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eLoran Performance in the Orkney Archipelago

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General Lighthouse Authorities of the United Kingdom and Ireland

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Introduction

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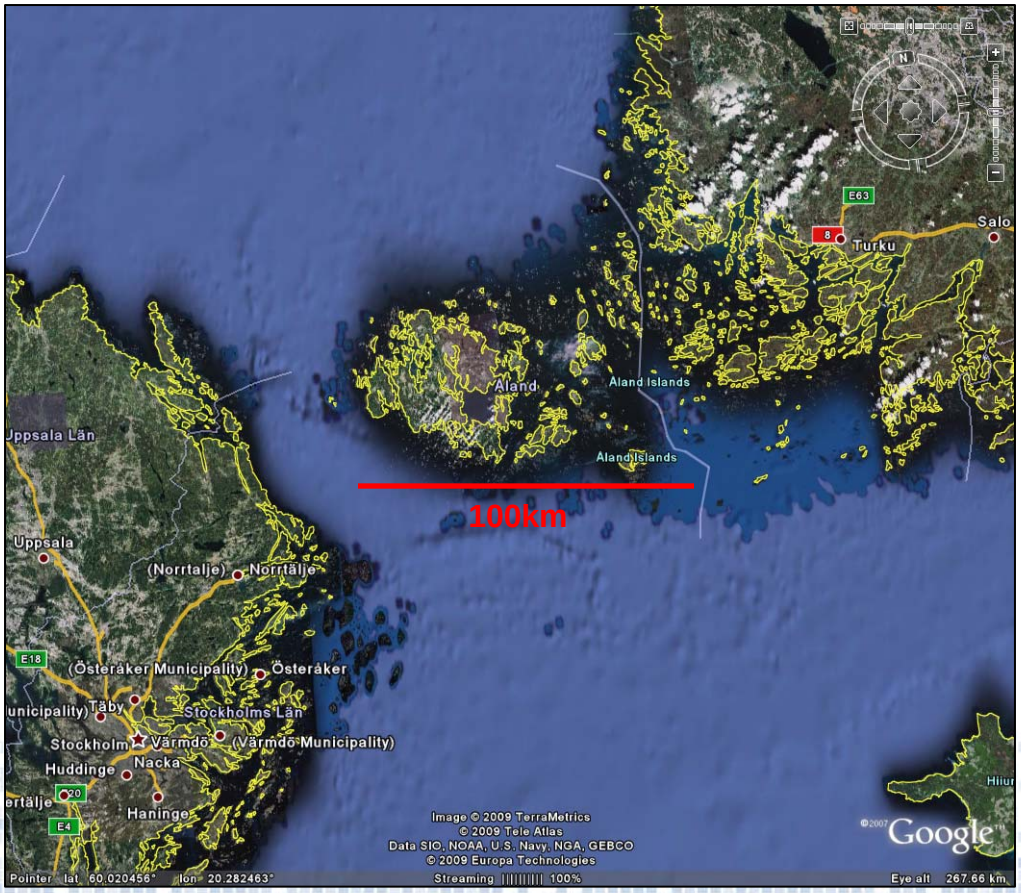
- There is wide support for eLoran in Europe from the UK, Ireland, France, Norway, and Denmark
- However, the Finnish Maritime Administration has raised concerns about performance of eLoran in densely packed island regions – archipelagos



Scandinavian Archipelagos

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The Orkney Islands

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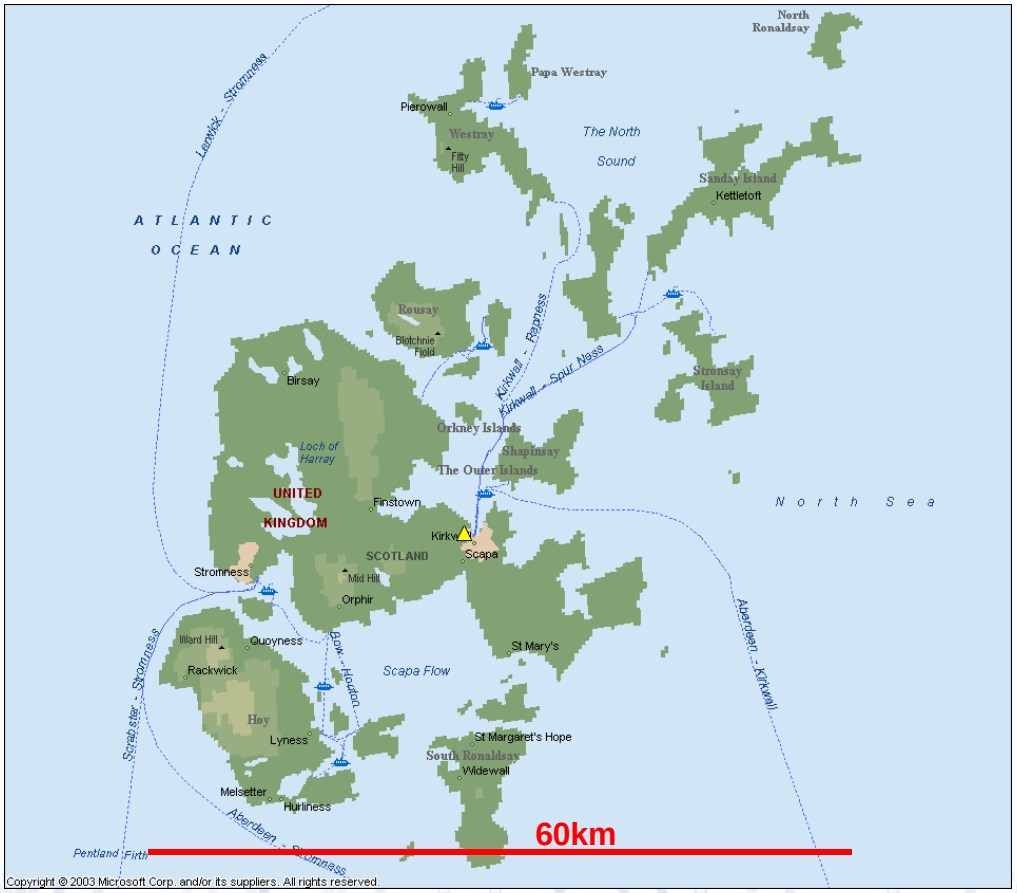
- The aim of the GLA's Orkney Island eLoran trial was to attempt to dispel these concerns



The Orkney Islands

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Based in Kirkwall

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Temporary dLoran Reference Station

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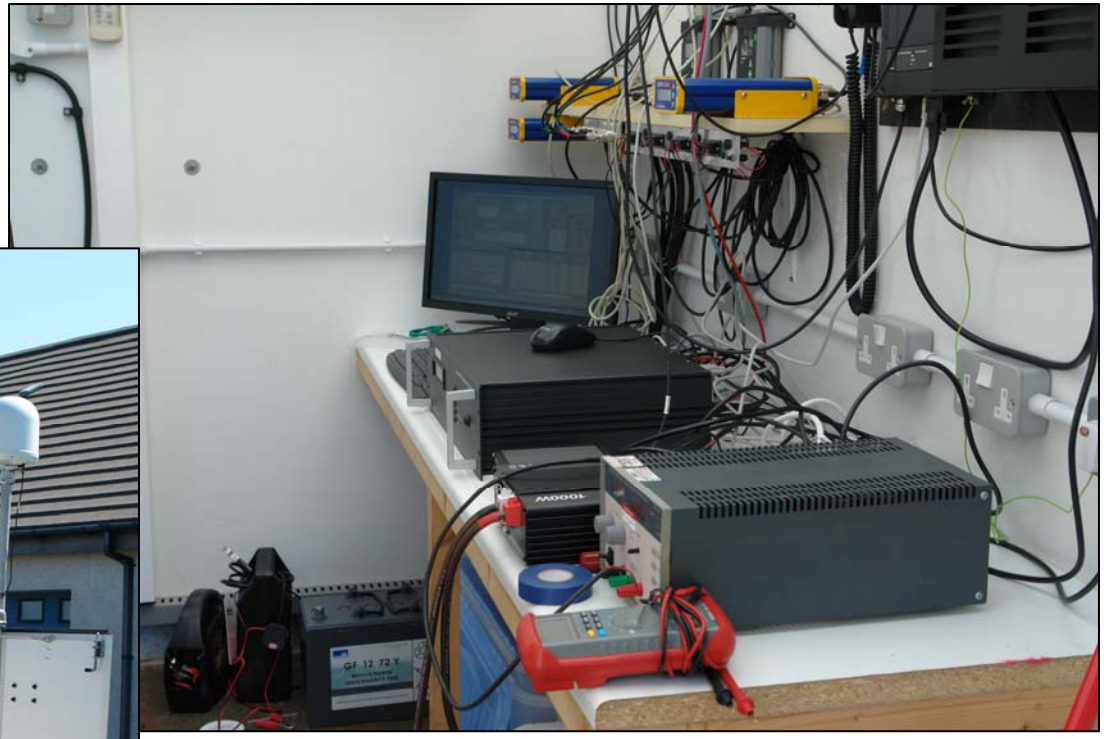
- NLB depot Kirkwall
- GLA's "Burger Van" (MMU)



- DGPS position survey performed
- Equipment can be setup as ASF Measurement Unit, or a Reference Station
- Brief nominal ASF measurement
- Loran stability measurements

Results: Static Data

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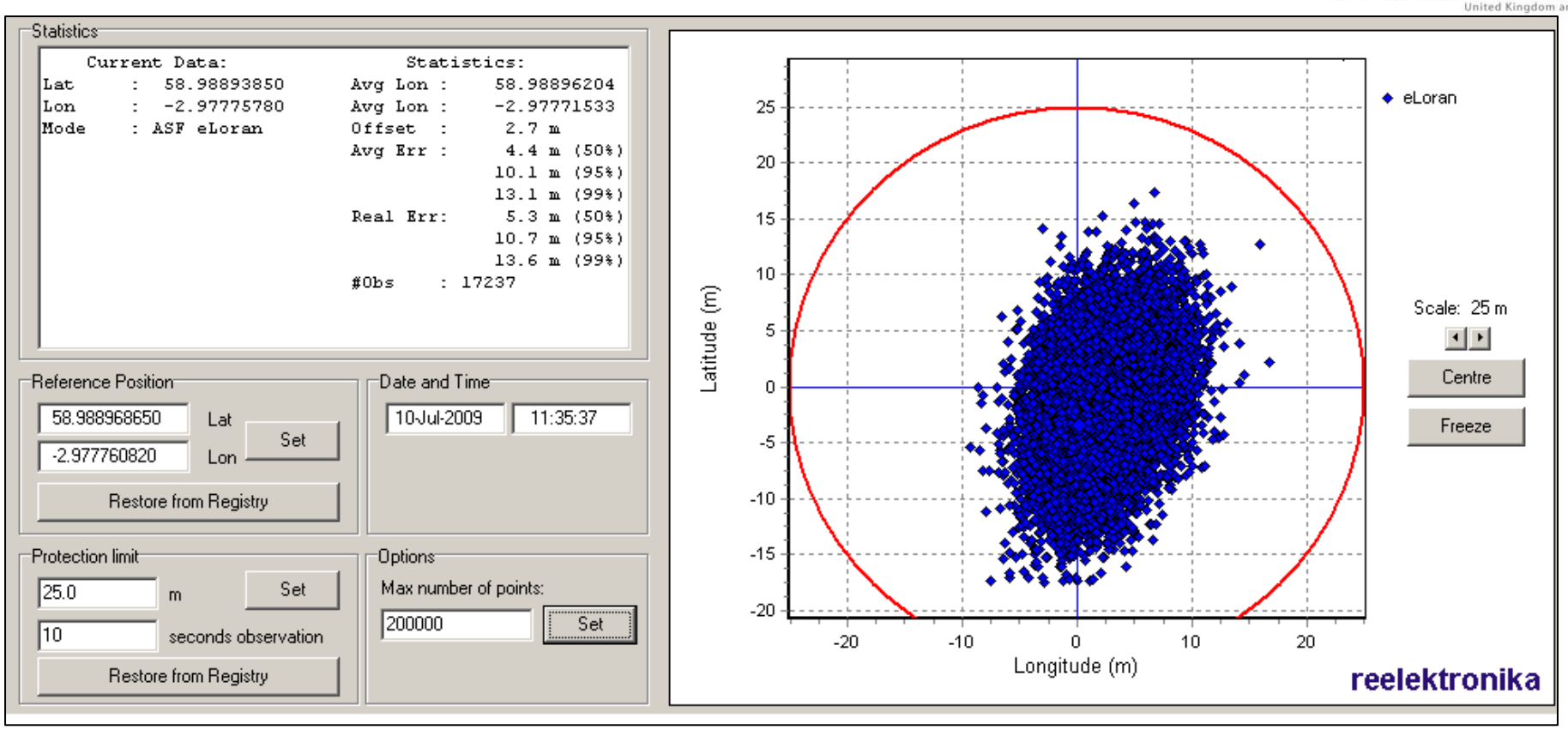

- 24 Hours data measured at Reference Station on 27th June 2009
- 10.7m (95%) “Real Error”
- There is an offset of 2.7m
- No differential corrections were broadcast – so this is just ASF Loran.

Sailing Routes

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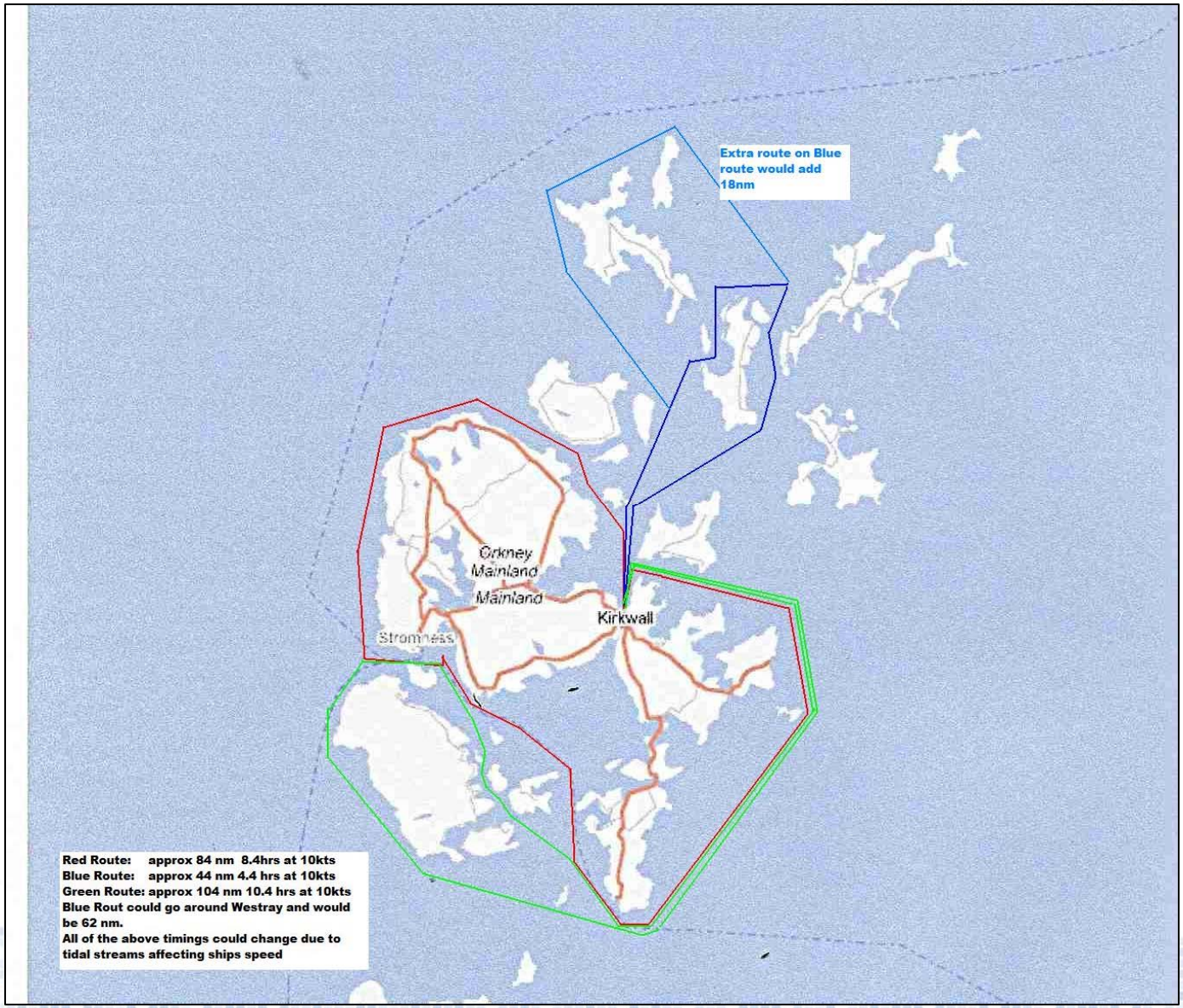
- Red, Blue and Green routes sailed in order on three separate days
- 230nm total length
- 23 hours worth of dynamic data at 10kts



Vessel Equipment

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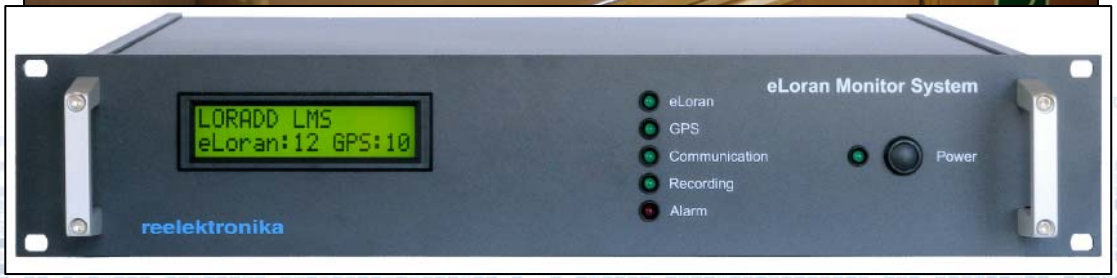
- NLV Pole Star
- Reelektronika ASF Measurement Unit
- Main unit: eLoran Monitoring System



Receiver Modes of Operation

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1. **Autonomous (or Standalone) Loran** - ASFs are not available within the receiver, there is no GPS calibration and no dLoran. Not eLoran!
2. **Calibrated Loran -** While GPS is available the eLoran output is periodically calibrated by the GPS position solutions. This is effectively the same as continuously using the GPS position as a “ground truth” and computing the offset of the eLoran positions from it. Almost like having ASFs everywhere. Not eLoran!
3. **ASF corrected Loran -** Additional Secondary Factors (ASF) are available and stored - the receiver will be capable of outputting a position solution based on ASF corrected Loran. eLoran for aviation NPA, but NOT for maritime Harbour Entrance and Approach!
4. **Differential-Loran (dLoran) -** If ASFs are available within the receiver, and differential-Loran corrections are available from a nearby differential-Loran Reference Station. This is eLoran for maritime Harbour Entrance and Approach!

Principle of Trials

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- Go out and assess Loran performance around as much of the the Orkney Islands as possible over the three days
- Calibrated Loran used as a quick first check
  - Sanity check
  - Some caveats as we shall see!
- Post-process results back in the laboratory (and aboard ship!)
  - Run logged data back through Reelektronika's logging software to get scatter plots
  - Also we have written our own software for more precise post-processing of raw Loran TOAs to demonstrate eLoran performance
- Attempt to do real-time dLoran harbour entrance and approach

Results: Calibrated – Red Route

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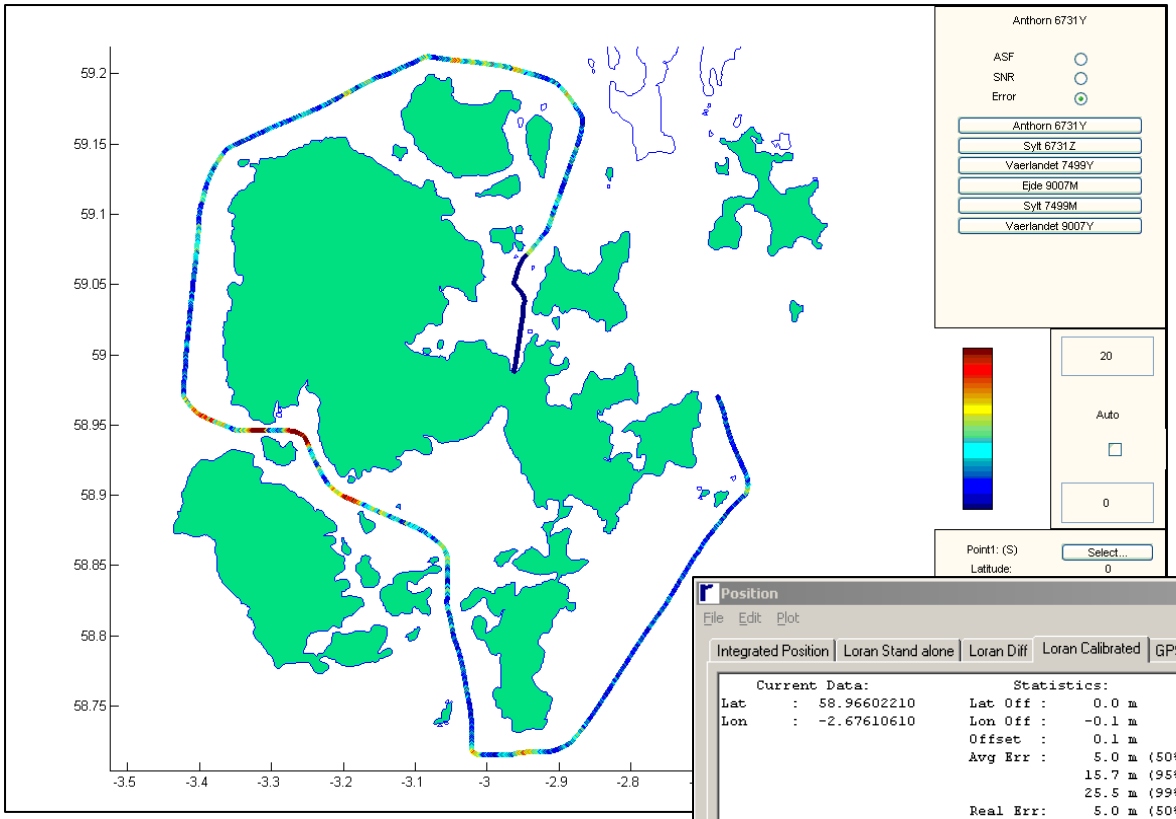
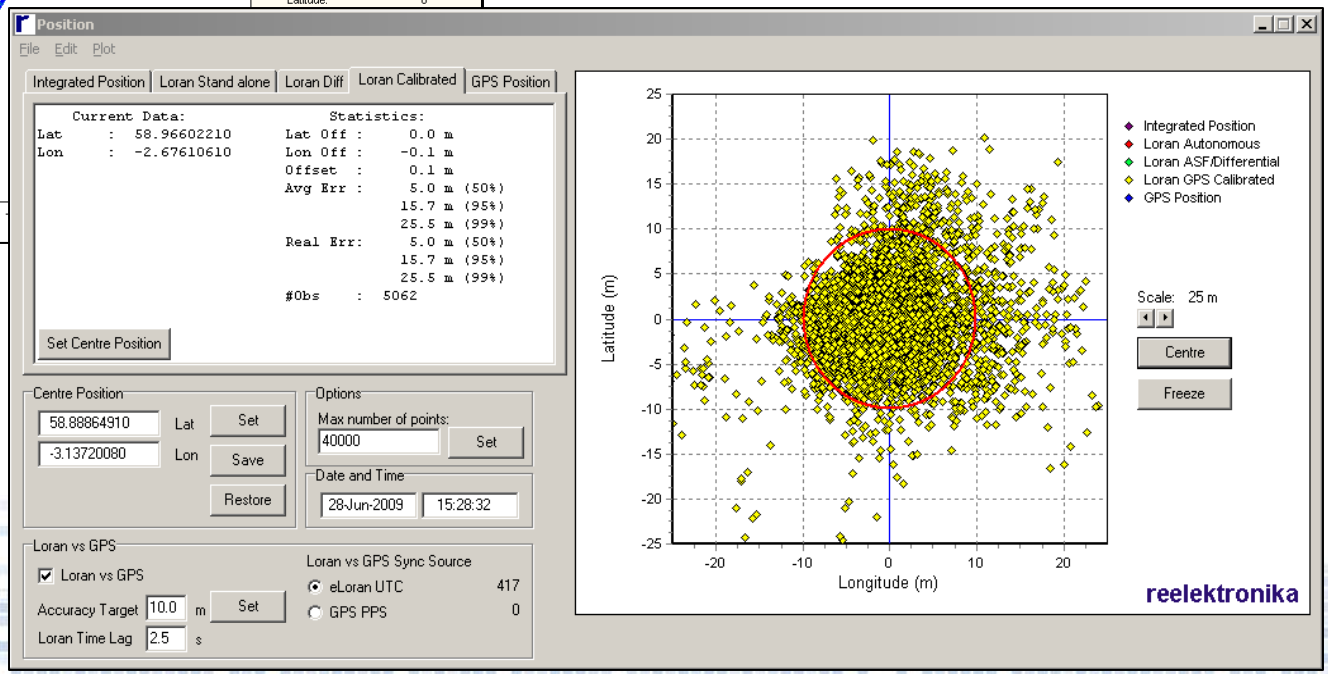


- Real Error: 15.7m (95%)
- Average Error: 15.7m (95%)
- Offset: 0.1m



Results: Calibrated – Blue Route

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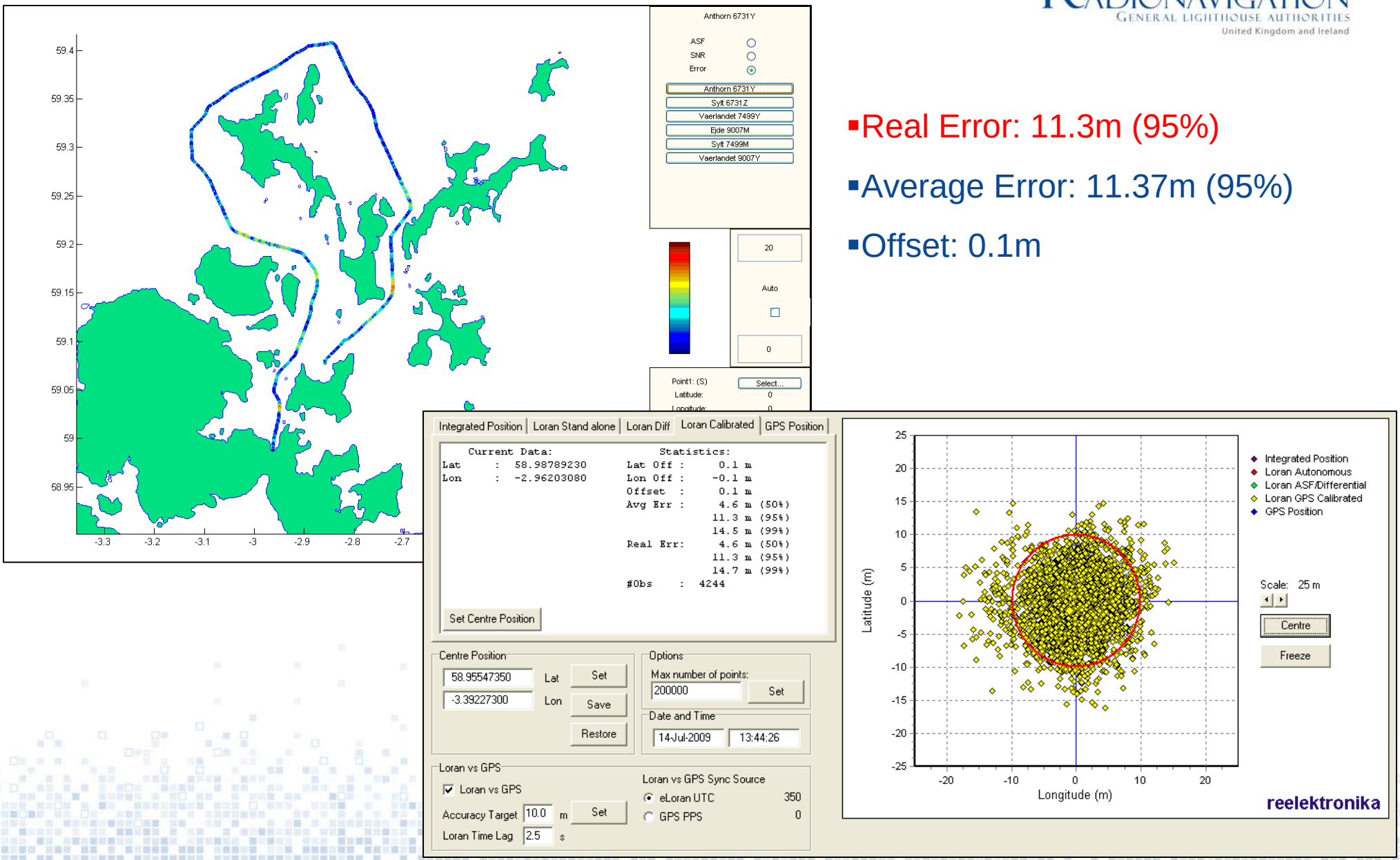

- Real Error: 11.3m (95%)
- Average Error: 11.37m (95%)
- Offset: 0.1m

Results: Calibrated – Green Route

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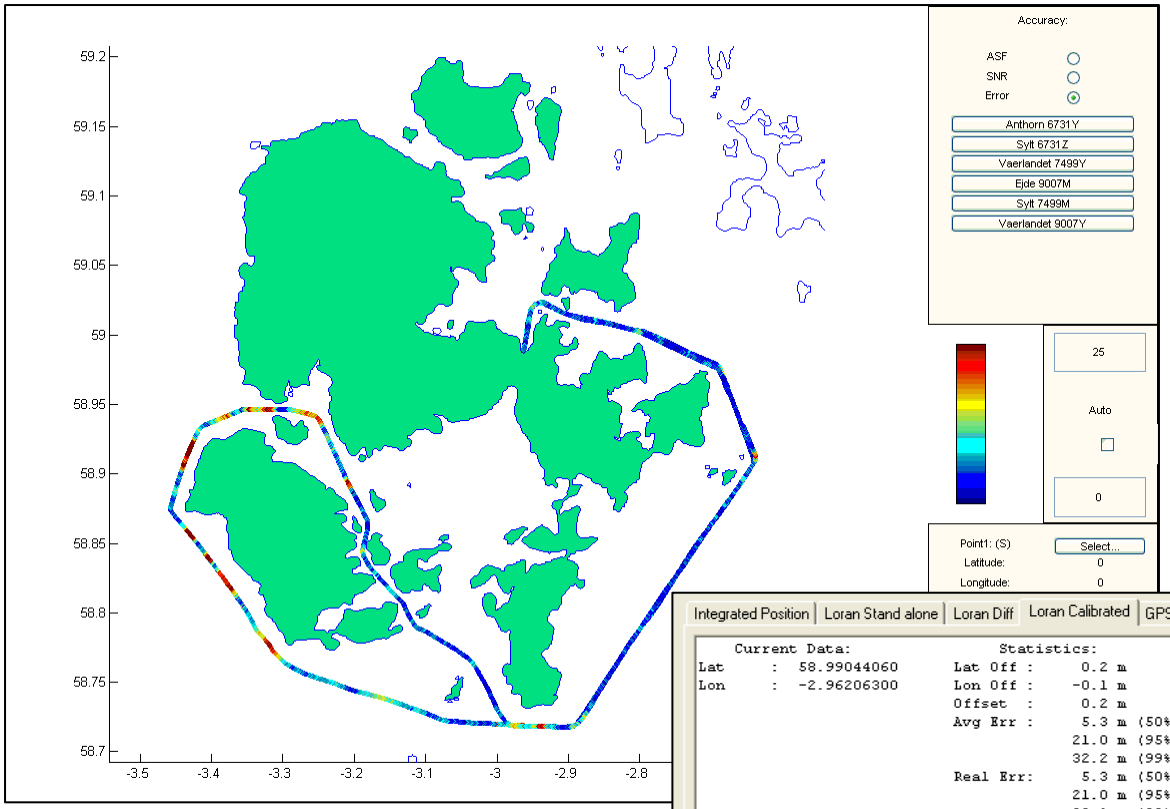
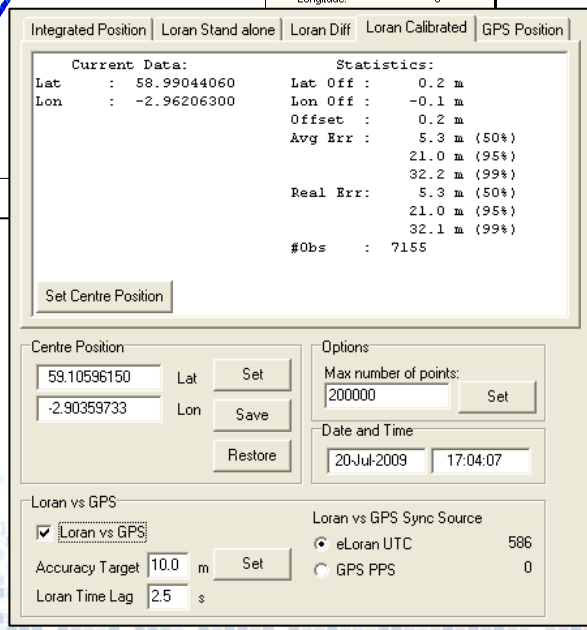
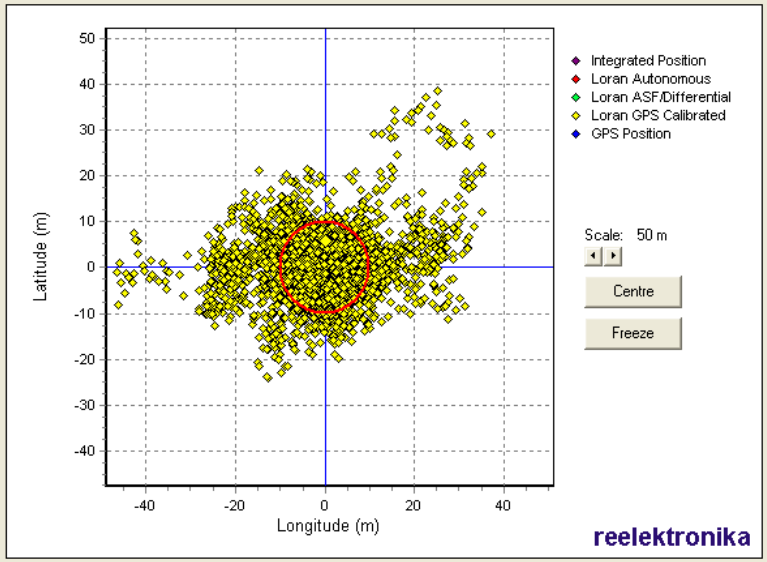
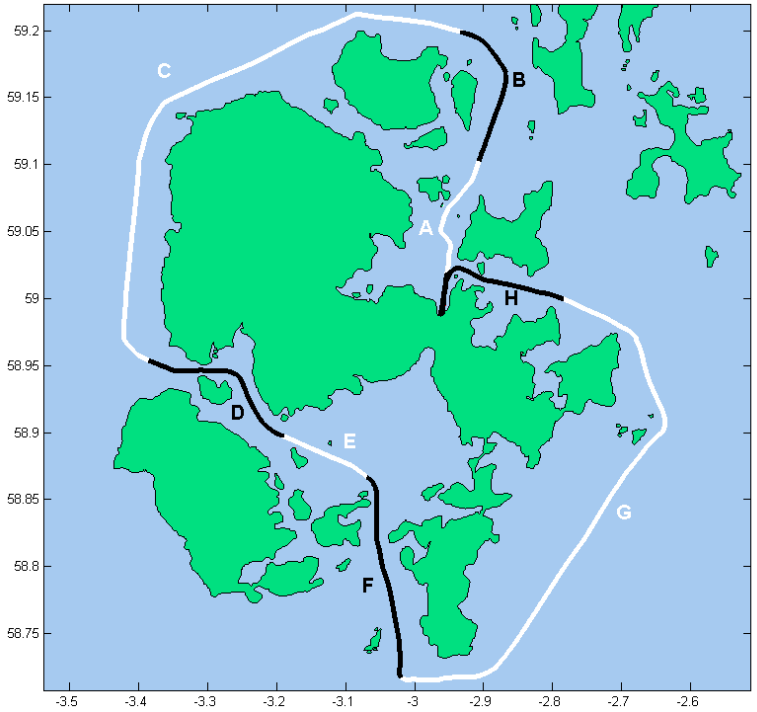






- Real Error: 21.0m (95%)
- Average Error: 21.0m (95%)
- Offset: 0.2m

Segmentation of Routes – Red Route



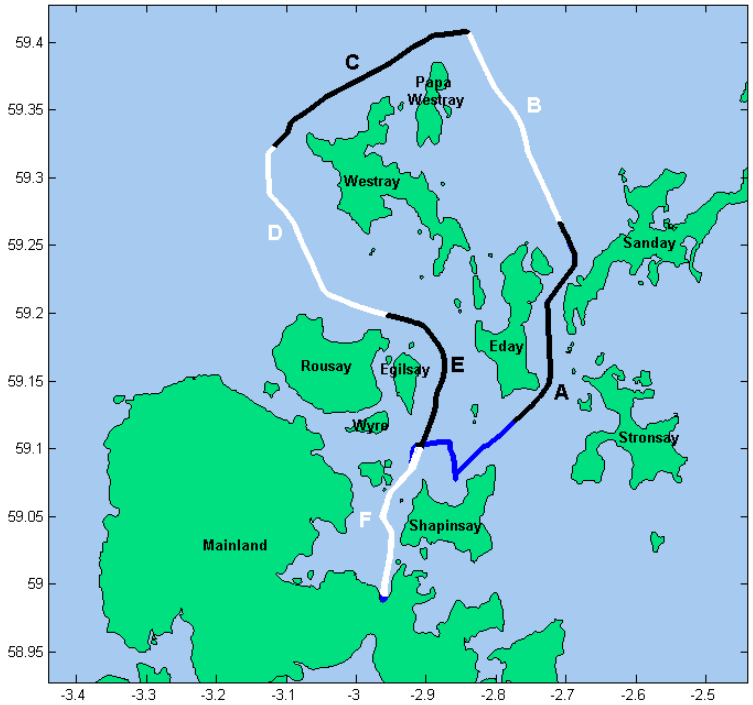
Green: Error<=20m

Amber: 20<Error<=25

Red: Error >25m

Segment ID	Overlaps with …	Autonomous (Average Error or precision) m (95%)	Calibrated (Real Error) m (95%)
Red A	Blue F	20.8	13.1
Red B	Blue E	14.7	11.2
Red C		43.9	12.6
Red D	Green D	44.8	29.7
Red E		19.7	20.8
Red F		14.3	12.0
Red G	Green B, G	37.1	11.8

Segmentation of Routes – Blue Route



Green: Error<=20m

Amber: 20<Error<=25

Red: Error >25m

Segment ID	Overlaps with …	Autonomous (Average Error or precision) m (95%)	Calibrated (Real Error) m (95%)
Blue A		29.6	13.1
Blue B		11.3	7.4
Blue C		22.4	8.1
Blue D		20.1	11.9
Blue E	Red B	23.9	11.7
Blue F	Red A	17.7	12.1

Segmentation of Routes – Green Route

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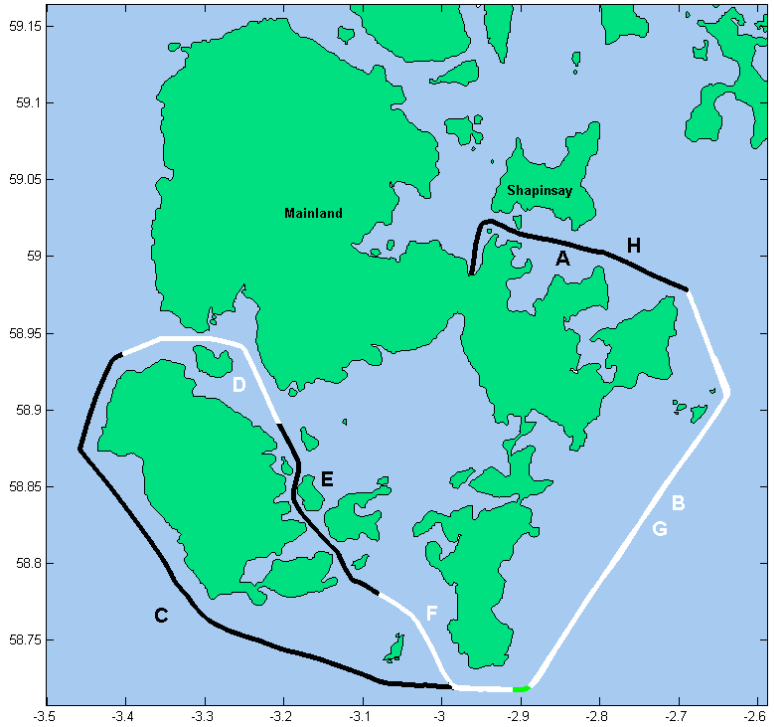

Green: Error<=20m

Amber: 20<Error<=25

Red: Error >25m

Purple: Error > 50m

Segment ID	Overlaps with …	Autonomous (Average Error or precision) m (95%)	Calibrated (Real Error) m (95%)
Green A	Green H	28.5	10.5
Green B	Red G, Green G	29.3	10.3
Green C		91.5	27.3
Green D	Red D	46.2	35.9
Green E		18.3	16.3
Green F		22.7	14.5
Green G (Extrapolated)	Red G, Green B	42.7	13.3
Green H	Green A	19.4	10.8

The Hoy Sound – Calibrated Results

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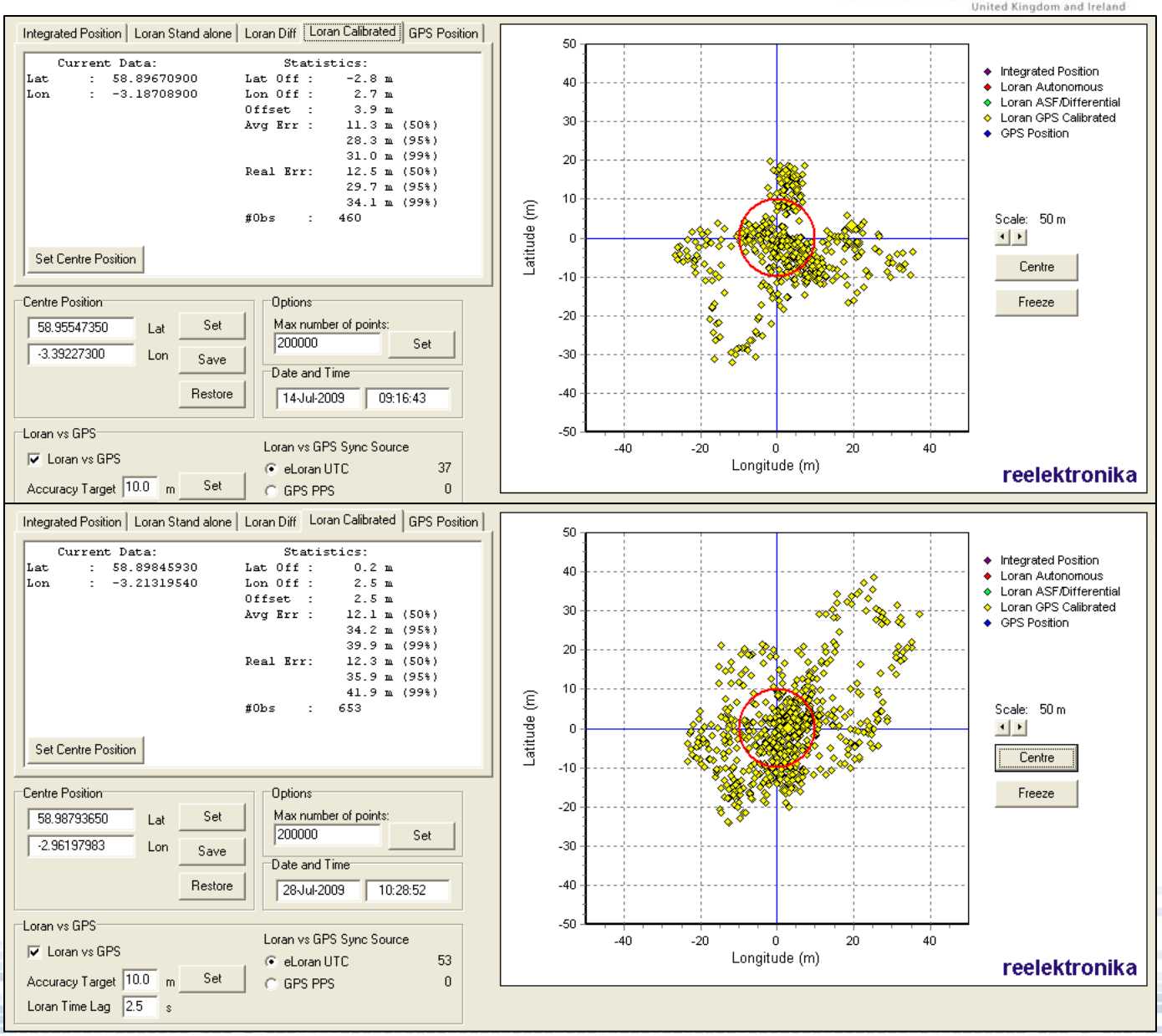
Red D
Real Error: 29.7m (95%)
Offset: 3.9m

Green D
Real Error: 35.9m (95%)
Offset: 2.5m



Hoy Sound: Instantaneous Error

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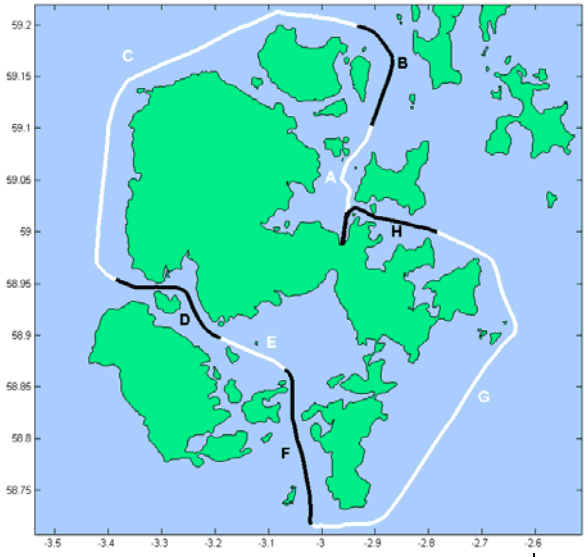

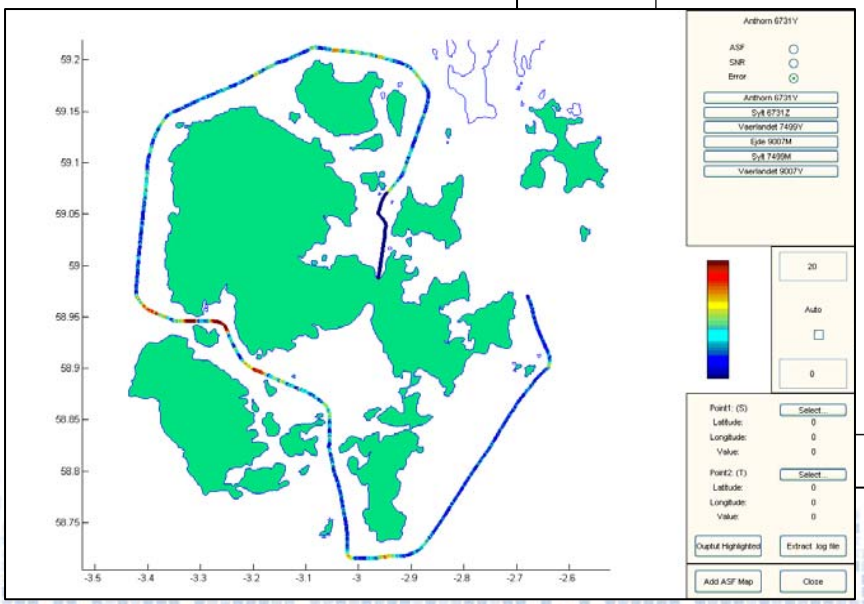

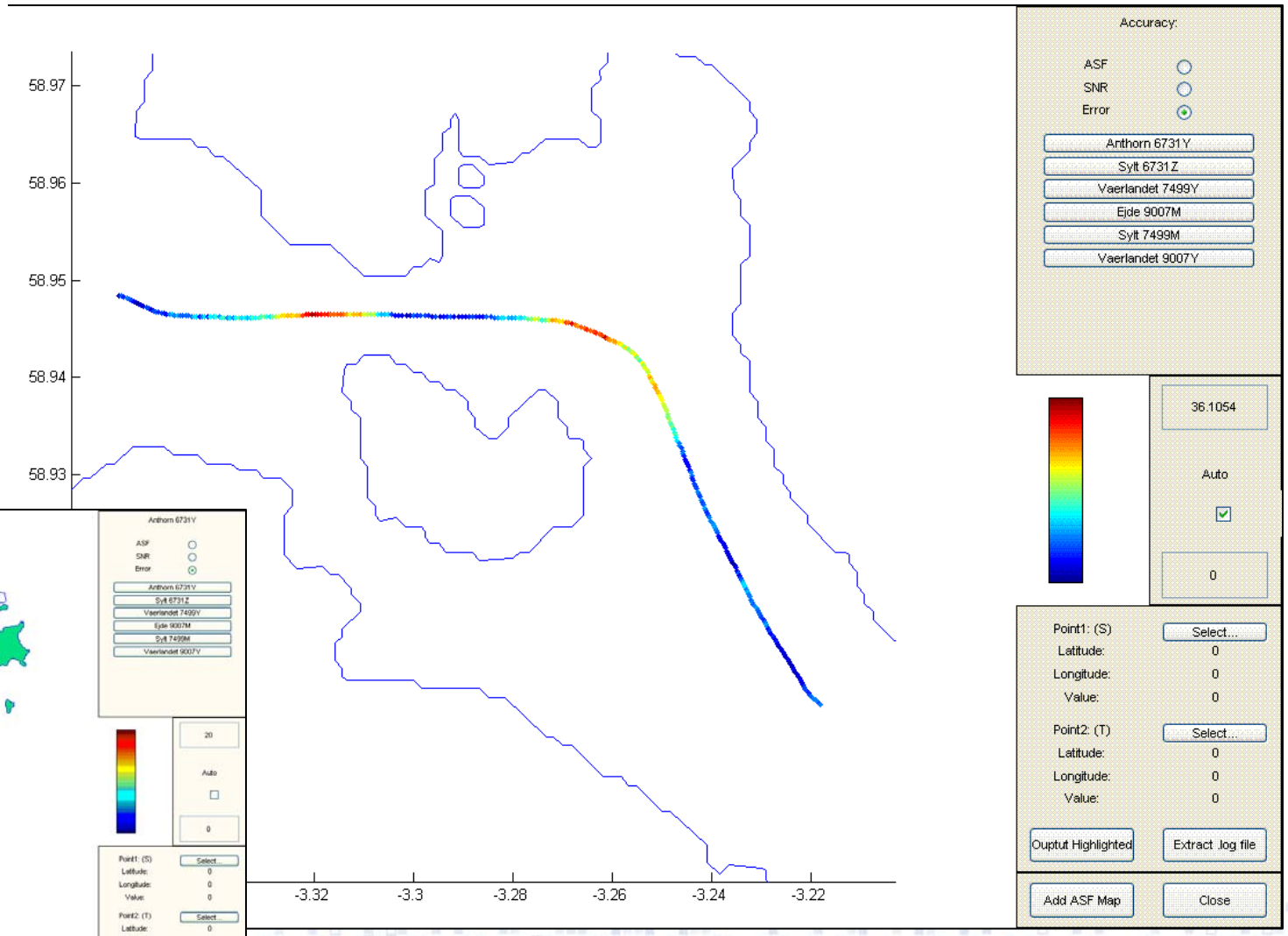

Anthorn-Ejde DASFs

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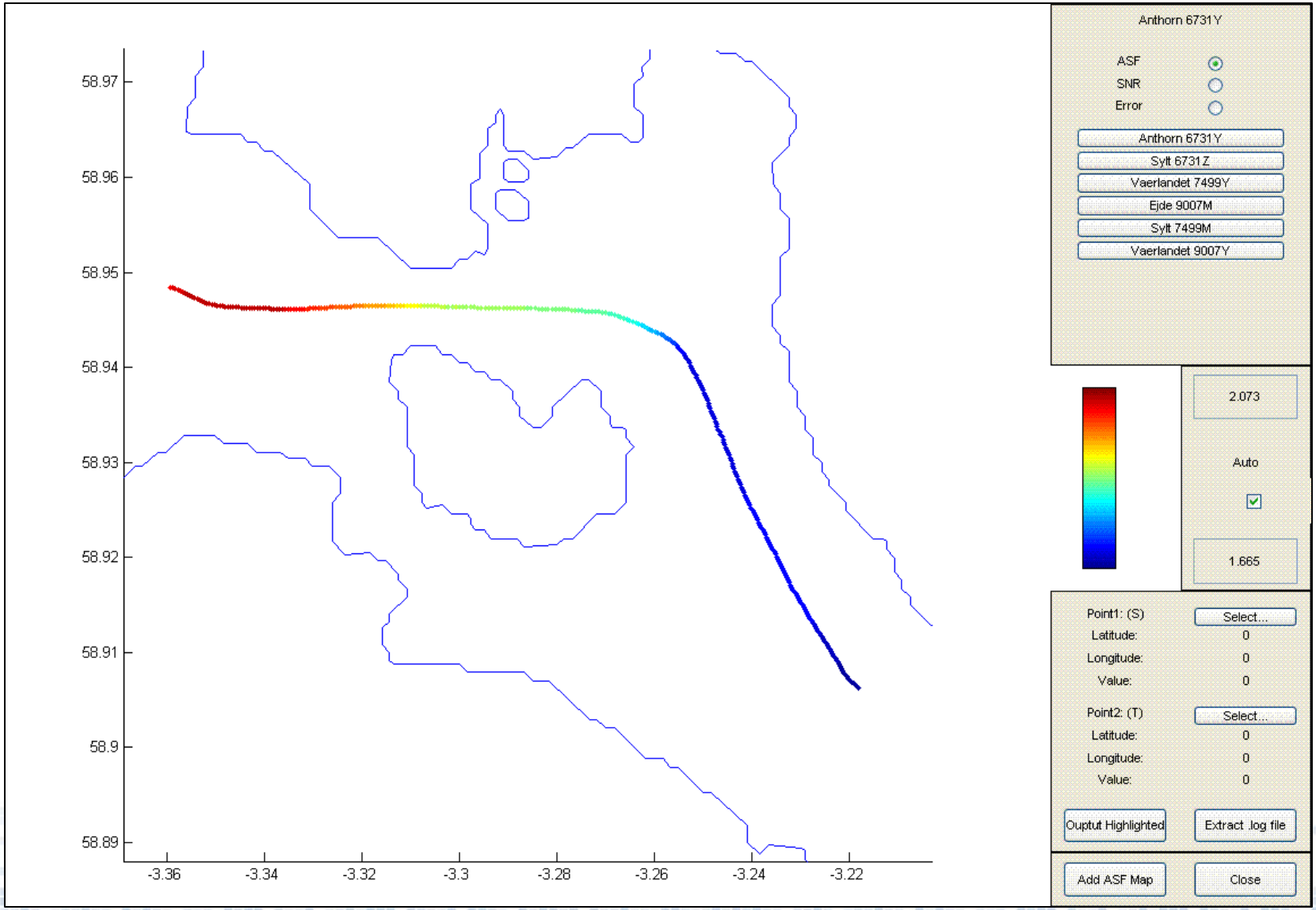

Effect of Averaging of GPS Calibration

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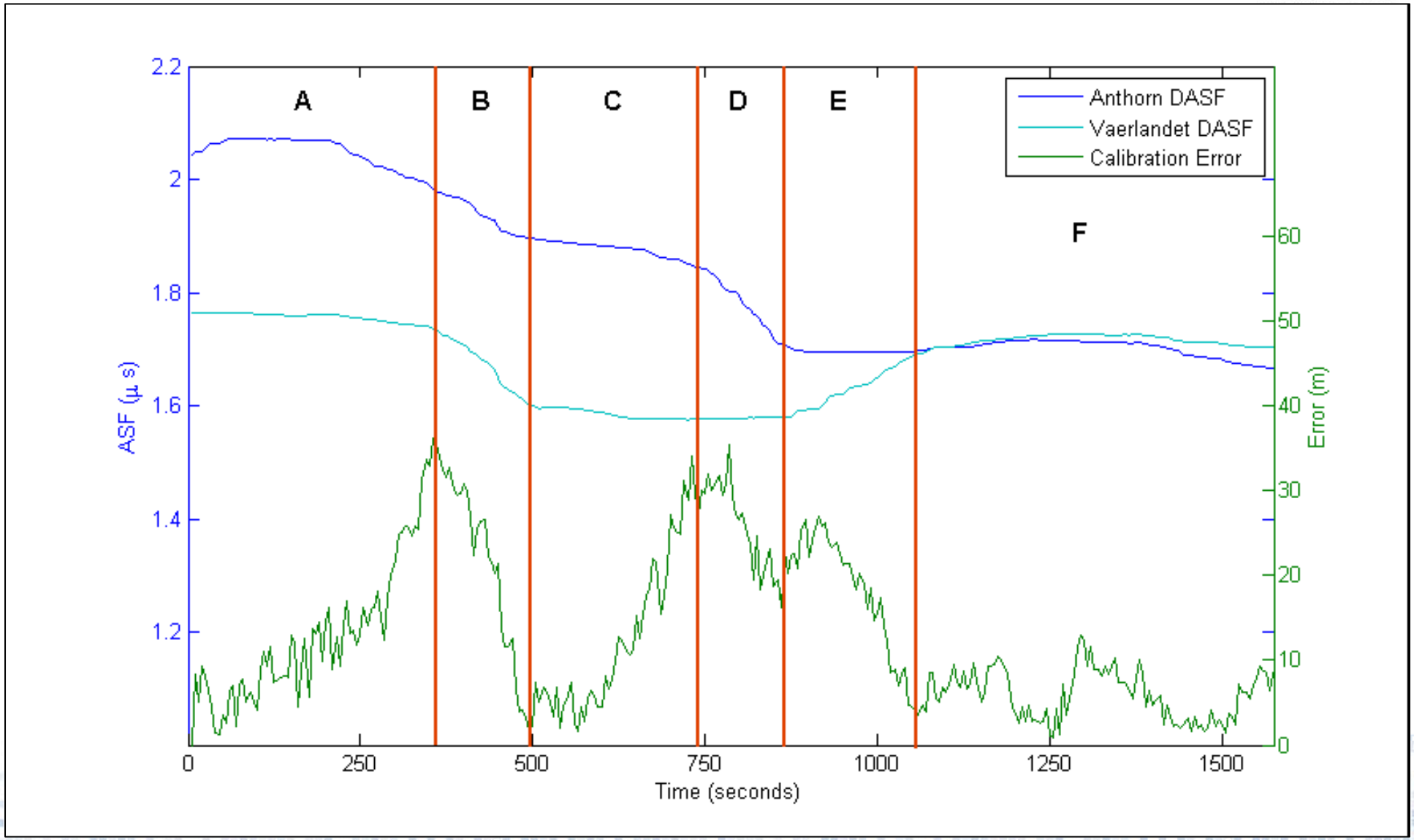

GLA DASF Measurements

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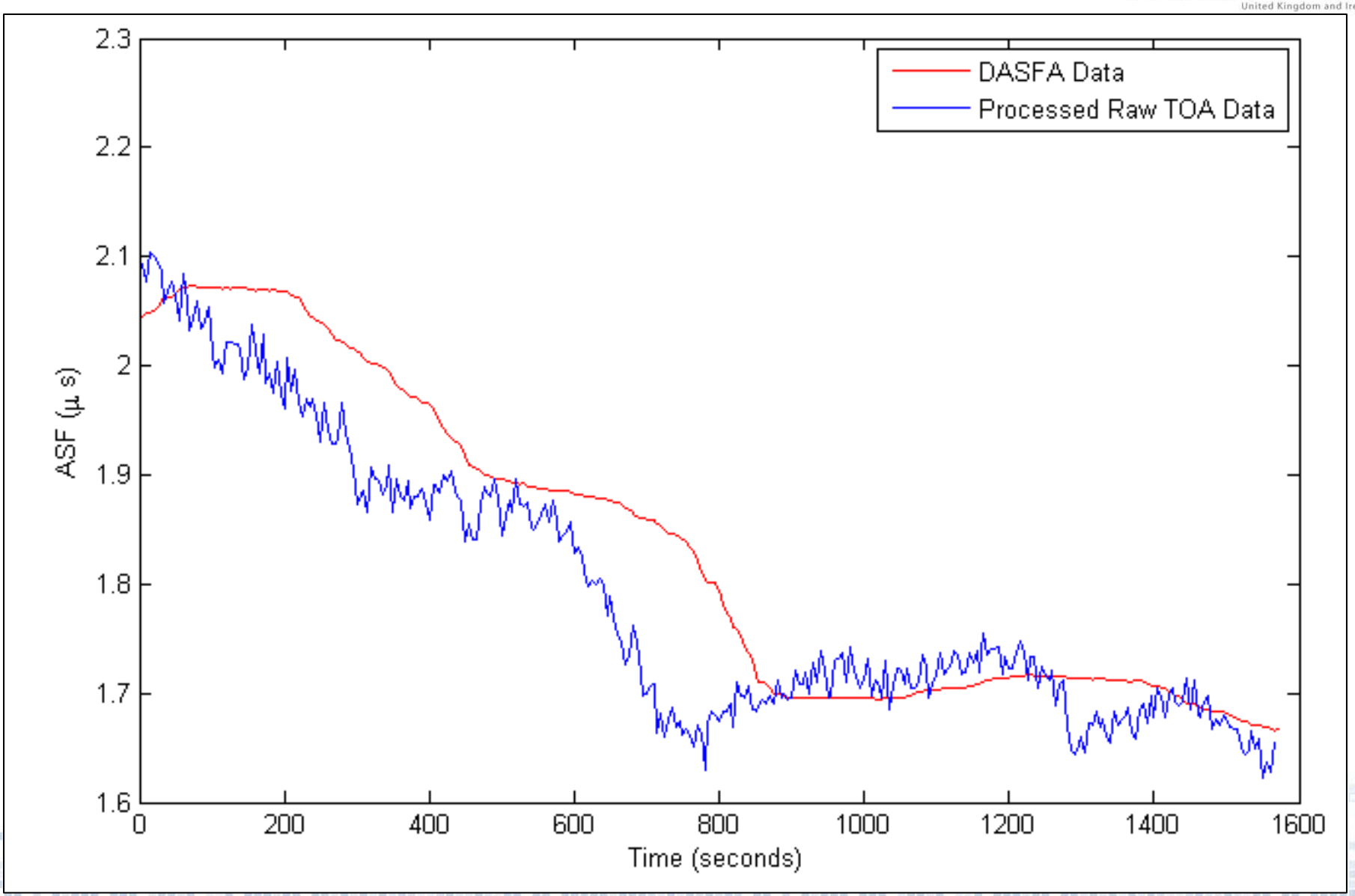

GLA DASF Grid

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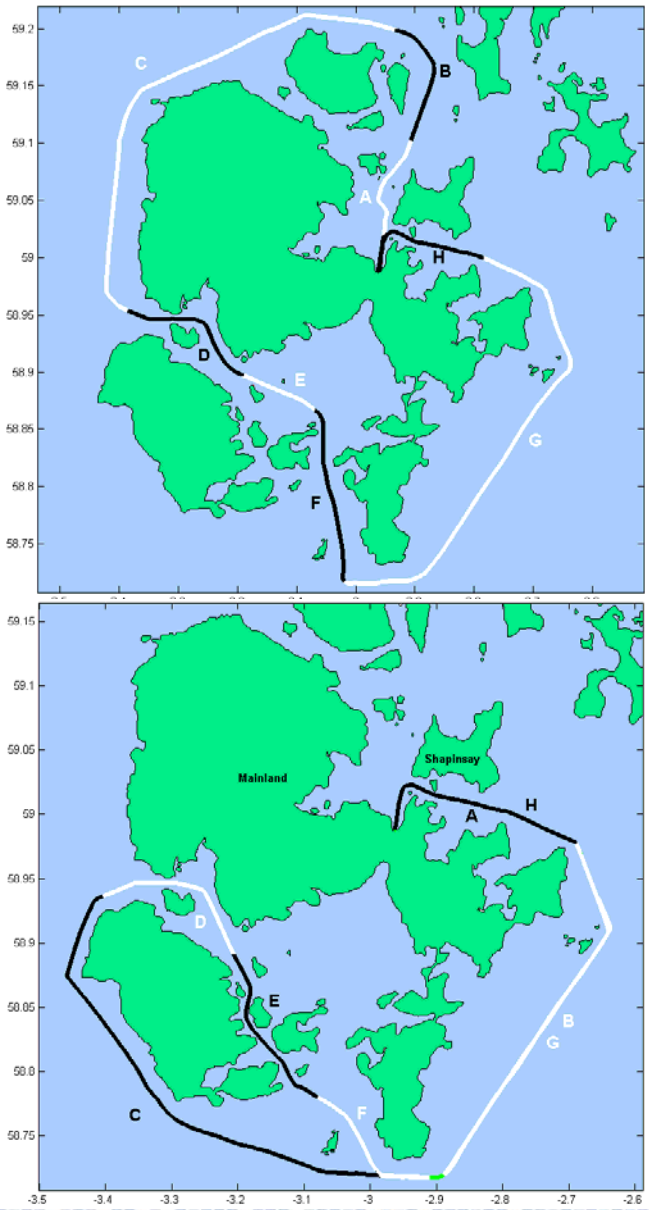

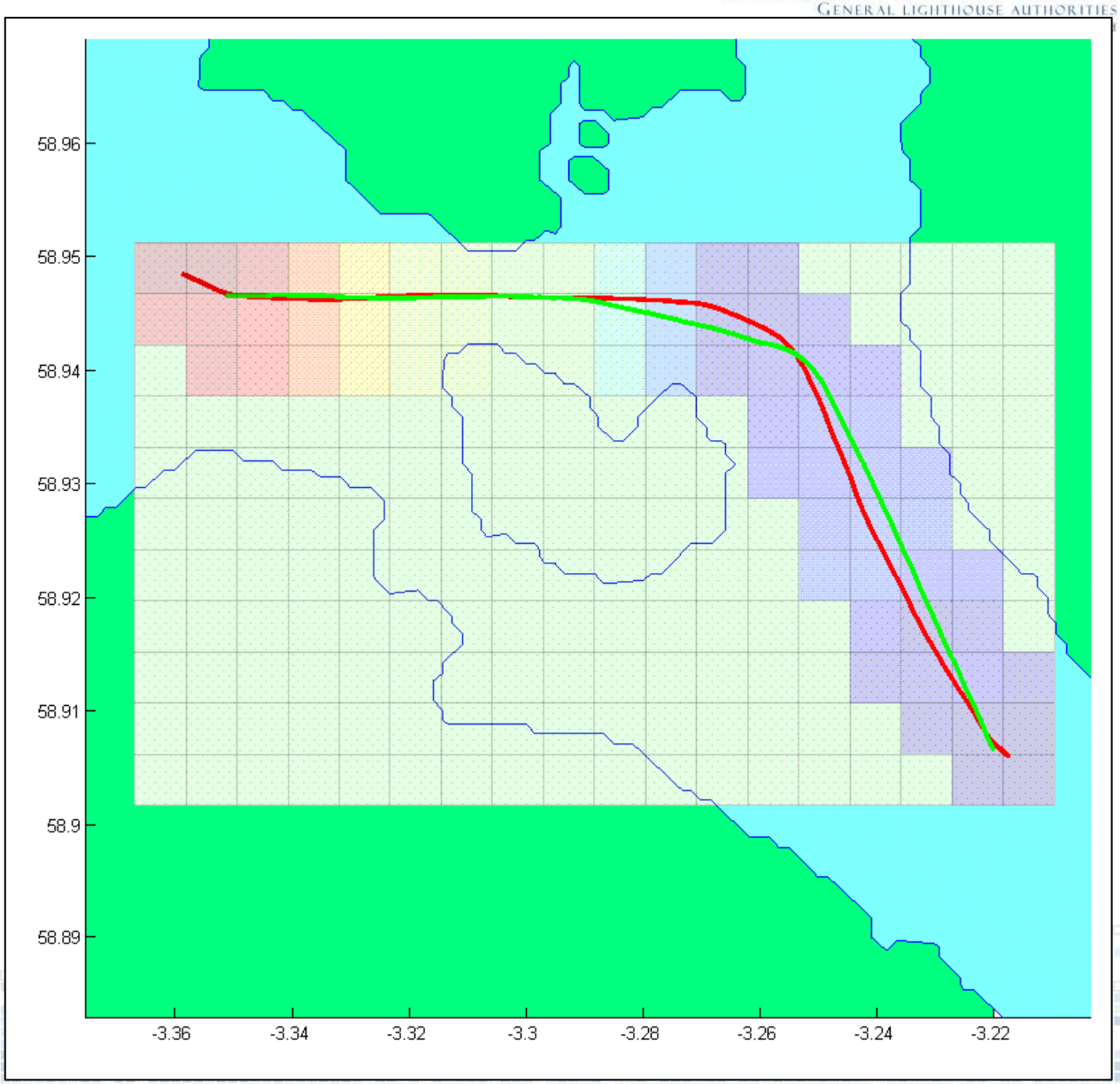

DASF Grids

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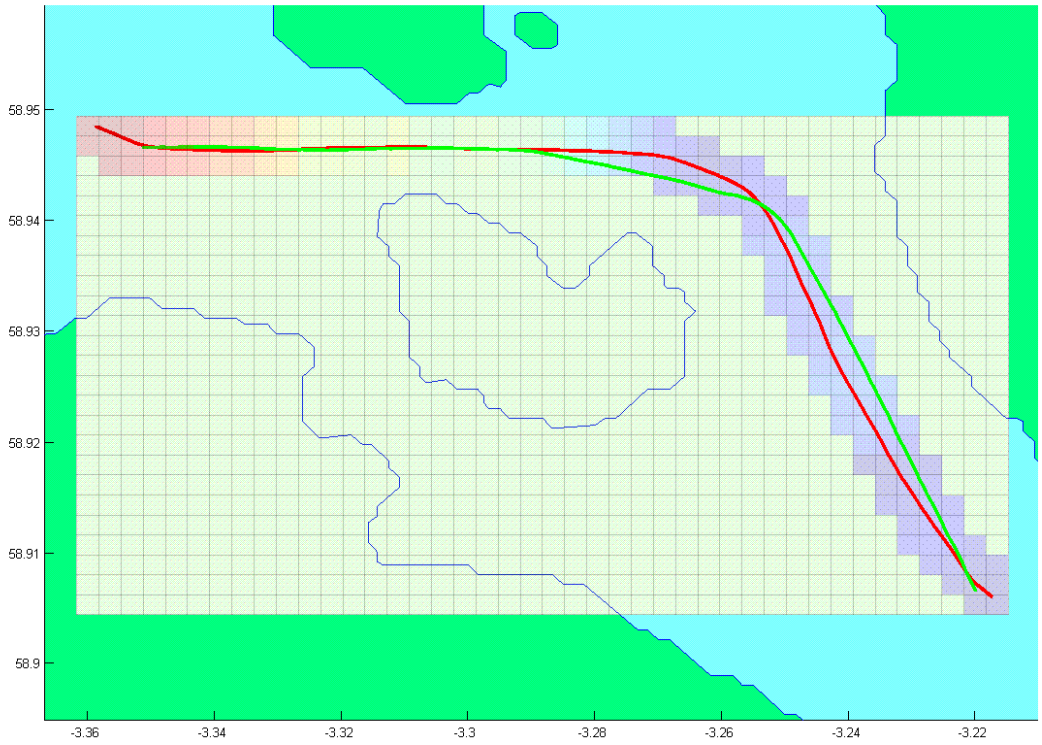
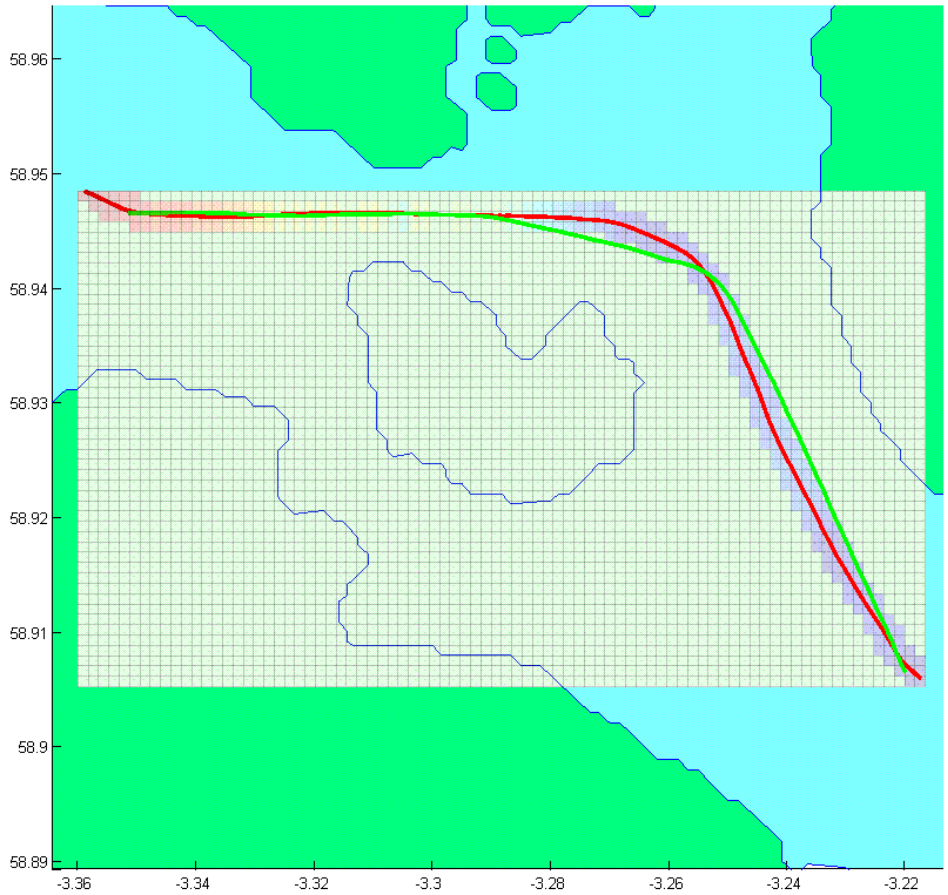
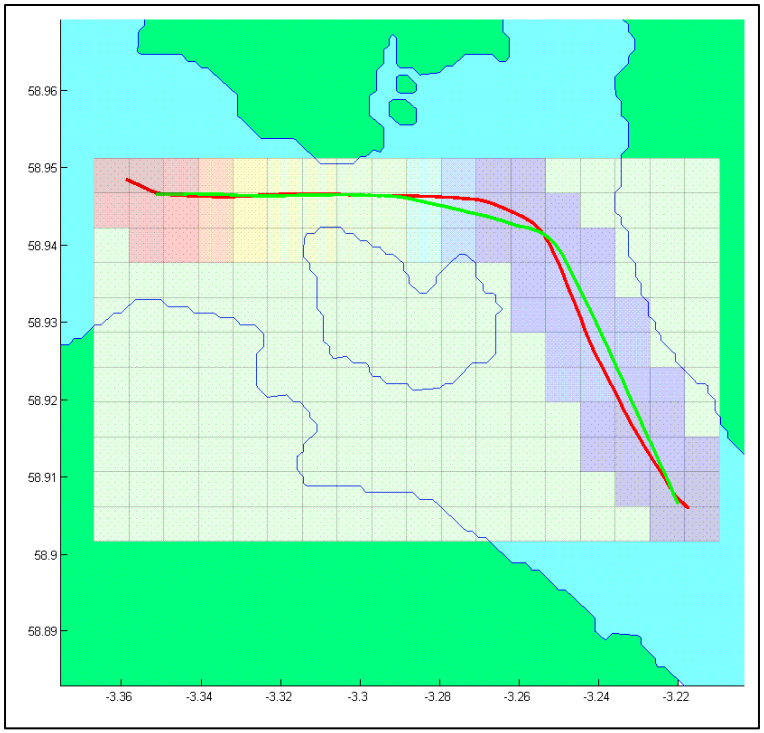


200m cell size



100m cell size

DASF Results



Grid Element Size (m)	Position Error		
	Average m (95%)	Real m (95%)	Offset (m)
Calibrated	24.1	24.5	5.8
1000	12.5	14.3	3.2
750	11.9	12.7	3.0
500	10.3	11.9	2.9
400	11.6	12.0	2.1
300	11.2	12.4	3.1
250	10.0	12.0	2.9
200	11.2	12.3	2.8
150	13.0	15.6	4.1
100	38.2	47.6	9.6

Differential Corrections

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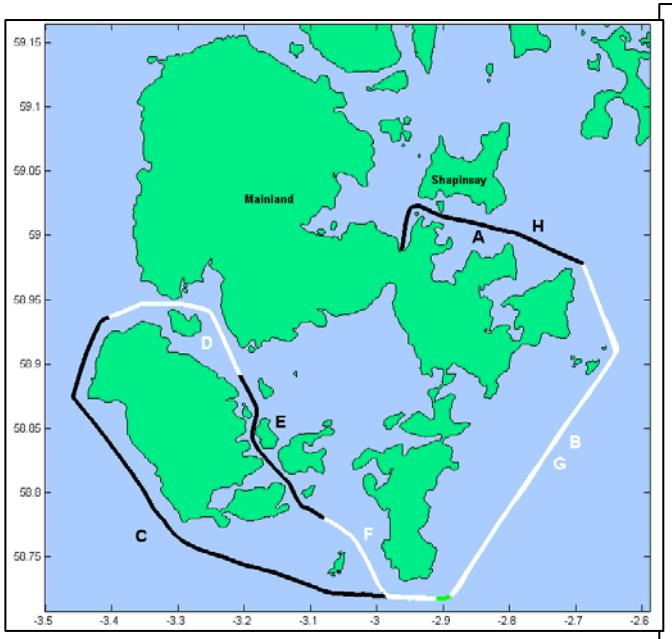
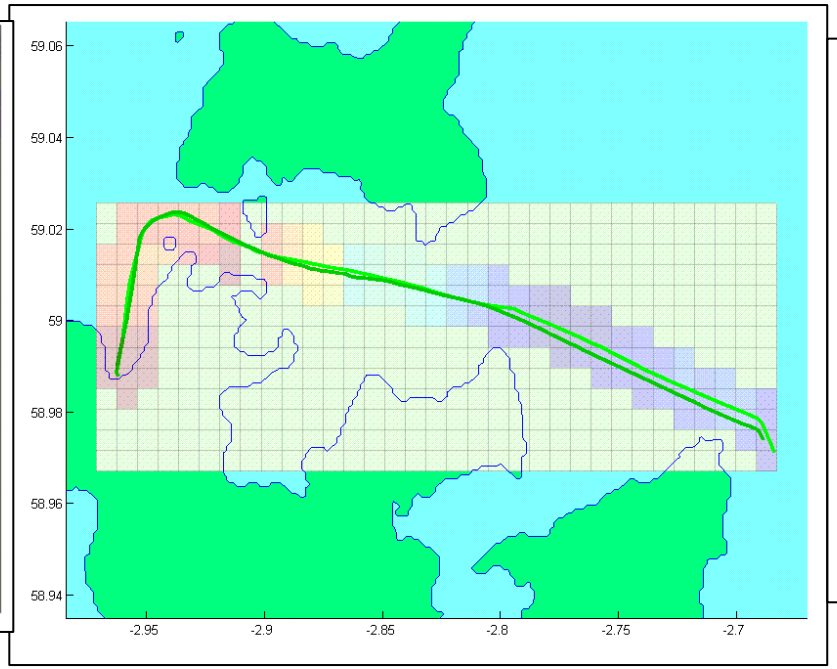
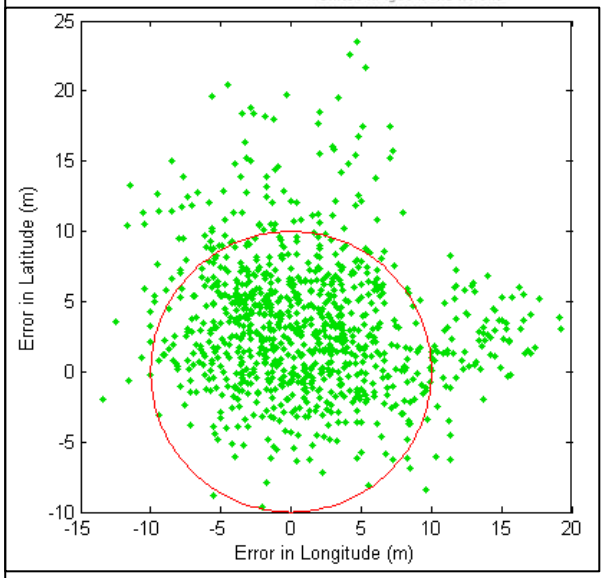
Filtering Type	Filtering Amount	Update Interval (Seconds)	Real Error (95%) (m)	Offset (m)
Calibrated	N/A	N/A	24.5	5.8
Non-differential (ASF Only)	N/A	N/A	11.9	2.9
None	N/A	10 (epoch-by-epoch)	16.2	1.4
Median Filter	10 Minute Window	30 per pair	10.9	0.6
Exponential 3 Mins	$\alpha = 0.05$	30 per pair	11.6	0.9
Exponential 8 Mins	$\alpha = 0.02$	30 per pair	11.0	1.2
Exponential 16.5 Mins	$\alpha = 0.01$	30 per pair	10.7	1.3

Kirkwall Approach via Shapinsay Sound





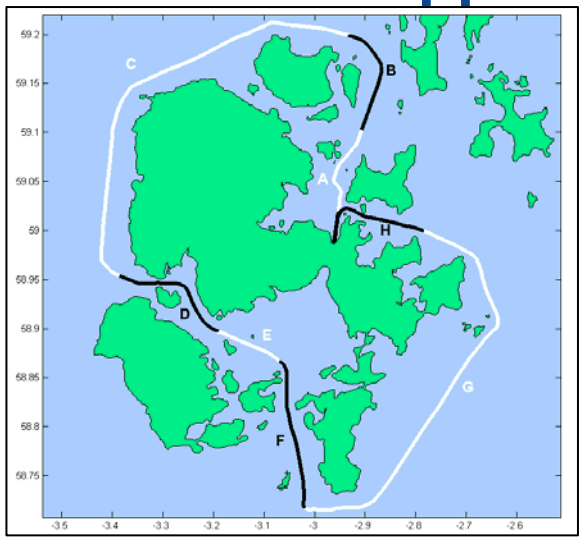


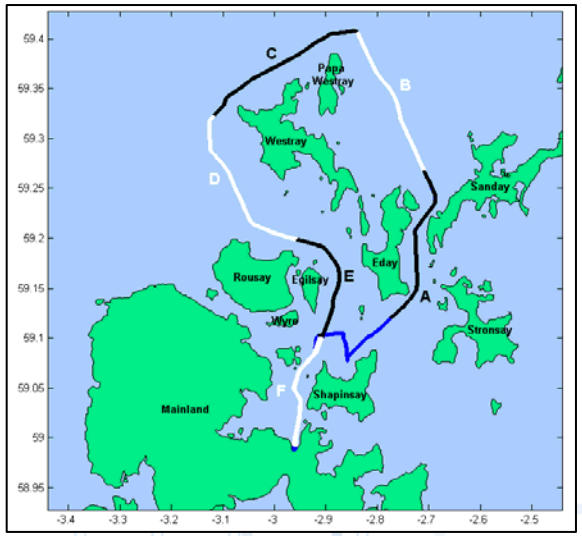
Green A – Measured DASFs

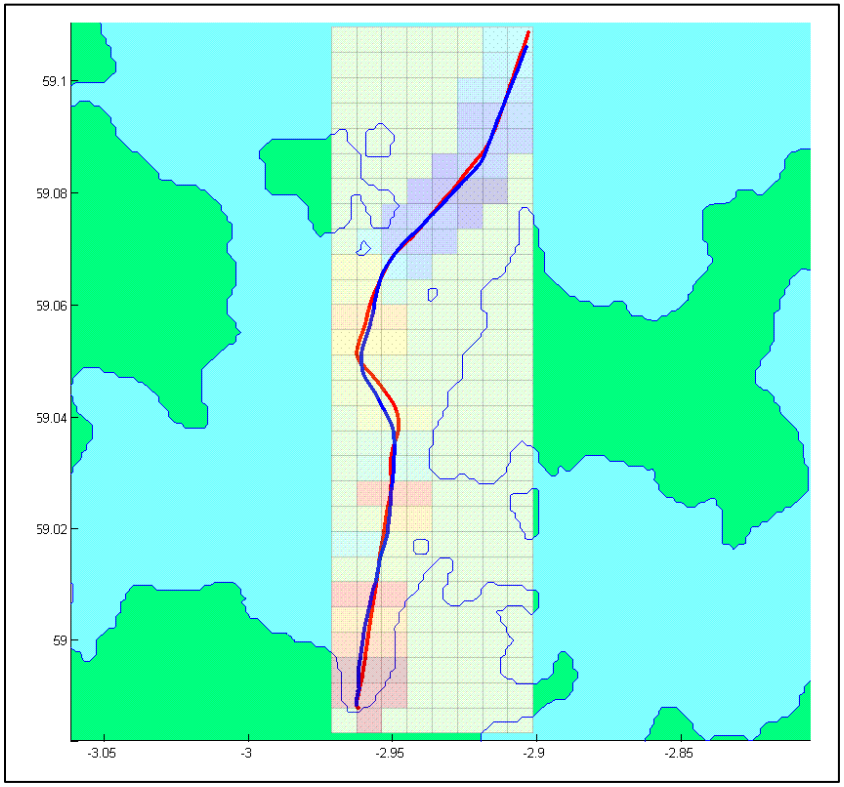
Green H – dLoran Harbour Approach

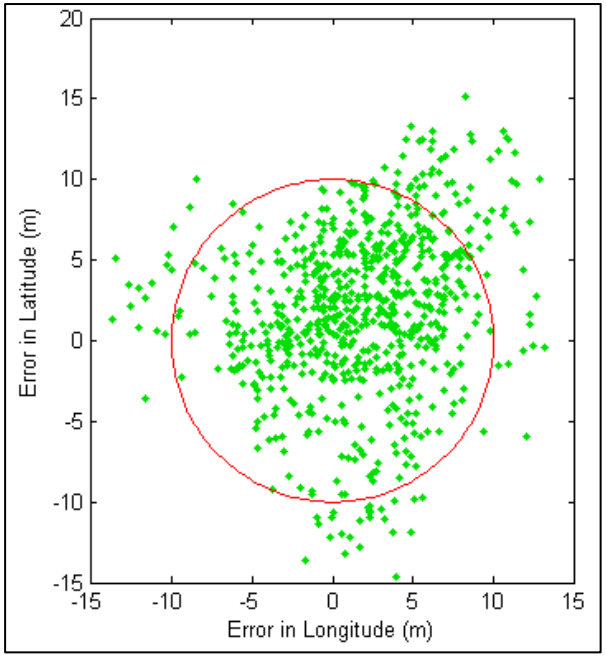
Positioning Type	Average Error (95%) (m)	Real Error (95%) (m)	Offset (m)
Calibrated	10.8	10.8	1.2
dLoran	13.5	15.0	3.2

Kirkwall Approach via Holm of Boray







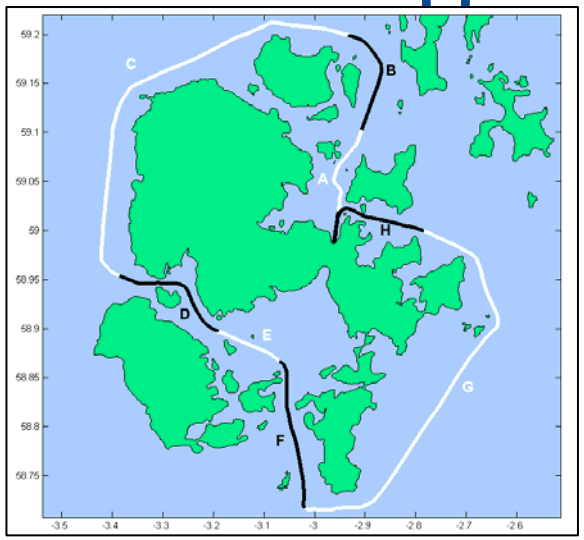


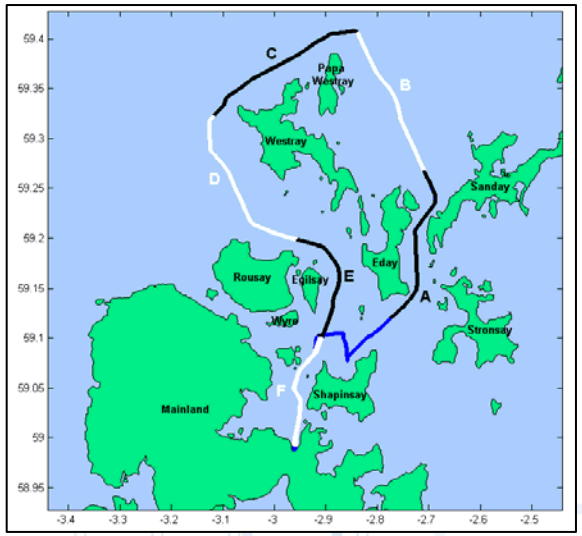
Positioning Type	Average Error (95%) (m)	Real Error (95%) (m)	Offset (m)
Calibrated	12.0	12.1	1.0
dLoran	12.7	12.9	2.5

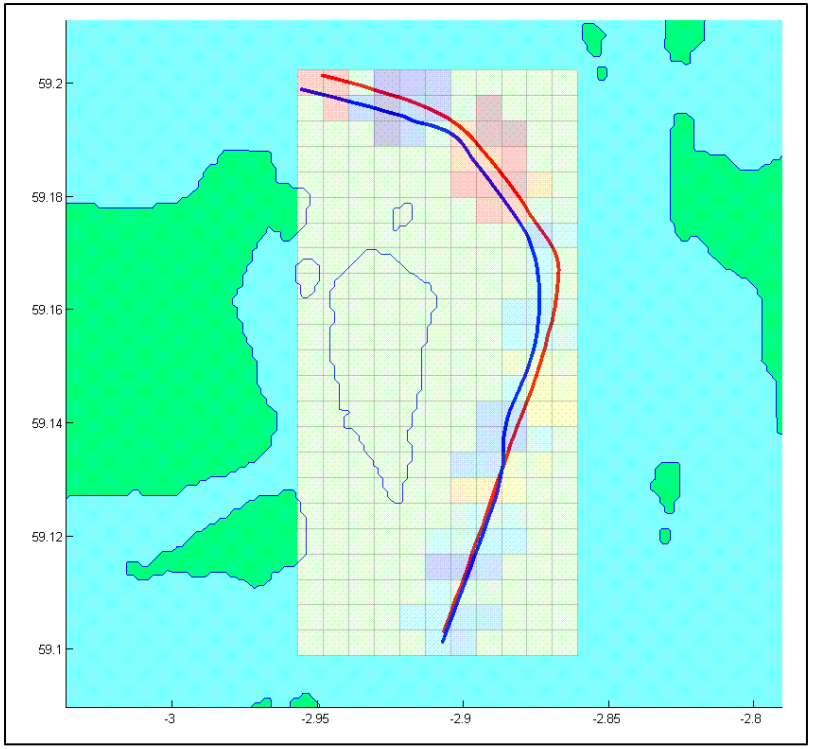
Red A – Measured DASFs

Blue F – dLoran Harbour Approach

Kirkwall Approach via Westray Firth







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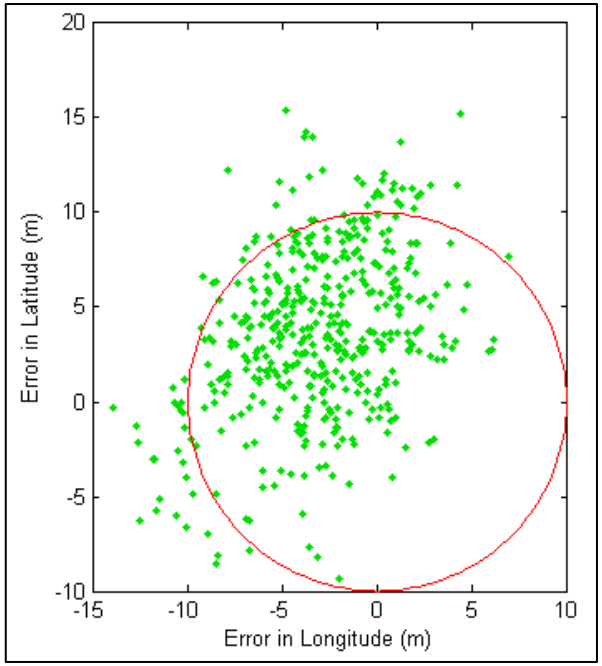

Positioning Type	Average Error (95%) (m)	Real Error (95%) (m)	Offset (m)
Calibrated	11.7	11.7	2.0
dLoran	10.7	12.0	4.8

Red B – Measured DASFs

Blue E – dLoran Harbour Approach

Conclusions – Orkney Islands

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- Loran functions exceptionally well in the Orkney Islands, with no loss of signal, and with potentially sub 20m accuracy available in most places
  - Position accuracy of 11m (95%) in Hoy Sound using ASFs and differential-Loran (eLoran)
  - Successfully applied differential corrections from a Reference Station 20km away
  - 500m ASF cell size agrees with US studies (Greg Johnson's team) and provides good results in the Hoy Sound

Conclusions – Calibrated Loran

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- GPS Calibrated Loran is good for quick assessment of potential Loran performance, but:
  - Not optimal for demonstrating eLoran's maximum potential accuracy performance
  - If you are a potential user evaluating eLoran be careful!
  - Nothing can replace making ASF measurements and using the good quality TOAs coming out of modern receivers in your own position solutions!
  - Can be used to identify regions of rapidly changing ASF, compared to smoothing time-constant, thus identifying where ASFs should be measured
  - Sanity check of eLoran results

Conclusions - Archipelagos

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- There is no reason why eLoran should not work in archipelago areas assuming:
  - Good eLoran station geometry
  - Good eLoran signal strength
  - ASFs are mapped along important narrow channels, augmented with dLoran, to cater for rapidly changing coastline profiles

Further Work

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- Further develop GLA's software
  - Live operation
  - Post-processing
- Solve latency issue in consultation with Reelektronika
- Further post-process data
  - Fine tune our techniques and algorithms
  - Look at other areas where we have DASF data available and repeated runs
- Revisit the Orkney Islands with more targeted tests in mind
  - Absolute ASF measurements – ASF Measurement Equipment
  - Live dLoran trial

Thank you!

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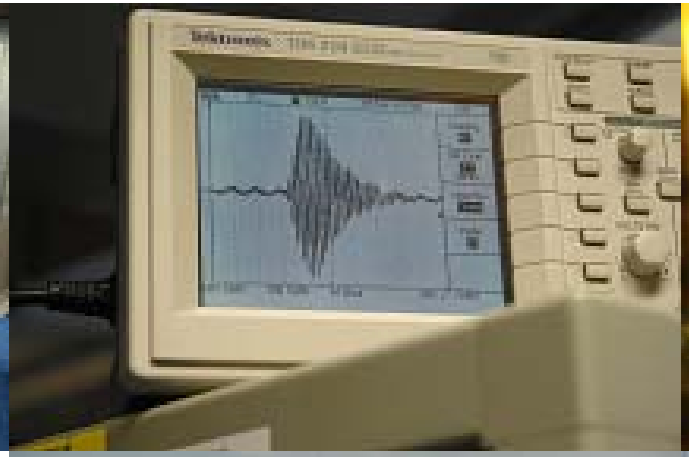
Pictures: Loran Station Anthorn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