ESA UTD Final Presentation

27th June 2025

UTD Project

- UTD = “UTC Time Distribution”
- ESA NAVISP Element 3 project 4000135940/21/NL/DB
- Endorsed by UK Government for Element 3 funding
- NAVISP EL-3-017
- 3-year project started in 2021 (extended until June 2025)
- UTD project aims were to measure and model Additional Secondary Factors (ASF) for eLoran signal propagation over land

UTD Project

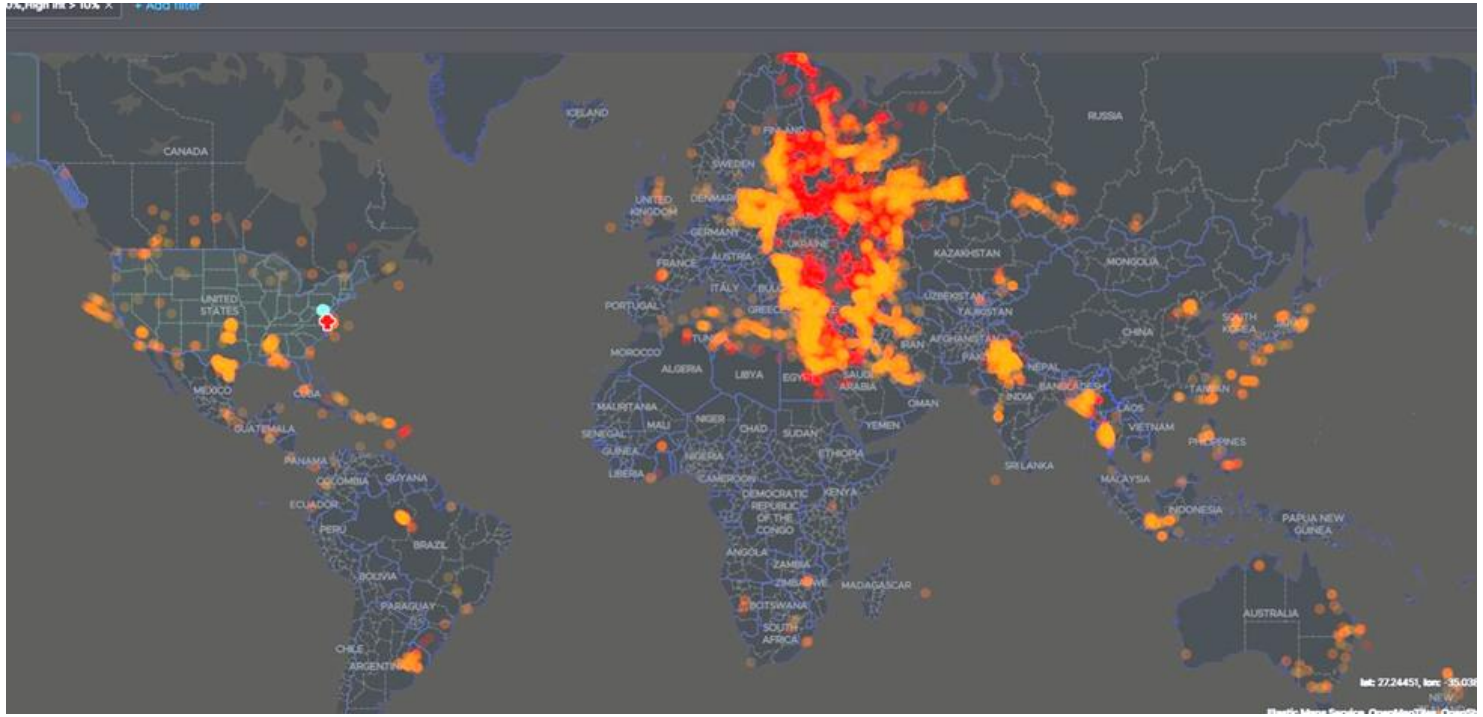
Background

- GNSS widely used by all CNI sectors as a source of UTC timing signals
- GNSS is very accurate, low cost and easy to use
- However, GNSS is known to be vulnerable to jamming, spoofing and space weather
- Industry is becoming increasingly aware of these vulnerabilities and the requirement for alternative timing technologies
- Ideal solution is to combine GNSS with alternative timing technologies to provide resiliency to such vulnerabilities

UTD Project

GNSS Jamming

- Significant day to day jamming events
- Particularly affecting eastern Europe and Scandinavia
- US DoT data



UTD Project

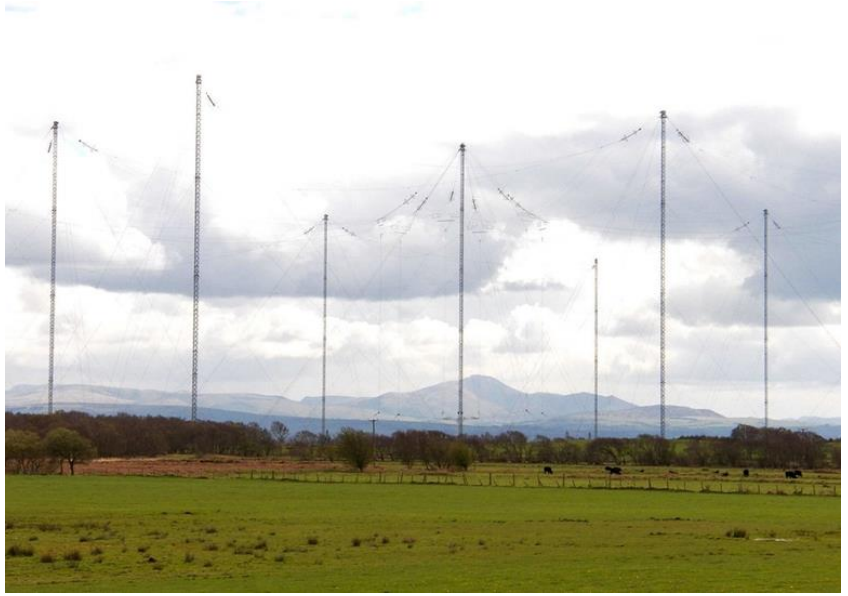
eLoran

- eLoran is a terrestrial system that has been deployed in the past (NELS and US) and more recently (South Korea, Saudi Arabia etc)
- eLoran is a terrestrial system and therefore is not exposed to the effects of space weather
- eLoran has very powerful signals that are much harder to jam and spoof
- eLoran broadcasts 100KHz signals that propagate as groundwaves and therefore are exposed to propagation delays due to changes in ground conductivity

UTD Project

eLoran

- eLoran still exists at Anthorn in the UK
- DSIT aspirations to deploy a fully operational UK eLoran system
- ASF data provision will be part of this UK system



UTD Project

Additional Secondary Factors

$$\rho = R + PF + SF + ASF + \delta$$

- ρ = received eLoran signal pseudo range
- R = Required true range
- PF = Primary Factor due to signal delay in the atmosphere
- SF = Secondary Factor due to signal delay over sea water
- ASF = Additional Secondary Factor due to signal delay over terrain
- δ = Variation in PF, SF and ASF

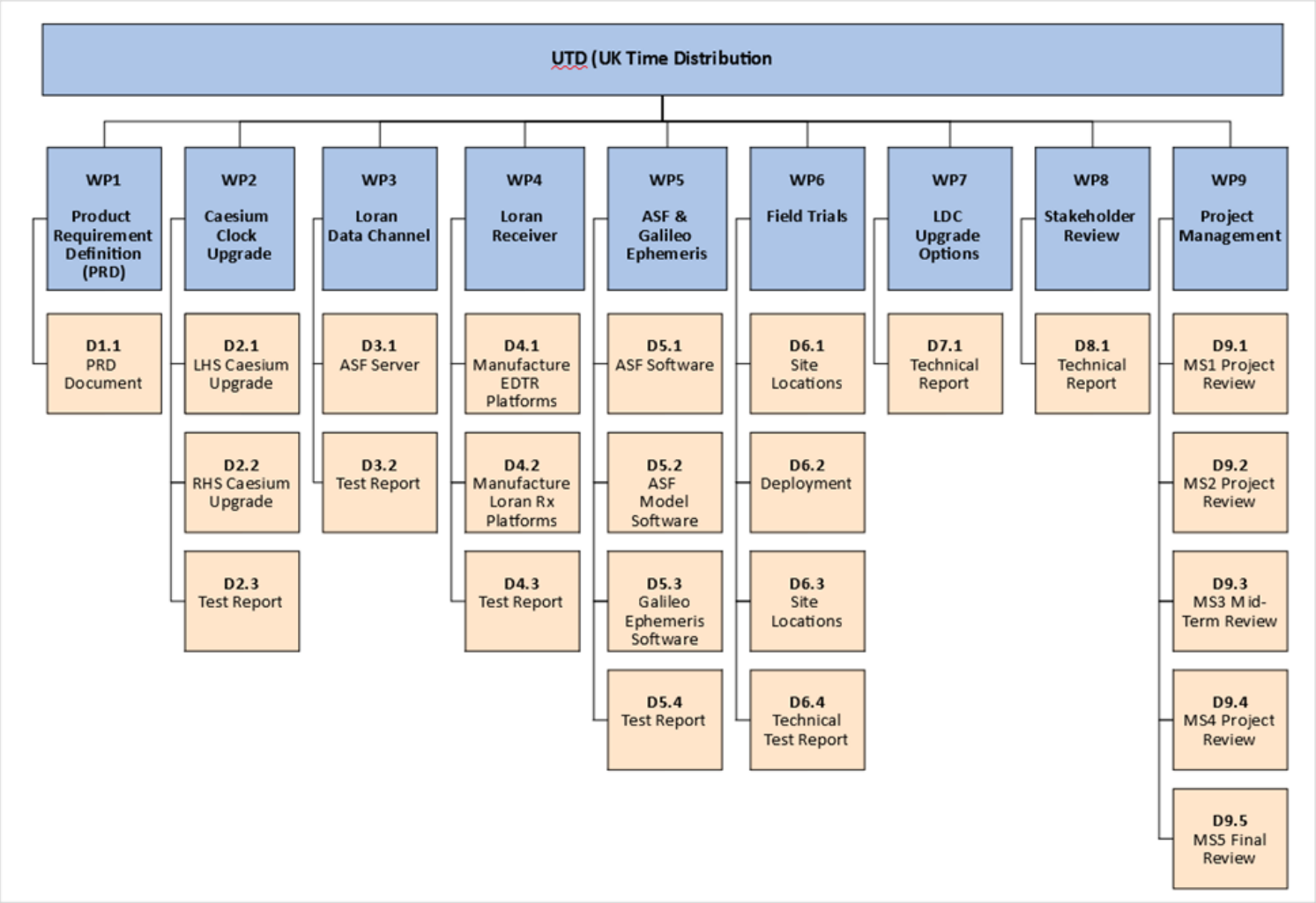
UTD Project

UTD Project Aims

- Replace existing failed Microchip 5071A caesium atomic clocks at the Anthorn transmitter
- Develop ASF measuring systems based on eLoran receivers
- Deploy ASF systems across the UK
- Develop ASF Models to compare to measured ASF data
- Undertake eLoran timing receiver trials

UTD Project

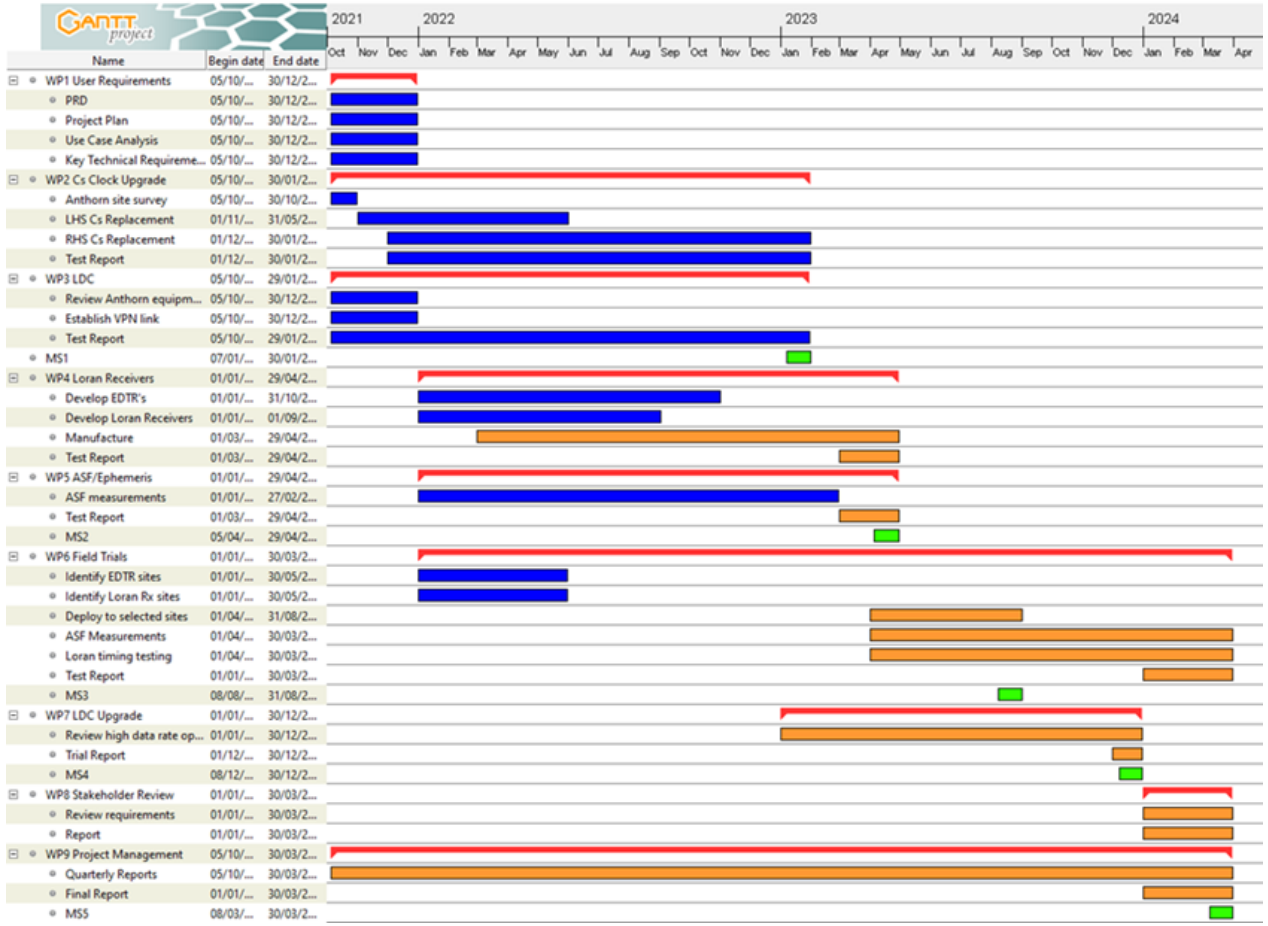
Work Package Structure



UTD Project

Project GANTT Chart

- 9 Work Packages
- Covered all areas from requirements capture, development, field trials and data analysis



UTD Project

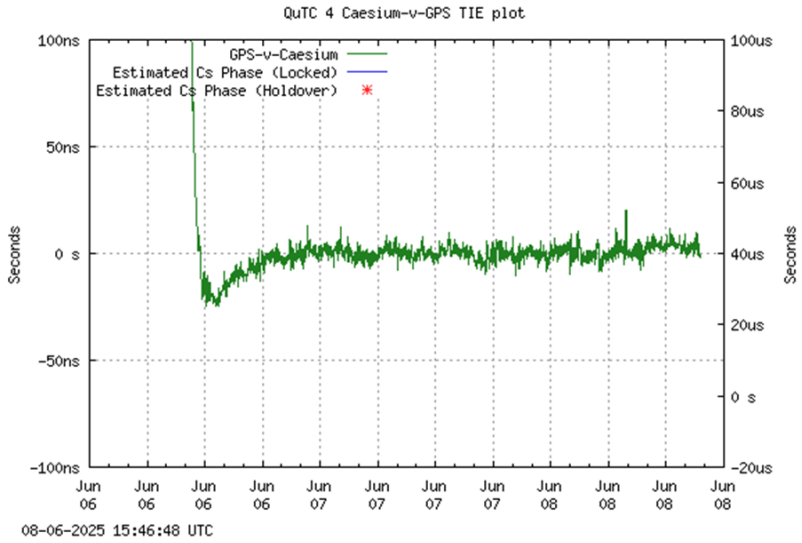
WP1 Requirement Capture

- Analysis of all requirements for each Work Package
- Initial list of suitable ASF measurement sites
- Stakeholder reviews (GRAD and Babcock)
- Wiring diagrams for 5071A Caesium clock replacement
- Anthorn transmitter access permissions
- Many thanks to GRAD and Babcock for their support during the UTD project

UTD Project

WP2 Anthorn Clock Replacement

- Site surveys of the Anthorn transmitter for 5071A replacements
- Installation and commissioning of the new 5071A clocks
- Resynchronisation to GNSS



UTD Project

WP3 LDC Access

- The Loran Data Channel (LDC) is a low bit rate channel with multiple message types
- The project plan was to load measured ASF data into one of the LDC message types and have the eLoran receivers download ASF data and apply to internal measurements to correct for propagation delays
- The eLoran receivers proved unable to reliably demodulate the LDC due to inadequate forward error correction software

UTD Project

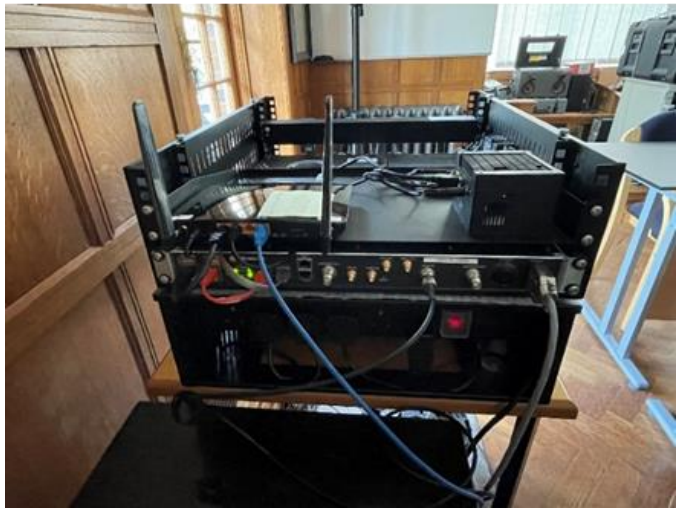
WP4 eLoran Receivers

- Prototype eLoran receivers were procured from Microchip in the US
- These receivers had embedded GNSS receivers to measure TOA data and compute ASF values
- These receivers could also be placed in timing mode to deliver UTC aligned 1pps outputs based solely on eLoran signals

UTD Project

WP4 eLoran Receivers

- eLoran receivers were built into self contained systems with PSU’s and 4G modems
- Included VPN connection to the ASF Server
- Fully tested and configured prior to deployment



UTD Project

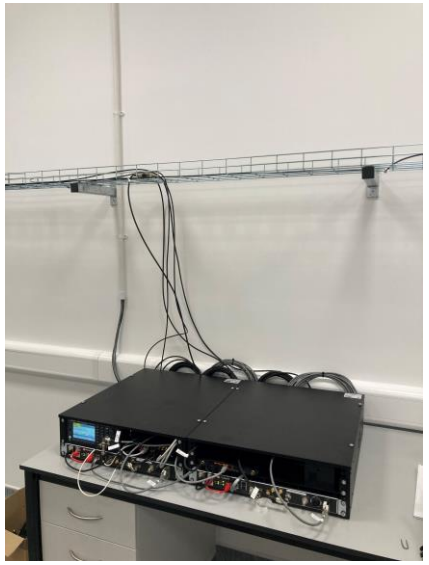
WP5 ASF Server Development

- Development of a cloud based ASF server
- Upload of measured ASF data to server via a VPN over 4G modems
- Development of ASF Model using terrain maps and weather data (temperature, humidity and rainfall)
- Comparison of modelled ASF data to measured ASF data for a given location

UTD Project

WP6 ASF System Field Trials

- Finalise field trial sites
- Deploy ASF systems to selected trial sites
- Measure and record ASF data
- eLoran timing testing



UTD Project

WP7 LDC

- Review potential techniques to increase LDC data rate
- Investigate any potential LDC data rate implications in terms of ASF data validity in terms of stale ASF data due to broadcast delays

UTD Project

WP8 Stakeholder Review

- Undertake stakeholder reviews at the end of the project
- Any necessary removal of deployed ASF systems
- Any updates from DSIT, GRAD and Babcock in terms of Anthorn or other equipment

UTD Project

WP9 Project Management

- Ongoing project management throughout the project
- Delivery of all document deliverables and meetings

UTD Project

Project Technical Issues

- The project encountered a number of technical issues;

(i) Significant component leadtimes in the 2021 post-COVID era that affected 5071A and eLoran receiver leadtimes

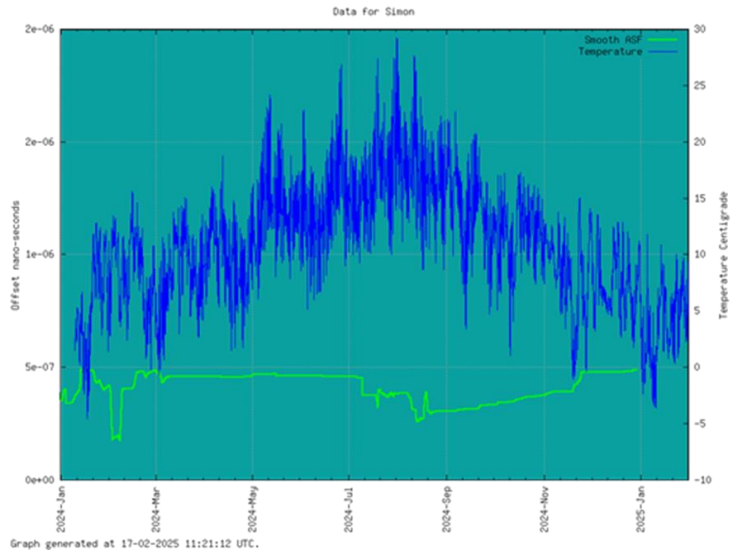
(ii) The eLoran receivers were at an early prototype stage and suffered from some stability issues due to a lack of noise filtering on the front end

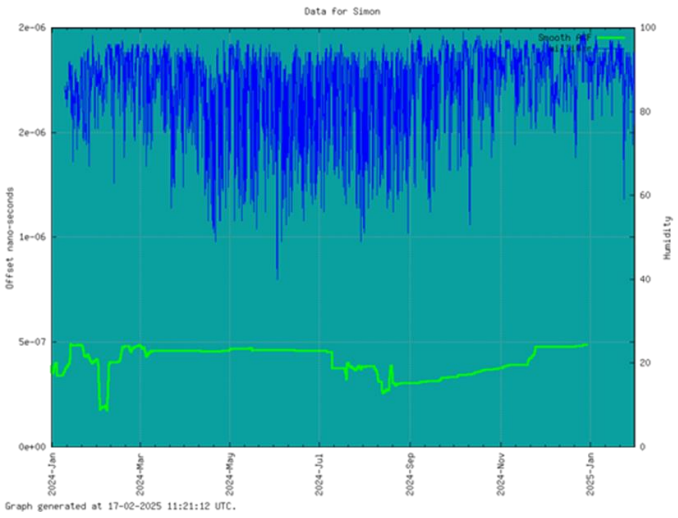
(iii) The Anthorn transmitter suffered from some equipment failures in July/Aug 2024 and again in early 2025

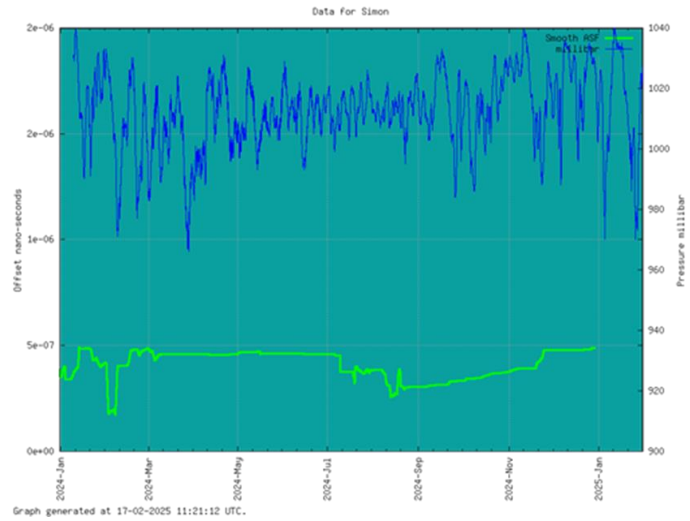
UTD Project

Project ASF Test Results

- 12-month ASF plots for all test sites
- Temperature, humidity and rainfall data
- ASF data is noisy but typically around 200ns peak to peak over the 12-month period



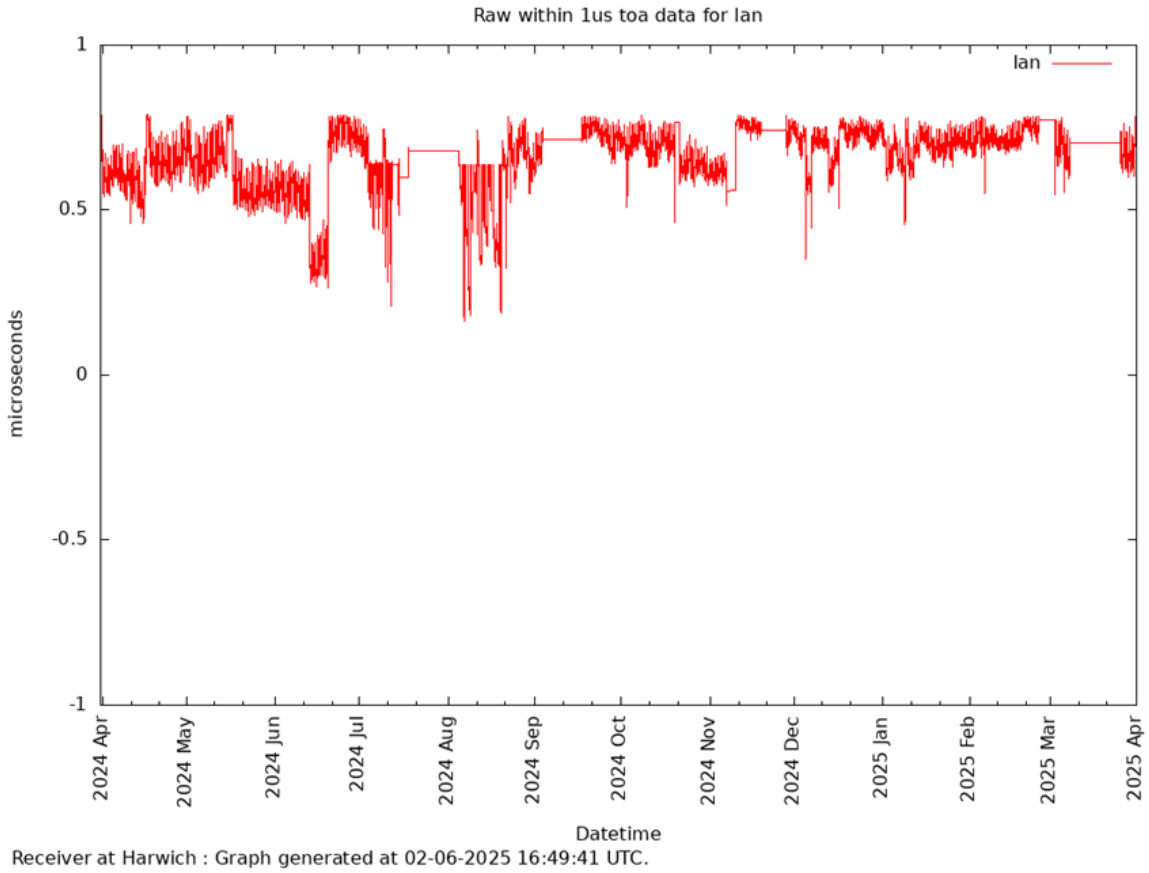




UTD Project

Project ASF Test Results

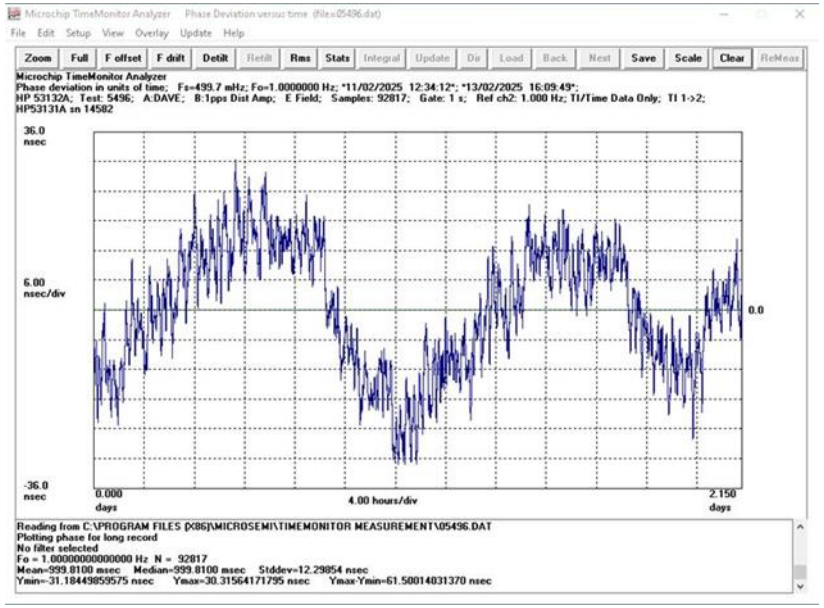
- 12-month ASF plots for Harwich
- Shows some Anthorn transmitter issues in June 2024 and in the last few months
- Typically around 200ns peak to peak over the 12-month period

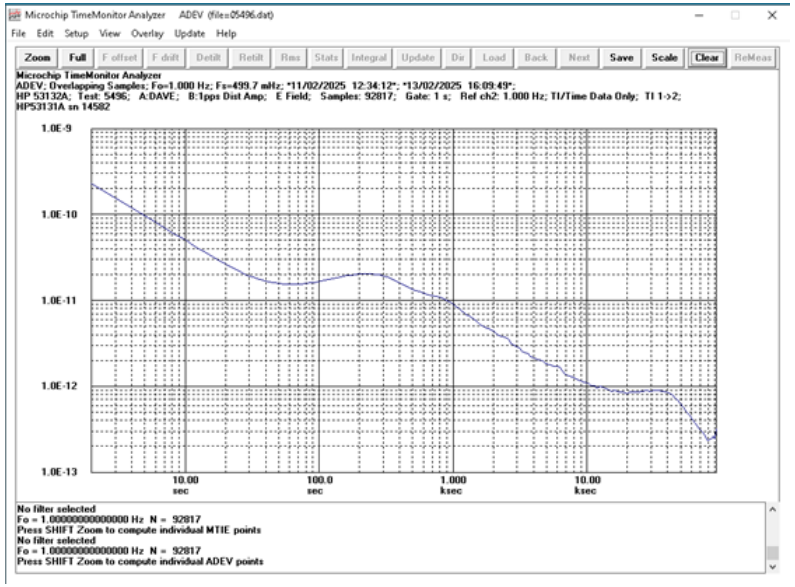


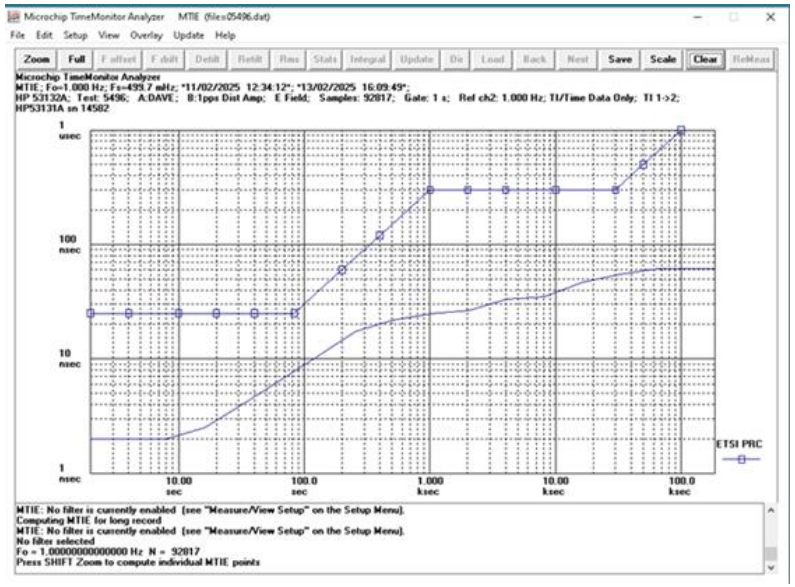
UTD Project

Project Timing Test Results

- In timing mode, the eLoran receivers produced excellent results, comparable to good quality GNSS timing receivers



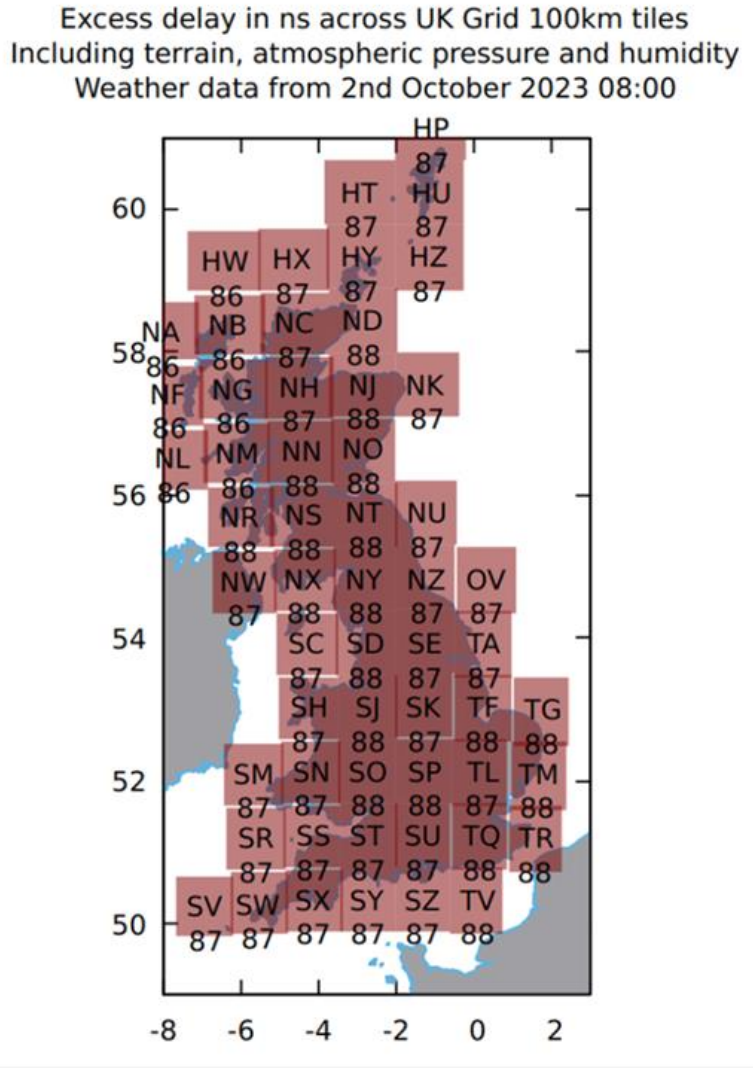




UTD Project

ASF Model

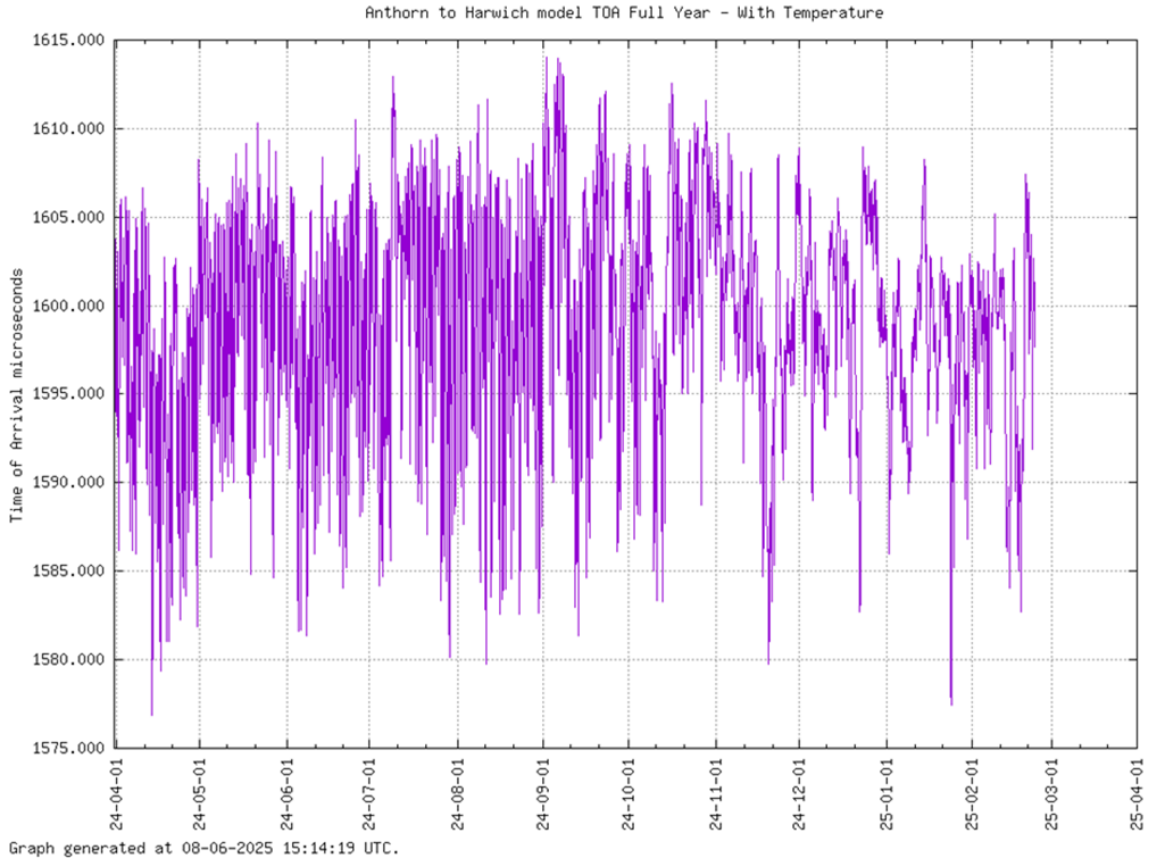
- Divides the UK into a grid of squares with 100km size
- Includes terrain, atmospheric pressure, temperature and humidity data for each square
- Concept is to sum the values of the squares for any location from Anthorn and then compare to measured values



UTD Project

ASF Model

- Modelled ASF data for Harwich
- TOA around 1.6ms (close to measured)
- No ground moisture data in model (only rainfall)
- Will carry on tuning the model post project



UTD Project

Lessons Learned

- The eLoran receivers used had no noise filtering on the front end which made them very susceptible to 100KHz interference and caused stability issues (typically cycle slips)
- More robust 3rd zero crossing algorithms are required for better stability and avoidance of 100KHz cycle slips
- Indoor signal reception with H-Field antennas is not practical without interference notch filtering
- H-Field antennas need temperature compensation algorithms

UTD Project

Conclusions

- Measured ASF data across the UK appears to only change by approximately +/-100ns over a 12-month period
- Further analysis of measured ASF data will require more stable eLoran receivers
- Modelled ASF data loosely correlates with measured data, but needs further model development including ground saturation data

UTD Project

Future Work

- D8.1 Final Stakeholder Meeting still to be conducted
- ESTEC Timing Receiver testing and analysis
- ASF model updates with moisture data post project
- Continue ASF measurements post project
- A number of UK eLoran initiatives including DSIT RFI for UK fixed system and military tactical system