
# Implementing a Wide Area High Accuracy UTC Service via eLoran

***ION PTTI, Boston, MA***
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# Overview

- Basis for consideration of eLoran as a source of precise time, frequency, and phase
- Brief summary of differences between eLoran and either GNSS or the former Loran-C
- As system and technology specialists, we can control the performance originating at the transmitter and processed at the receiver. The challenge is natural propagation effects, with both temporal and spatial decorrelation
- Established a differential UTC reference station in Belgium to conduct measurement trials
- Data shows temporal effects can be eliminated
- Presently investigating spatial component

# Current US Gov't Investigation on GPS back-up

## Complementary PNT Tiger Team (CPNT3)

- **On October 10, 2014 the Space-Based Positioning, Navigation & Timing National Executive Steering Group initiated the CPNT Tiger Team**
- **The Tiger Team will:**
  - Re-explore eLORAN as a back-up GPS technology
  - Evaluate other technologies as a back-up to GPS
  - Investigate the ability to provide P, N & T separately
- **The Tiger Team will out brief their findings to the PNT Executive Committee on December 15, 2014**

# 2007 DHS Requirement (tighter now)

| GPS Timing Essential CIKR Sector | Timing Accuracy Requirements* | Oscillators Used** | | | Least Robust Oscillator | Osc. Holdover Time (Hours) |
|---|---|---|---|---|---|---|
| | | TCXO | OCXO | Rb | | |
| Communications Sector | ~ Nanoseconds (SONET, CDMA) | | X | X | OCXO (HS) | 24 + |
| Emergency Services Sector | ~ Nanoseconds (CDMA E911, LMRs) | | X | | OCXO (HS) | 24 + |
| Information Technology Sector | 20 to 100 Nanoseconds (PTP)* | | X | | OCXO (MS) | 1 |
| Banking and Finance Sector | Millisecond- Microsecond (HFT)^ | X | X | X | TCXO | < .24 -1.7 |
| Energy/Electric Power Subsector | 1-4.6 Microsecond (Synchro-Phasors; Fault Loc.) | | X | | OCXO (MS) | 1 |
| Energy/Oil and Natural Gas Sector Subsector | Microsecond (exploration, SCADA) | | X | X | OCXO (MS) | 1 |
| Nuclear Sector | 1 Microsecond (Synchro-Phasors) | | X | | OCXO (MS) | 1 |
| Dams Sector | 1 Microsecond (Synchro-Phasors) | | X | | OCXO (MS) | 1 |
| Chemical Sector | Sub Microsecond-Microsecond | | X | | OCXO (MS) | 1 |
| Critical Manufacturing Sector | Millisecond | X | X | | TCXO | 1.7 |
| Defense Industrial Base Sector | Millisecond | X | X | | TCXO | 1.7 |
| Transportation Sector | ~ Nanoseconds (Wireless modal comms) | | X | X | OCXO (HS) | 24 + |

# GPS and eLoran for Timing

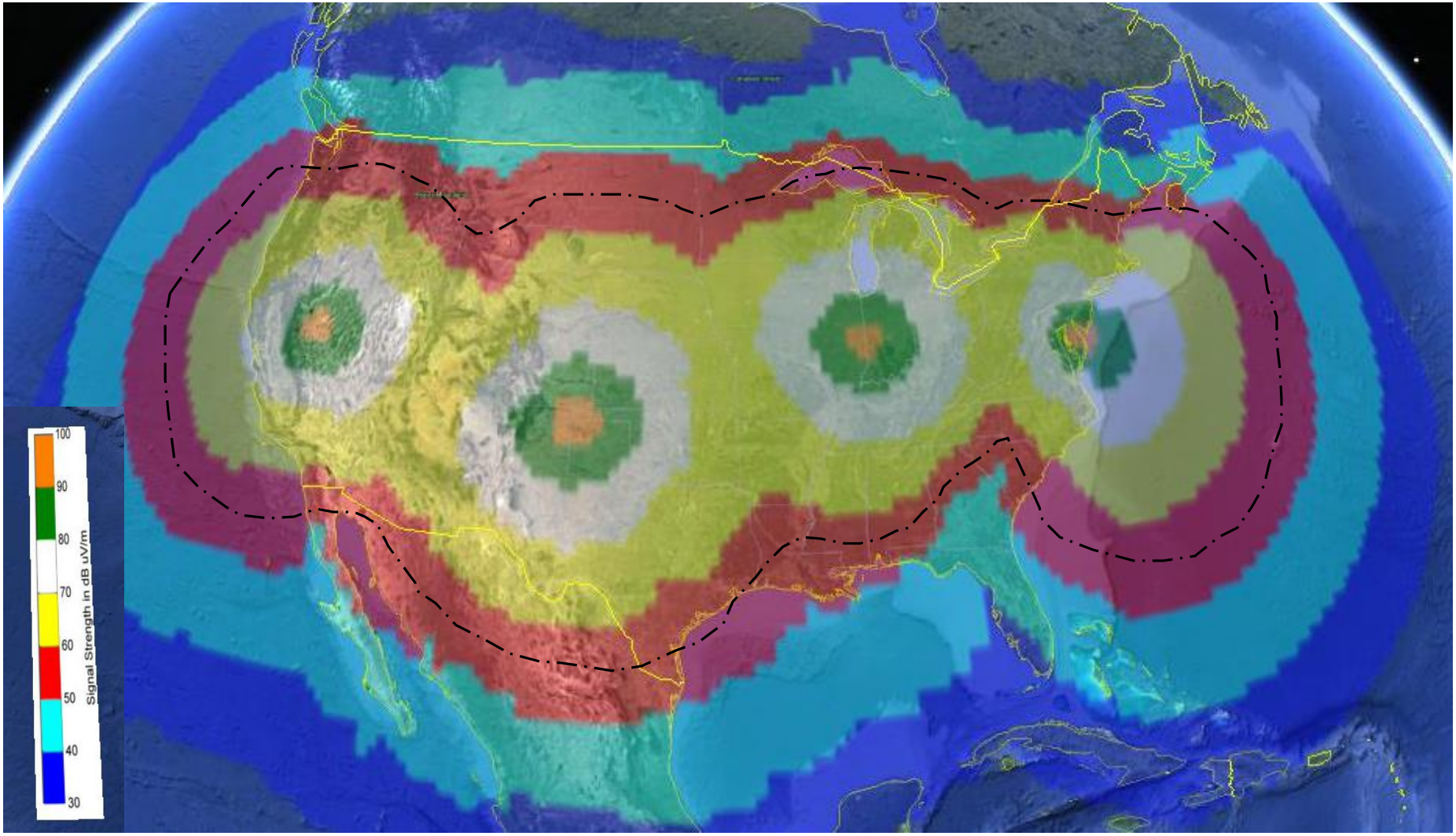
| Parameter | eLoran | GPS |
|---|---|---|
| Frequency | 100 kHz | 1.2-1.5 GHz |
| Propagation | Groundwave | Line of Sight |
| Propagation Error | Conductivity, troposphere variations | Iono delay variations* |
| Penetration | Walls, ground, 6' seawater | Very little penetration |
| Modulation | TD + CD | Spread spectrum CD |
| Signal Strength | Relatively high | Very low |
| Timing Basis | Triple Cesium | Rubidium at present |
| Tx Location | Ground - stationary | Space - moving |
| Data Channel | Yes | No |

* Propagation errors are affected at different times and places by components of solar storms
* GPS propagation variations are not correlated with Loran-C propagation errors.

# Main Differences between eLoran and Loran-C

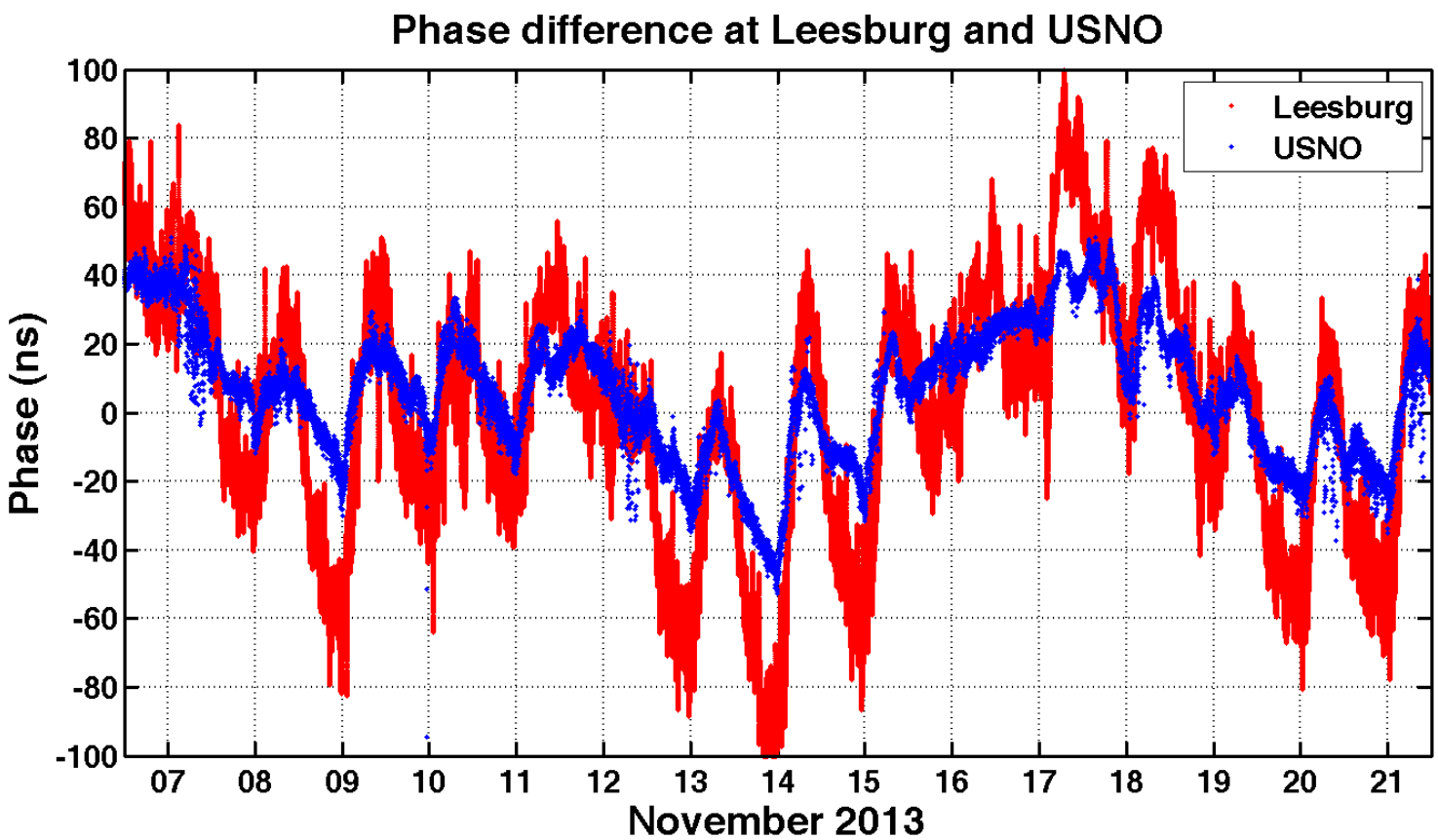
- Each transmitting site synchronized to UTC using "ensembling" of technologies and methods
  - Three Primary Reference Standards vs One
  - TWSTT (Two way satellite time transfer)
  - TWLFTT (Two way low frequency time transfer)
- Tighter Timing Tolerances and Signal Standards
- Application of ASF maps and Differential corrections for highest Positioning and Timing accuracies
- Receiver applies All-in-View signals vs Chains
- Loran Data Channel (LDC)
  - Robust data channel for system related data
  - Station ID and Health
  - UTC messages for Date and Time of Day distribution
  - Differential corrections
  - Other communications / navigation messages

# Potential 4 Station Timing Coverage




Coverage at SNR>0 from a minimum of 1 former USCG Loran station upgraded to eLoran

# eLoran Timing Test from 2013



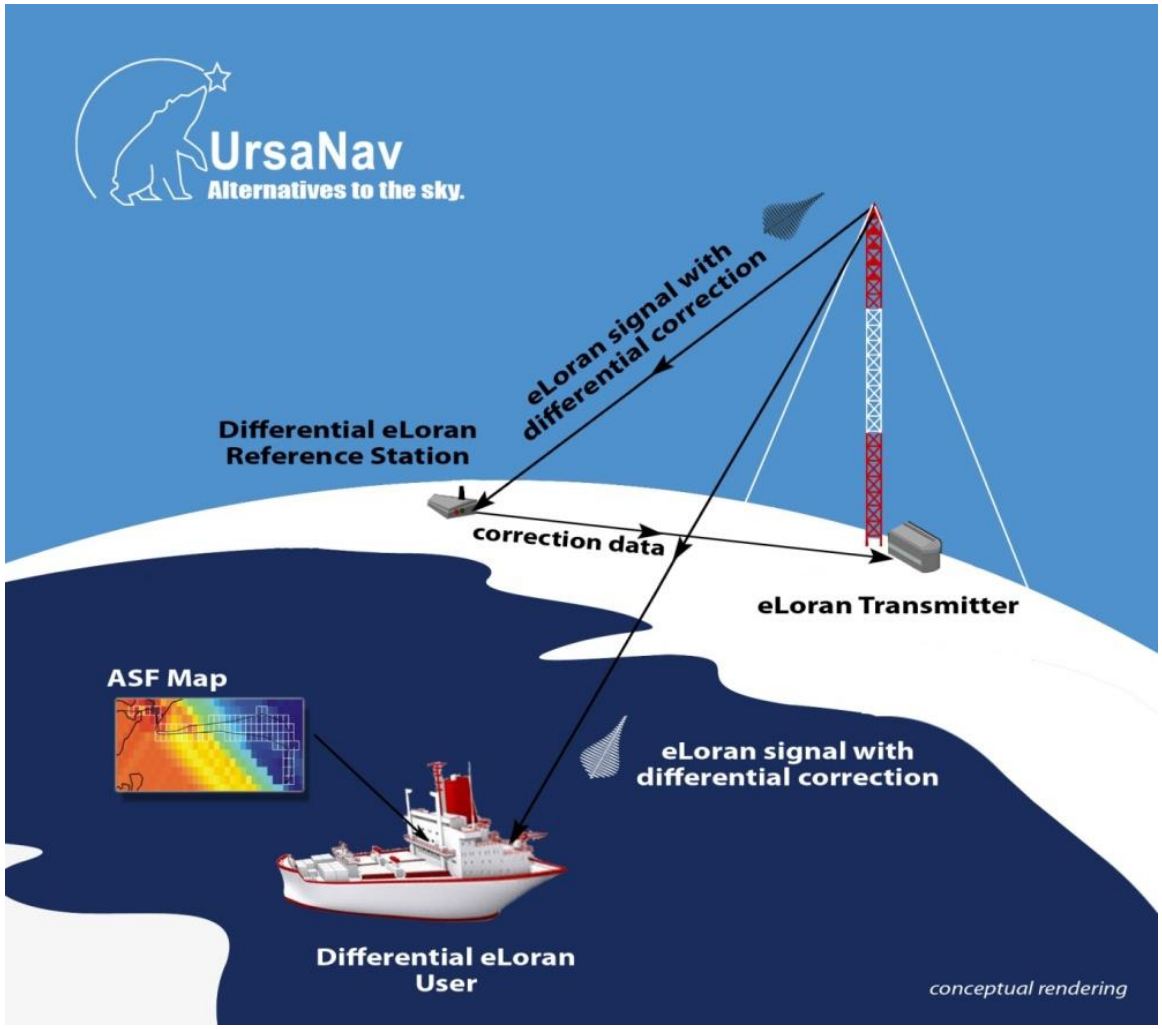

- High correlation between phase differences at Leesburg and USNO
- Amplitude of phase changes higher at Leesburg
- Correlation indicates that differential corrections from USNO would benefit a user at Leesburg ( ~ 25 miles)

# General Lighthouse Authorities' eLoran IOC

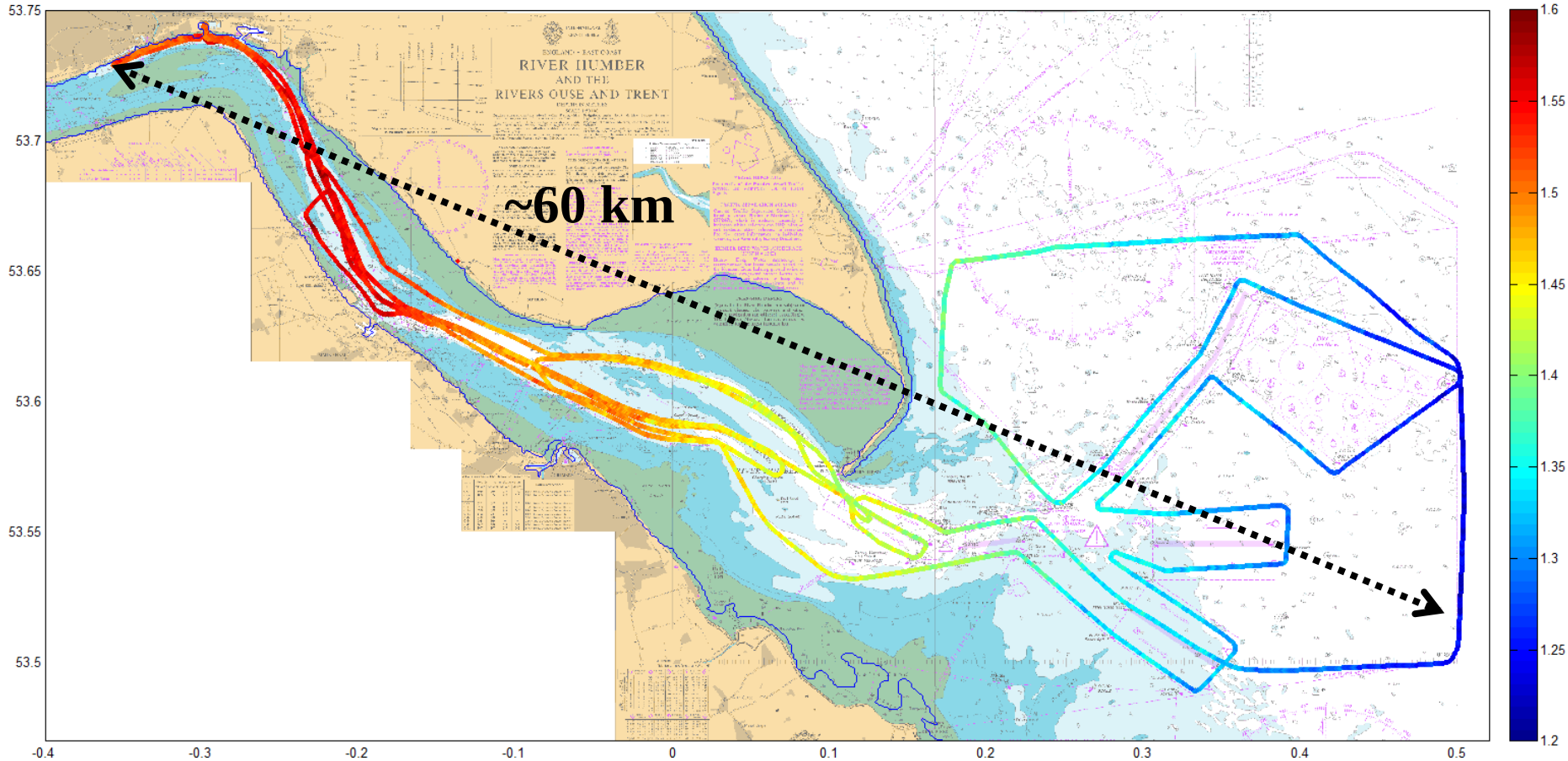

- GLAs have installed Differential eLoran Reference Stations at seven harbors along the UK East Coast
- RSIMs generate corrections for eLoran maritime **navigation** to enable 10-meter accuracy positioning to mariners
- Initial Operating Capability announced last month

# dLoran concept

- User is equipped with a receiver that has a stored ASF map
- Corrections for the area of operation calculated at a fixed site
- Correction info sent to transmitter for broadcast via data channel
- Corrections can be applied by receiver and are monitored for integrity



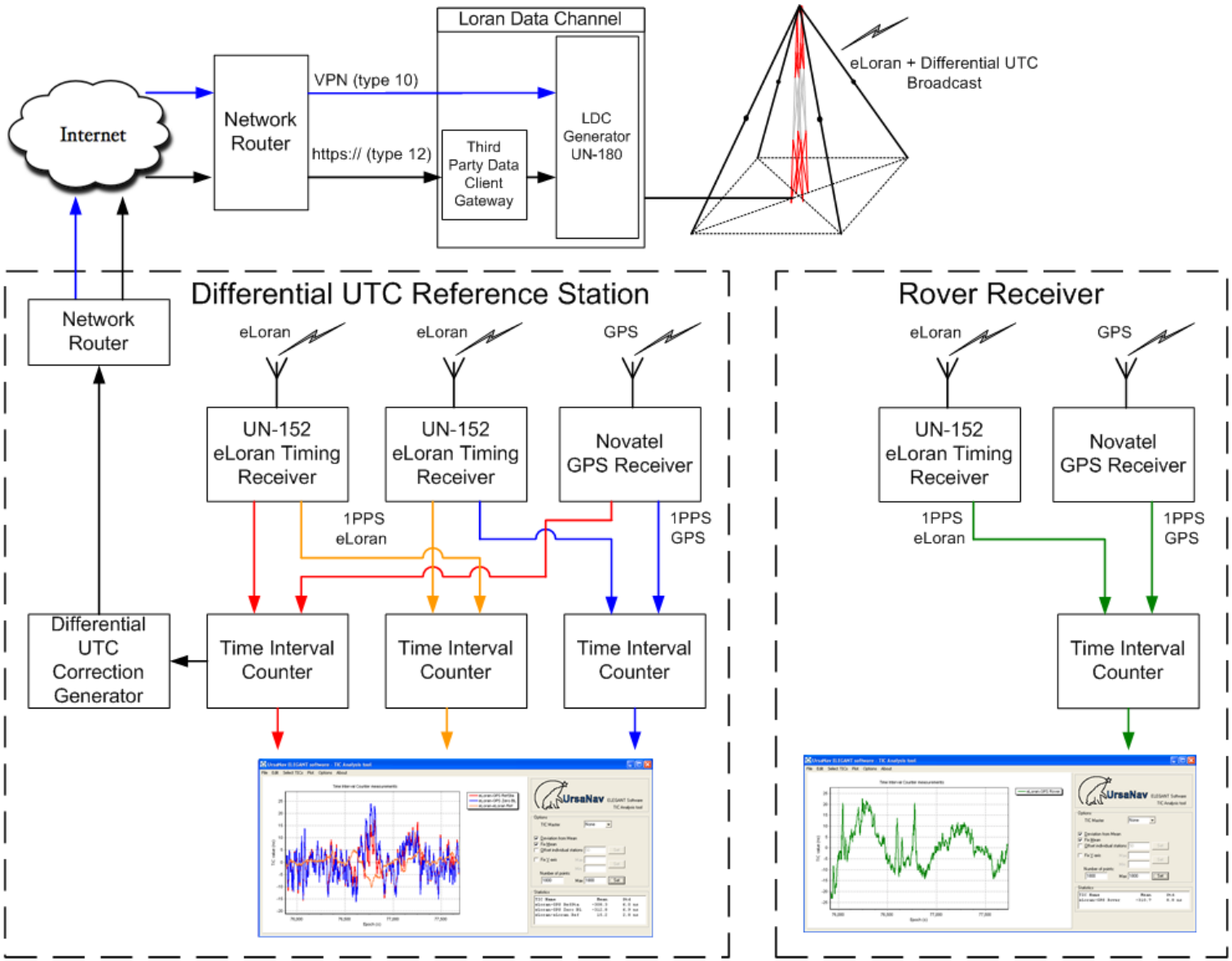
# Variation of Lessay ASF at Humber




- ASF map shows that the propagation delay can change by 400 ns over a distance of 60 km

**Graphic courtesy General Lighthouse Authorities of UK and Ireland**

# Bertem Test Block Diagram



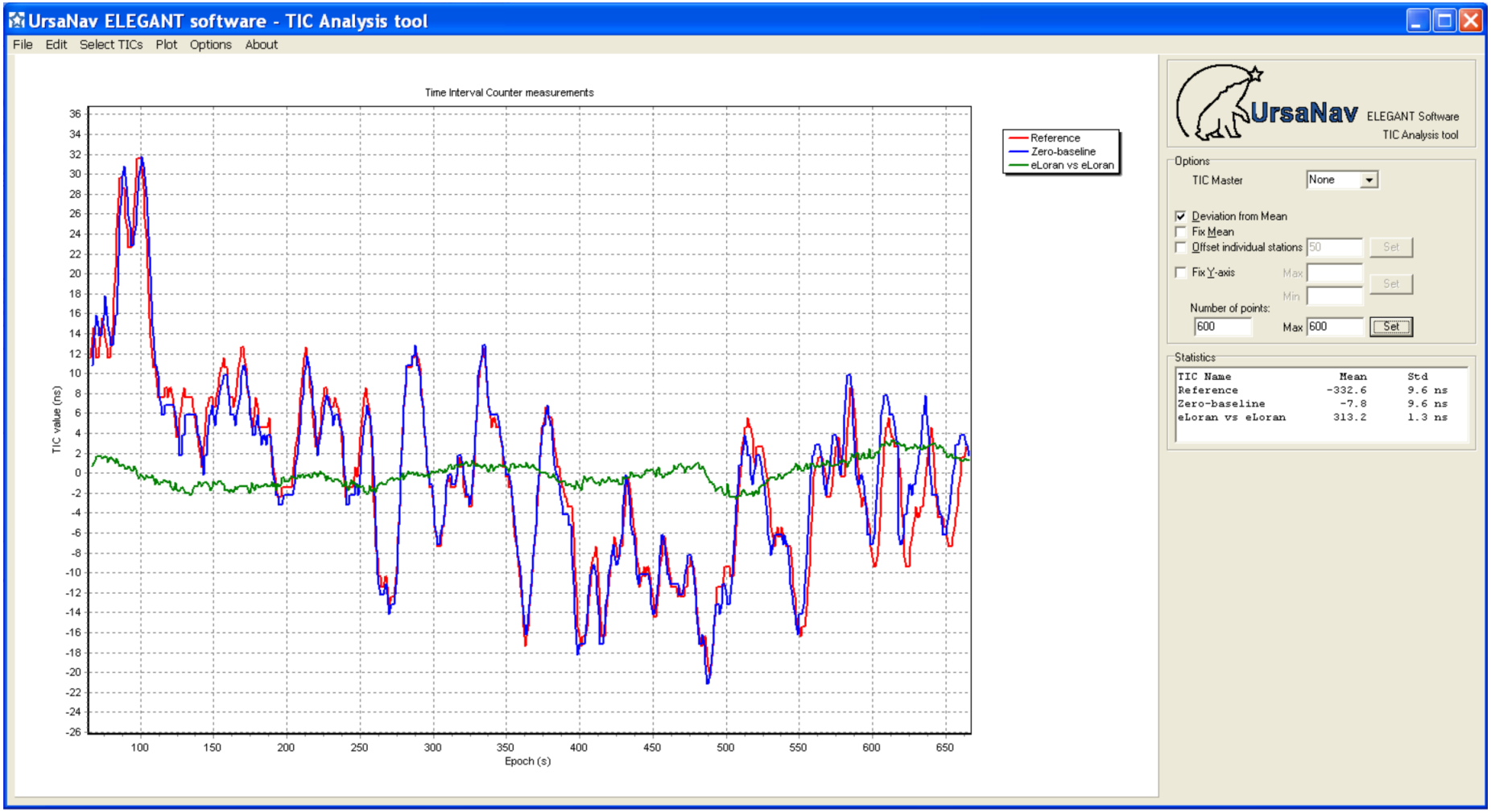
# Data Collection Receiver


- UN-155 Resilient PNT Receiver
  - GPS/DGPS/eLoran
  - Dual band (100/300 kHz) e-field antenna
  - Custom user interface
  - USB ports to access stored data
- Includes a UN-152 eLoran Timing receiver
  - Receiver oscillator disciplined by signals from Lessay Loran transmitter

# Reference Receiver Antennas

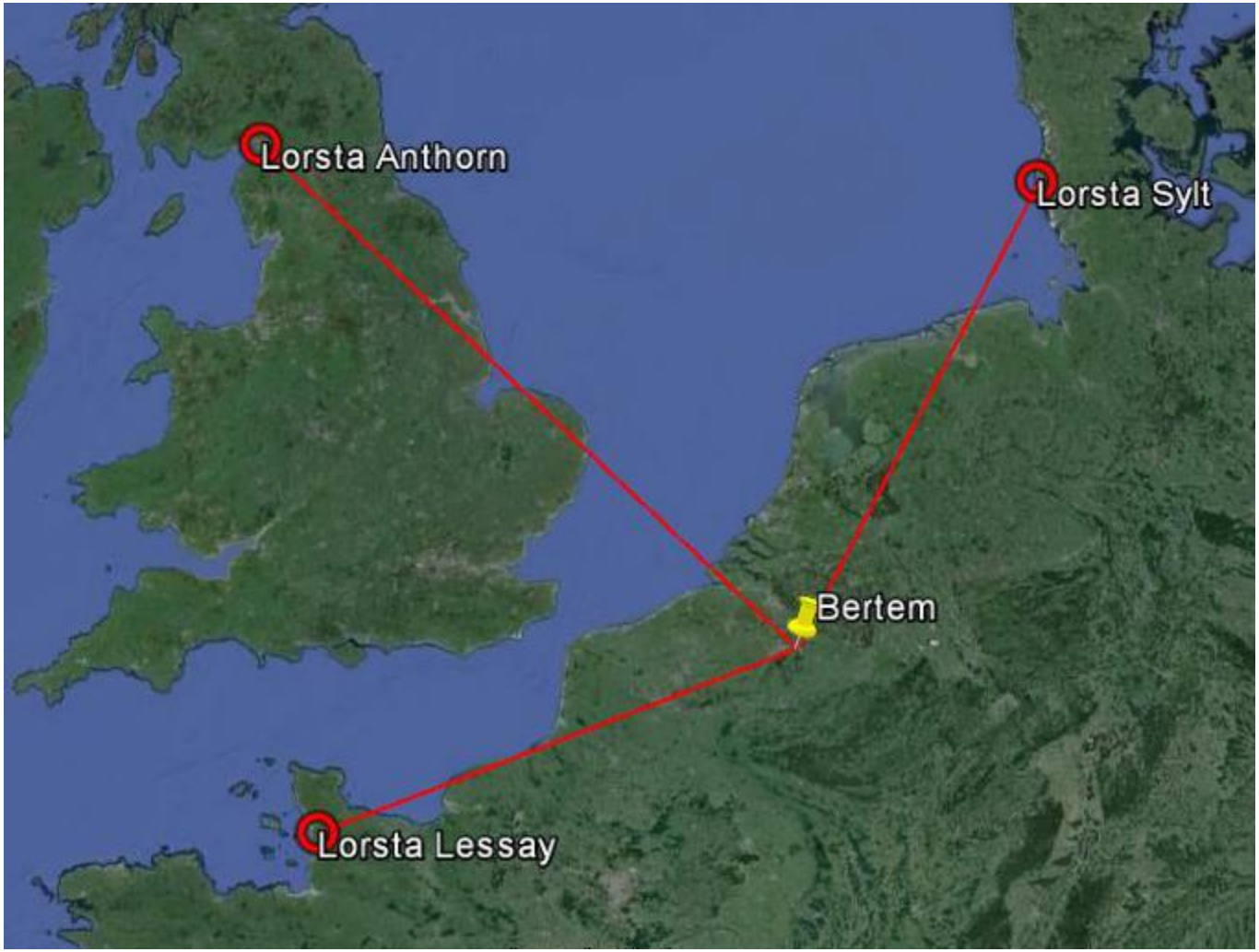
- Reference Station eLoran antenna
- Zero-baseline Monitor eLoran antenna
- GPS antenna to provide independent source of UTC
  (Both Reference Station and Zero-baseline Monitor use the same GPS as a UTC reference)

# Zero Baseline Data




Correlation between Reference and Zero-baseline Monitor TIC data using the same GPS reference

# eLoran System Geometry at Bertem

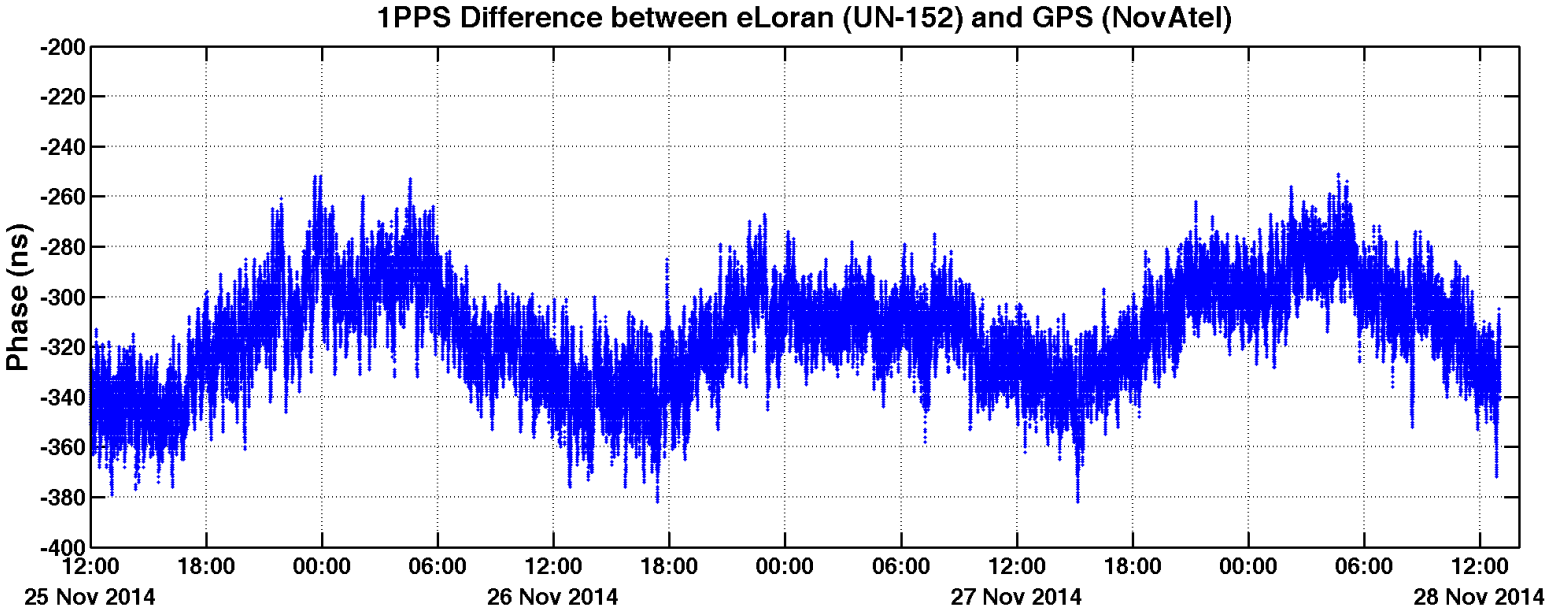



Distances
from Bertem

| | |
|---|---|
| Lessay | 480 km |
| | 300 miles |
| Anthorn | 690 km |
| | 430 miles |
| Sylt | 500 km |
| | 310 miles |

- Receiver oscillator disciplined by signals from Lessay Loran transmitter

# Zero Baseline Data

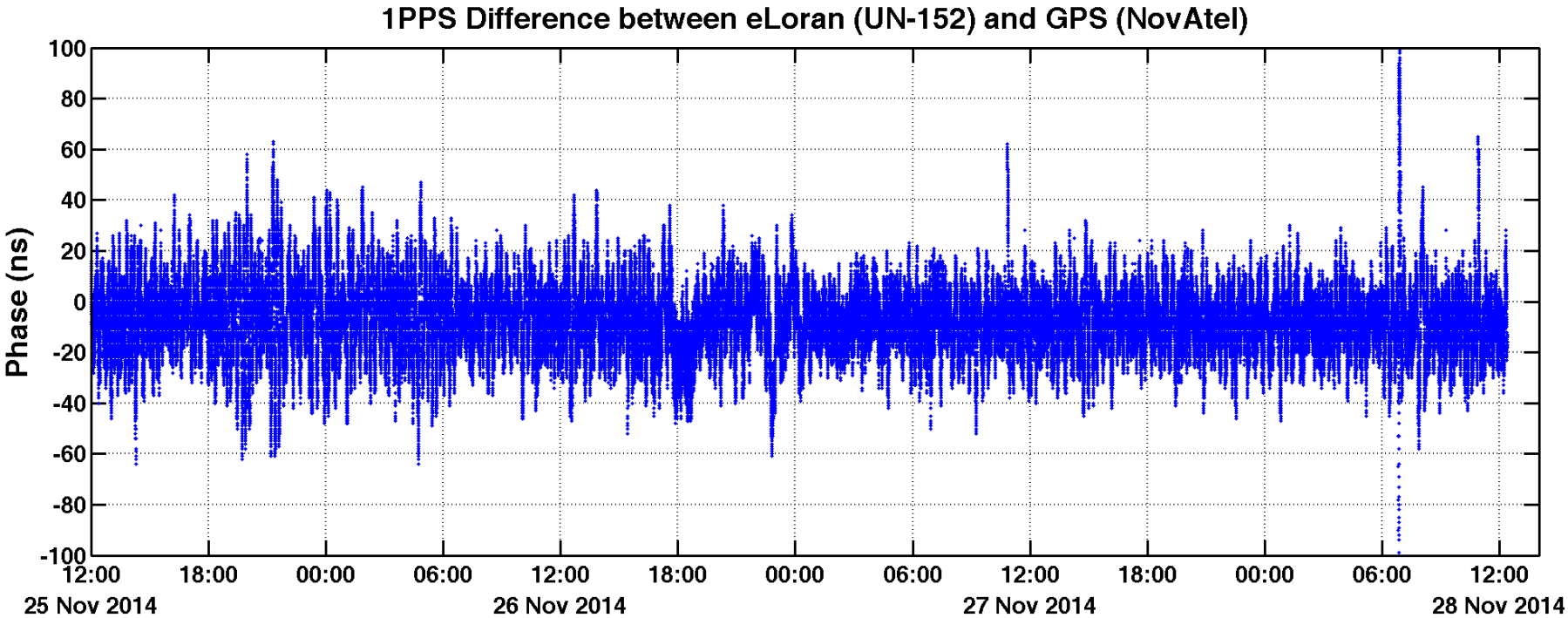



Raw Data as measured by reference station

Mean value of the data set is: -314.7 ns
Standard deviation is: 20.2 ns

Corrections based on 10-minute observation intervals, sent over the LDC every 2 minutes

# Zero Baseline Data



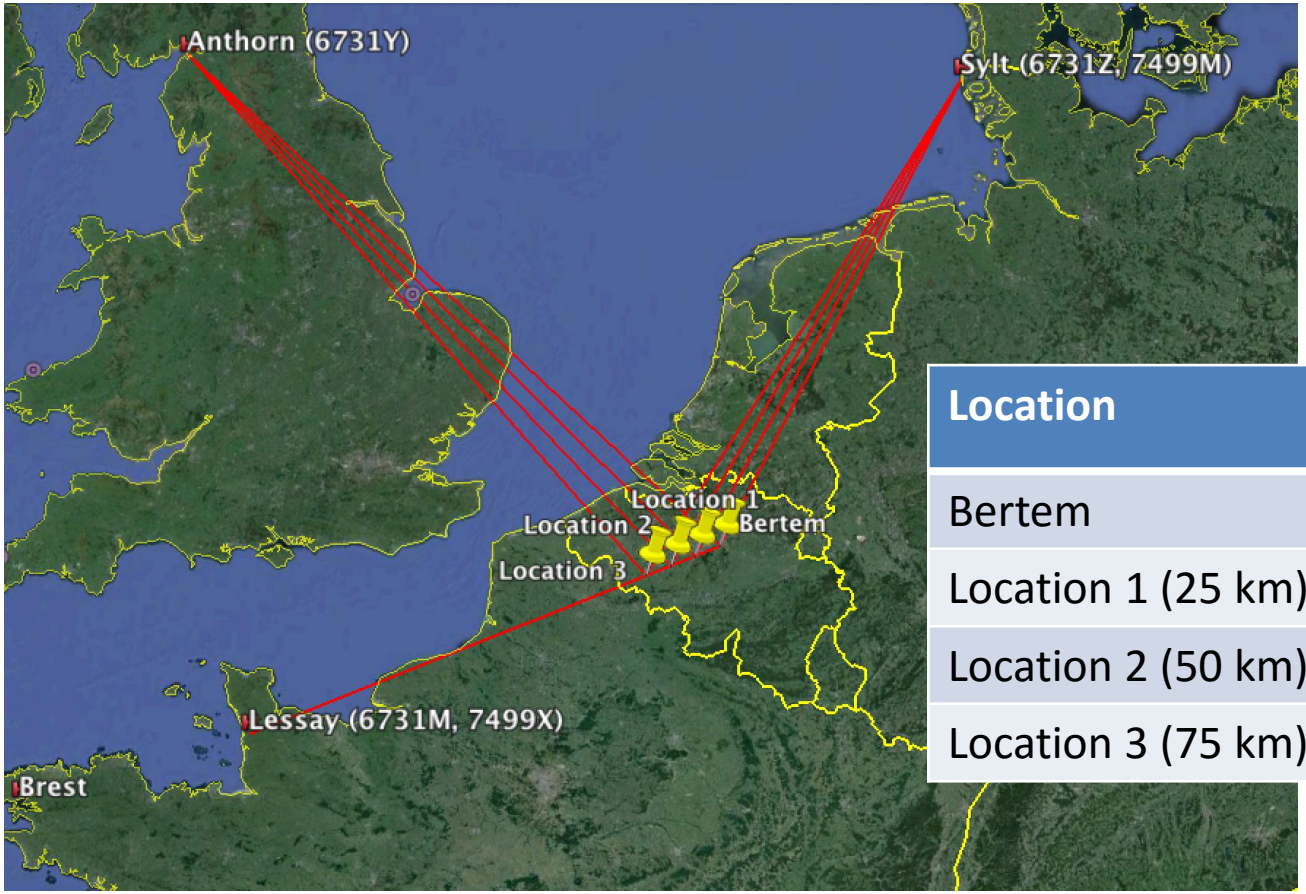

Zero-baseline after application of corrections

Mean value of the data set is: -7.3 ns
Standard deviation is: 14.4 ns

# Rover Receiver


- Initial Rover data collection started to assess the spatial decorrelation of ASFs and Differential Corrections

# Initial Rover Receiver Results




| Location | Measured Offset (Std) |
|---|---|
| Bertem | -7 ns (14.4 ns) |
| Location 1 (25 km) | 118 ns ( 8.5 ns) |
| Location 2 (50 km) | -57 ns ( 8.5 ns) |
| Location 3 (75 km) | 270 ns ( 6.7 ns) |

- No ASF map used, only corrections from Reference Station applied
- Short duration (20 minutes) measurements
- Measured offsets within expected range of ASF change

# Conclusions and Further Work

- We implemented a Differential eLoran service for Timing applications
- The application of Differential Corrections for eLoran Timing receivers removes diurnal variation (zero-baseline)
- Differential corrections are applicable over larger distances but application of an ASF map (or one-time calibration) is needed to eliminate the offset due to different nominal ASFs at Reference and Rover sites
- Work in progress to analyze ASF variation around the Reference Station to increase the application area of Differential Corrections (ASF survey)
- Use of eLoran H-field antennas

# Acknowledgements

Thanks and acknowledgement to Martin Bransby, Paul Williams and Chris Hargreaves of General Lighthouse Authorities of the United Kingdom and Ireland (GLA) for their inputs to this paper and for allowing UrsaNav to trial differential UTC corrections from the transmitter at Anthorn, Cumbria, UK.

# *Thank you!*

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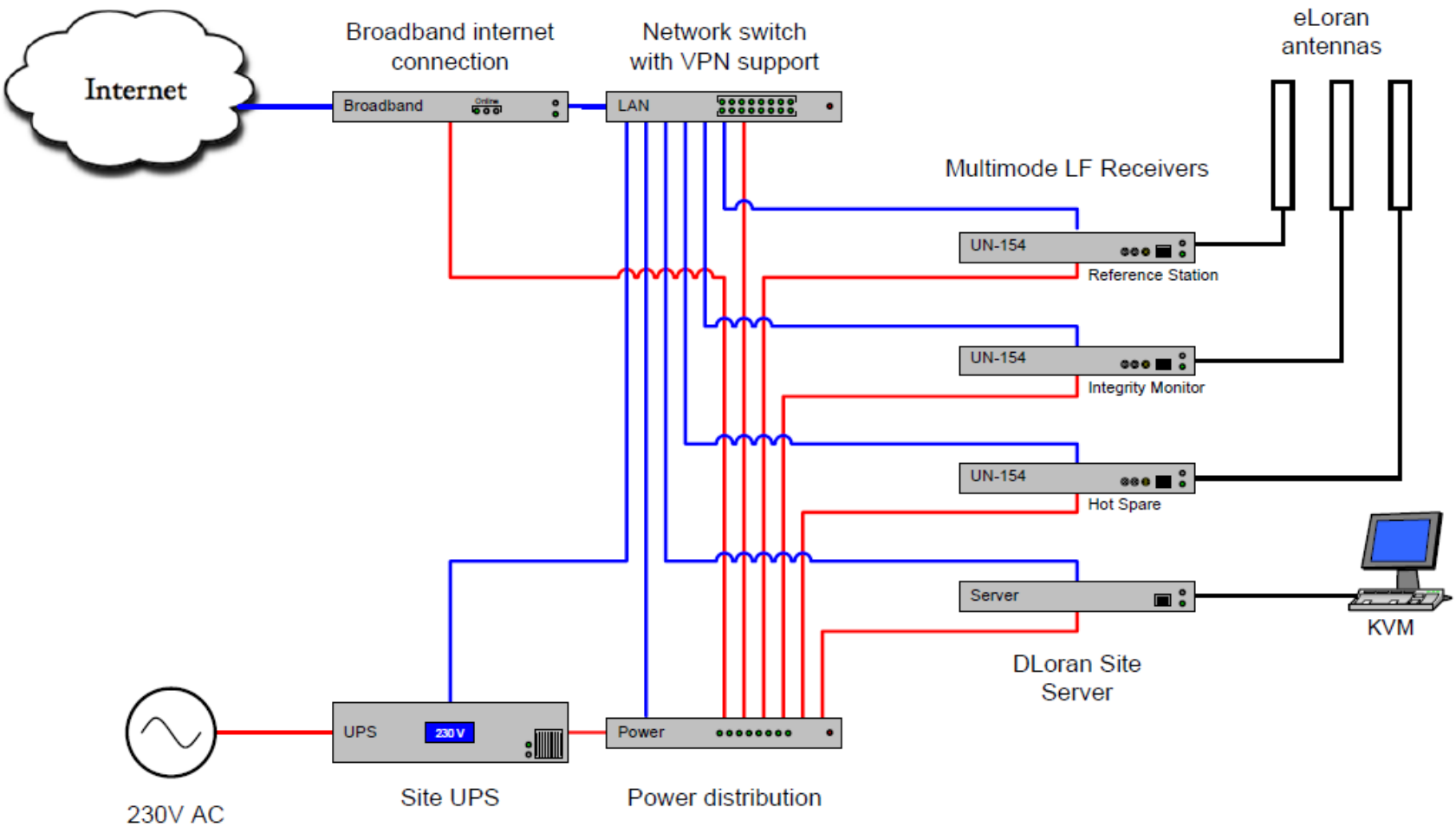
# Block diagram of dLoran RSIM

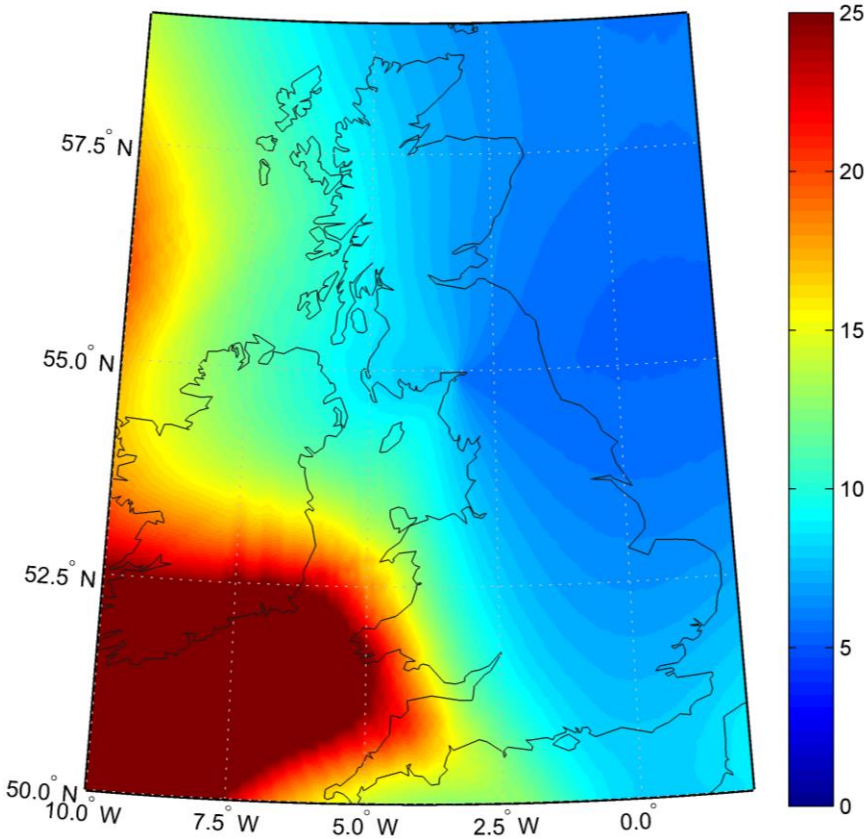


# Predicting eLoran performance

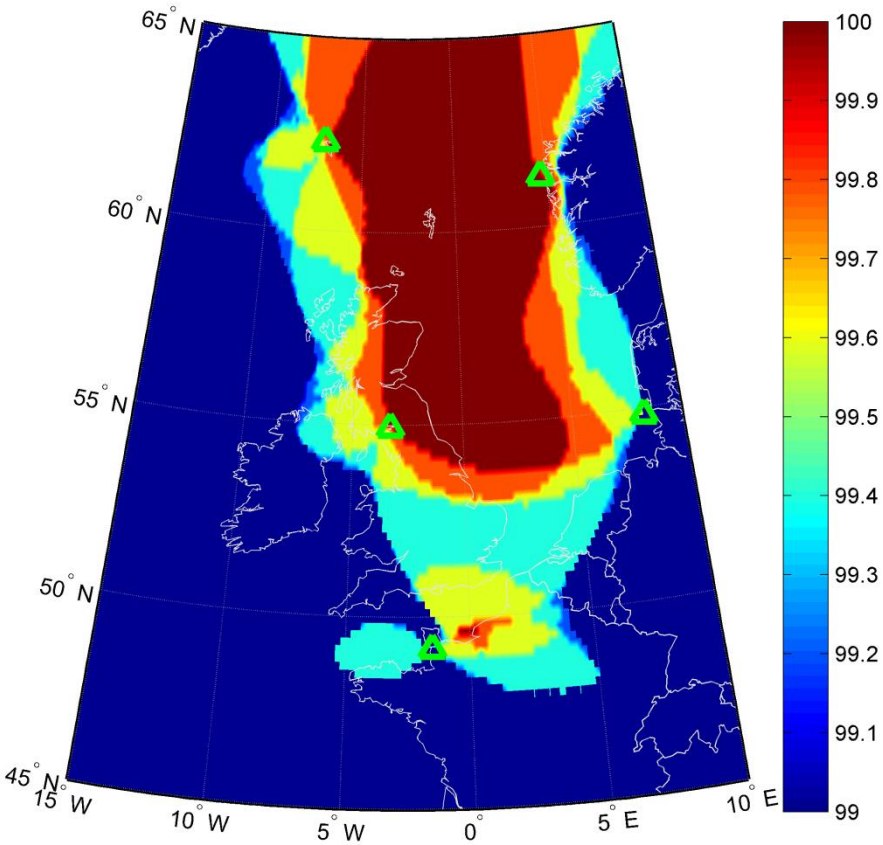
- The GLA have developed a comprehensive software suite for modeling eLoran system performance
- Model accounts for
  - Ground wave propagation over non-homogenous terrain
  - Atmospheric noise
  - Skywave expected strength and delay
  - dLoran errors due to spatial decorrelation

| Data | Source | Notes |
|---|---|---|
| Ground Conductivity | ITU-R P.832-3 | Digitised and rebuilt in places using DTED |
| Groundwave | ITU-R P.368-9 | $8^{th}$-order polynomial fitting of GRWAVE output |
| Skywave | ITU-R P.1147-4 | Proprietary conversion of sky-field to TOA error |
| Background Noise | ITU-R P.372-6 | Median converted to arithmetic mean power |
| Receiver Performance | GLA | RTCM SC-127 MOPS & IEC |

# Accuracy and Availability

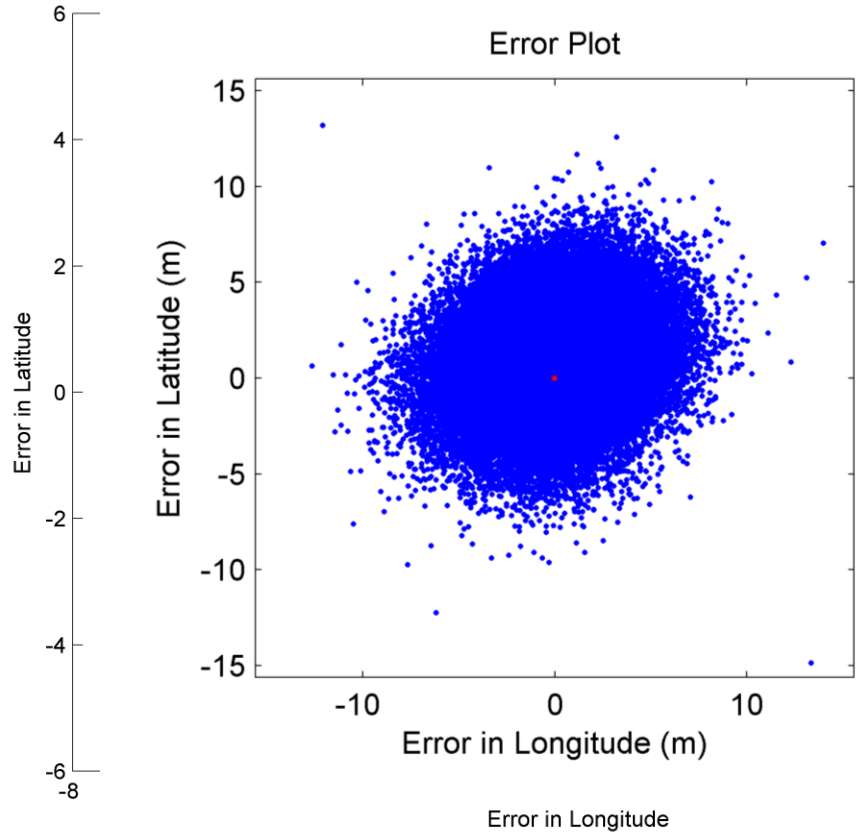


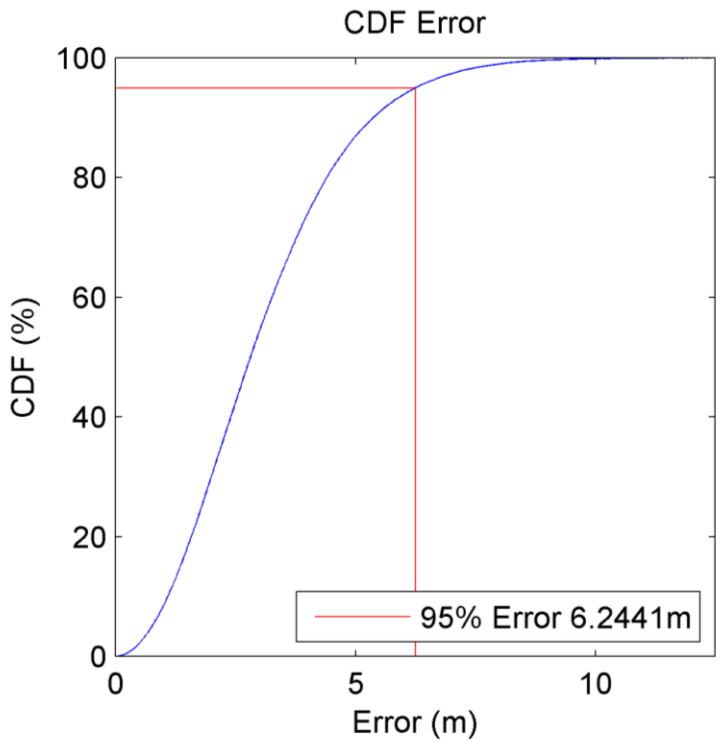

Theoretical Zero-Baseline Accuracy in meters




Availability Scale is percentage

# Humber


Error Plot
Error in Latitude (m)
Error in Longitude (m)
15
10
5
0
-5
-10
-15
-10
0
10
6
4
2
0
-2
-4
-6
-8
Error in Latitude
Error in Longitude


CDF Error
CDF (%)
Error (m)
100
80
60
40
20
0
0
5
10
95% Error 6.2441m