., “continental”)
- Penetrates indoors
- Protected spectrum
- Fully independent and redundant
- Diverse failure modes from GNSS
- Idle Loran-C assets & spectrum
- Completely “sky-free”
- CPNT + Data + Azimuth
- Enables Trusted Time
- Enables Trusted Position
- Resilient PNT Ecosystem Enabler

Take Aways

- ✓ eLoran ***is*** a stable, wide area (i.e., continental) source of PNT for redundancy and resiliency in critical infrastructure and key resource sectors.
- ✓ It works in many locations where GPS is not available.
- ✓ It works when GPS may be untrustworthy.
- ✓ ***Without*** differential corrections, eLoran easily meets the 2014 FRP timing user requirements of +/- 1 microsecond over very wide areas.
- ✓ ***With*** the application of differential corrections, eLoran is capable of meeting the needs of higher accuracy timing users of better than +/- 100 nanoseconds over a local area.
- ✓ With an initial four transmitting stations, eLoran can provide resilient and complimentary timing, frequency, and data over the Lower 48 United States.
- ✓ With additional transmitting stations, eLoran can provide additional resilience and complementary positioning and navigation over the Lower 48 United States.
- ✓ eLoran is efficient, economical, and can be provided expeditiously. A four-site configuration focused on timing users can be operational within one year.

UrsaNav

Leaders in what's now. Innovators of what's next.

Building bridges to resilience with eLoran!

Contact Us for Collaborative Efforts!

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