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Reliable GPS:
Interference, Jamming and the Case for eLoran

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General Lighthouse Authorities of the United Kingdom and Ireland

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Context

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- The GLAs value highly the operational and safety benefits of GPS and it is a vital component in our Radio Navigation Plan[1]
- GPS will remain the primary radio navigation means of position fixing from berth-to-berth for at least another ten years GPS
- It's a primary source of Position, Navigation and Time (PNT)
- The introduction of GPS has encouraged mariners to navigate in areas where, and under conditions in which, they had not previously ventured
- The introduction of e-Navigation will further change the way that ships operate
- As part of this, we need to understand what happens when key e-Navigation components (e.g. GNSS) are unavailable

1. *GLA Radio Navigation Plan*. General Lighthouse Authorities of the United Kingdom and Ireland, May 2007

Use of GPS in Maritime Sector

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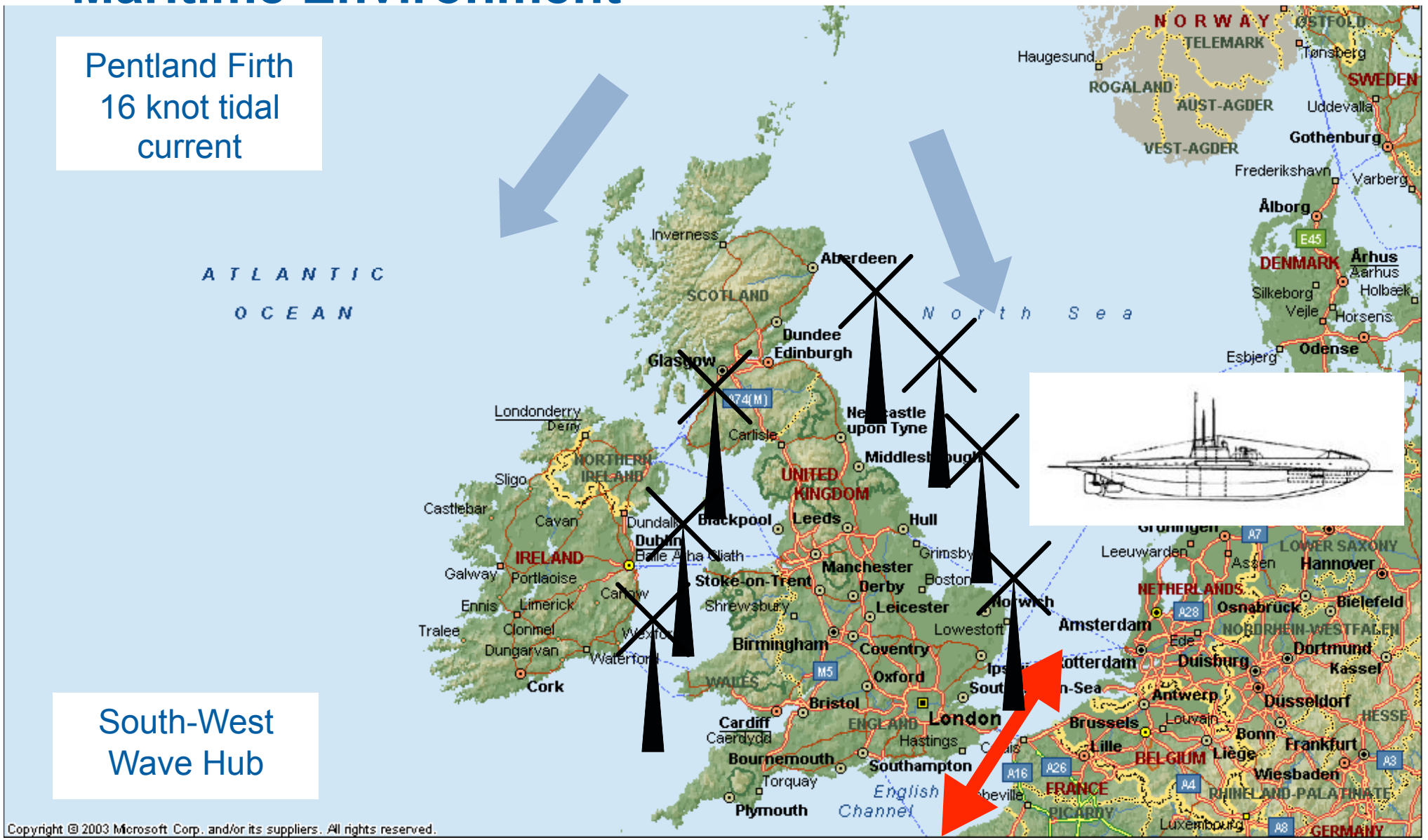
- **Positioning**
  - -Dynamic positioning of AtoNs
  - -Remote monitoring of AtoN Locations
  - -DGPS service provider
  - -Digital Selective Calling – Emergency Button
- **Navigation**
  - -DGPS chart input
  - -Calibration of inertial navigation systems
- **Timing**
  - -AIS
  - -Synchronised Lights

GPS is everywhere!

Maritime Environment

Pentland Firth
16 knot tidal
current

South-West
Wave Hub



GPS Jamming Trial

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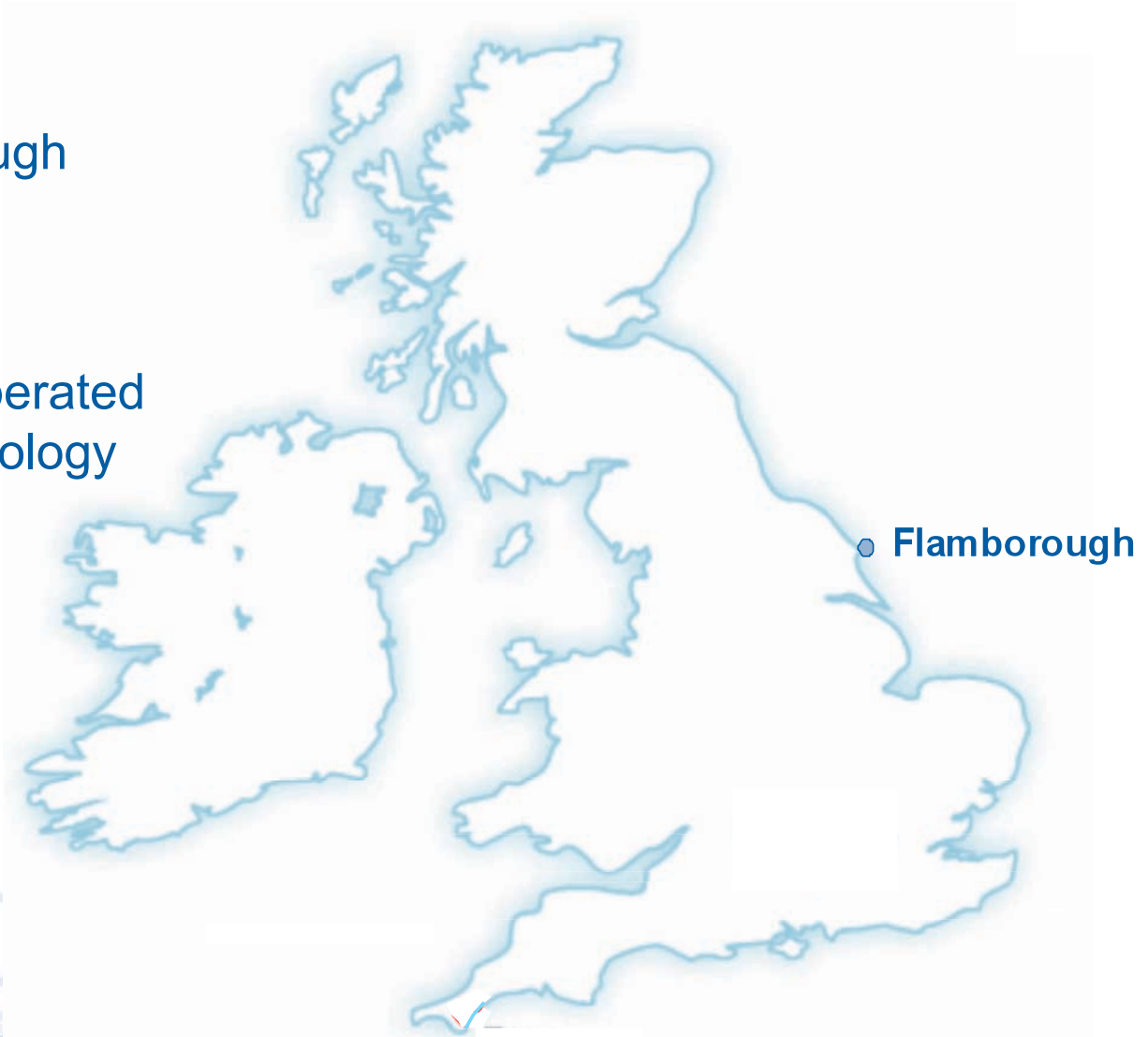
2-4th April 2008 from Flamborough Head on the East Coast of the United Kingdom.

Jamming units provided and operated by Defence Science and Technology Laboratories (DSTL)



GPS Jamming Trial

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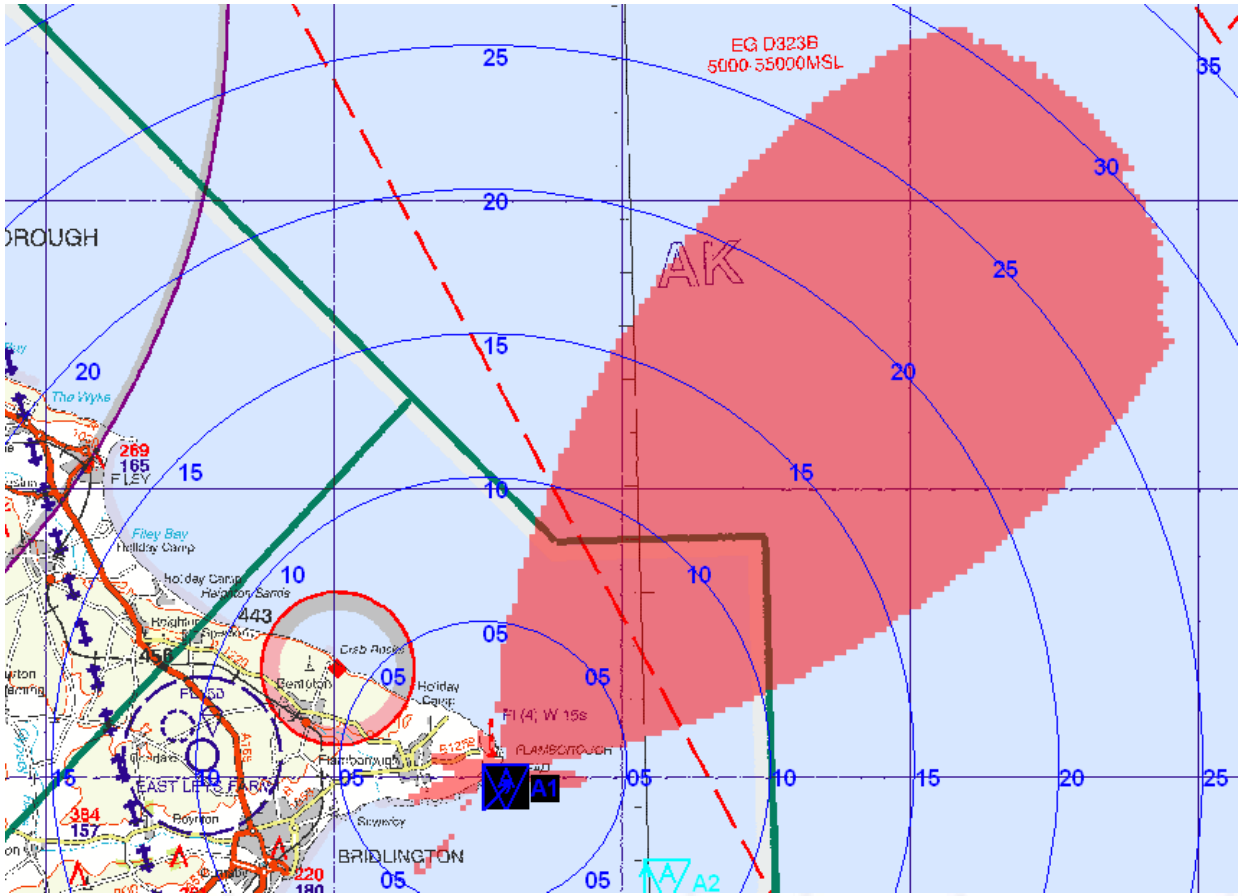

Coverage area of main lobe of the GPS jamming unit at 25m above sea-level on maximum power of 1.58W ERP across the 2MHz Bandwidth of L1.

(Image courtesy of DSTL)

Elements under review

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Effect of GPS jamming on:

- Aids to Navigation (AtoN)
  - eLoran
  - Differential GPS
  - AIS as an AtoN
  - Synchronised Lights
- Ship
  - Navigation and positioning systems
  - Situational awareness
- Shore
  - Vessel Traffic Management/Services
  - Service provision - DGPS
- People
  - Safe navigation

Two Trial Phases

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- Dynamic tests onboard NLV Pole Star
- Static tests on land at Flamborough Head

Dynamic Tests

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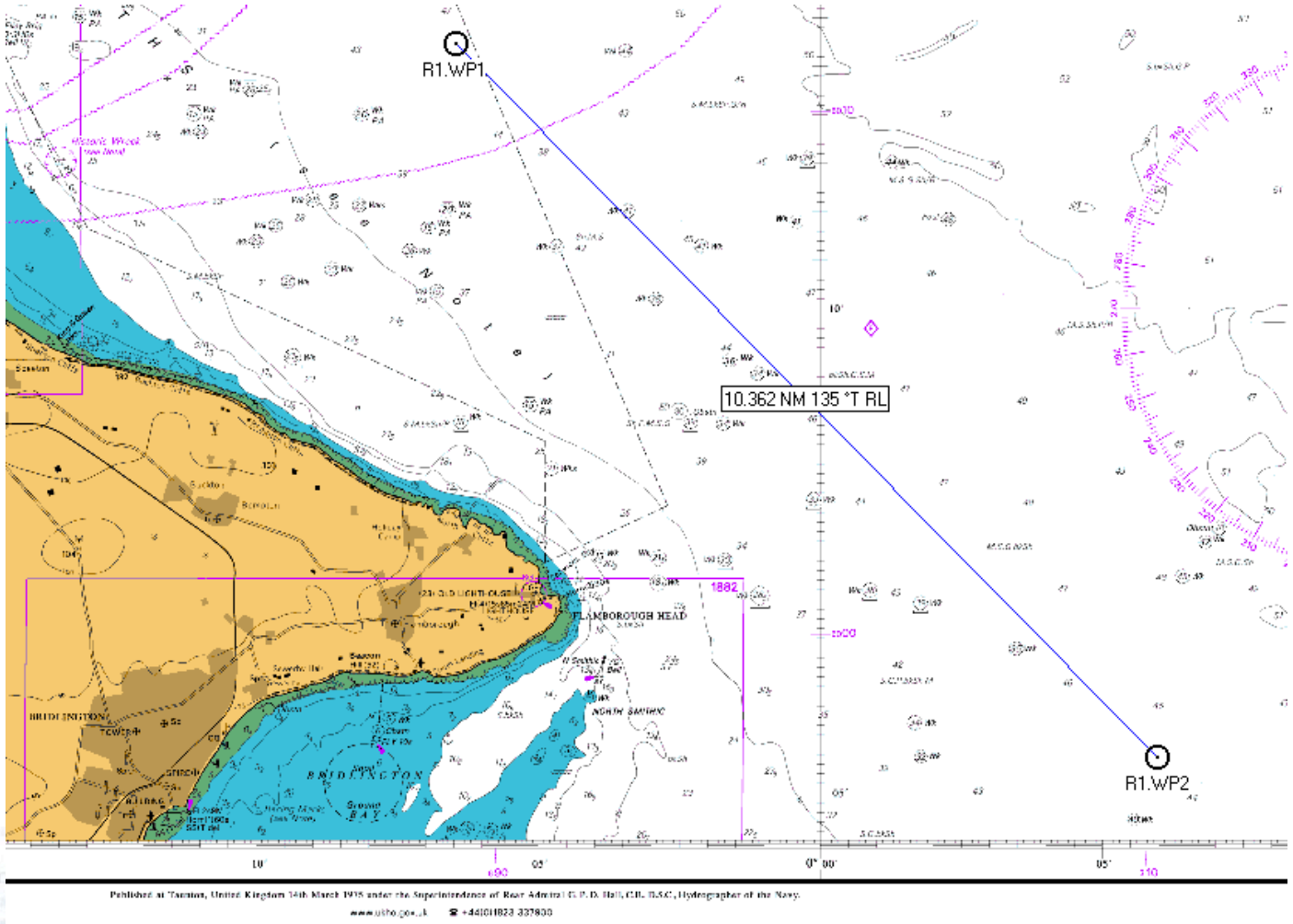
- Three different GPS receivers:
  - -A and B marine grade
  - -C survey grade
- One eLoran receiver
- 10Nm Route at 10kt
- 1 Hour sailing time



Dynamic Tests

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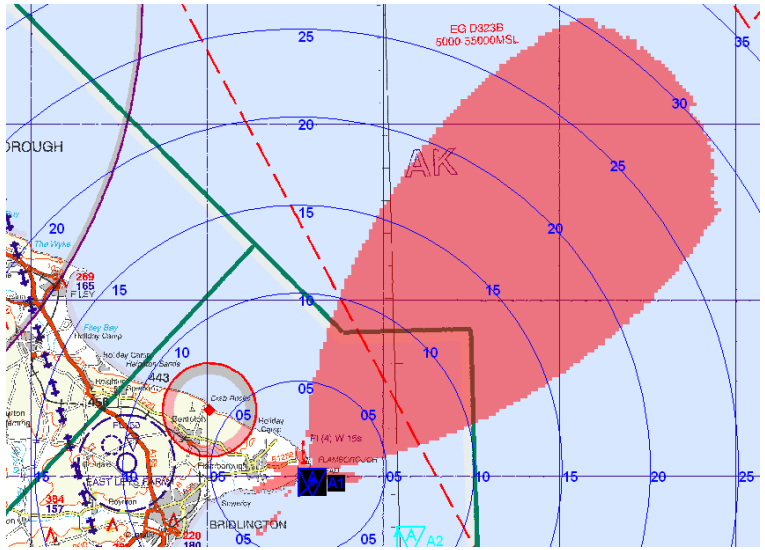

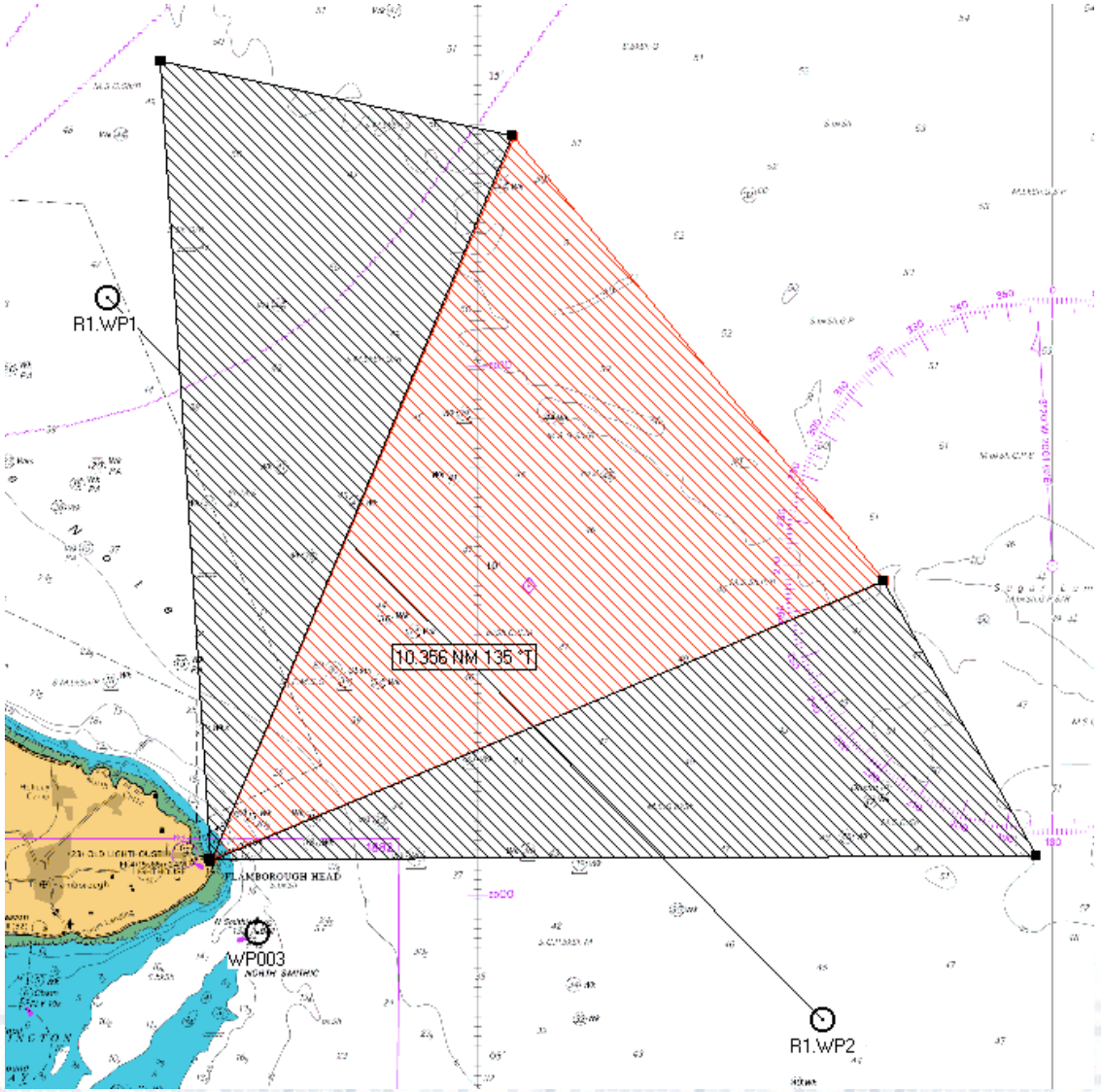

- Side lobes are present too
- Waypoints positioned outside jamming zone
- Performed a total of 8 runs along route over 2 days of dynamic tests

eLoran Receiver

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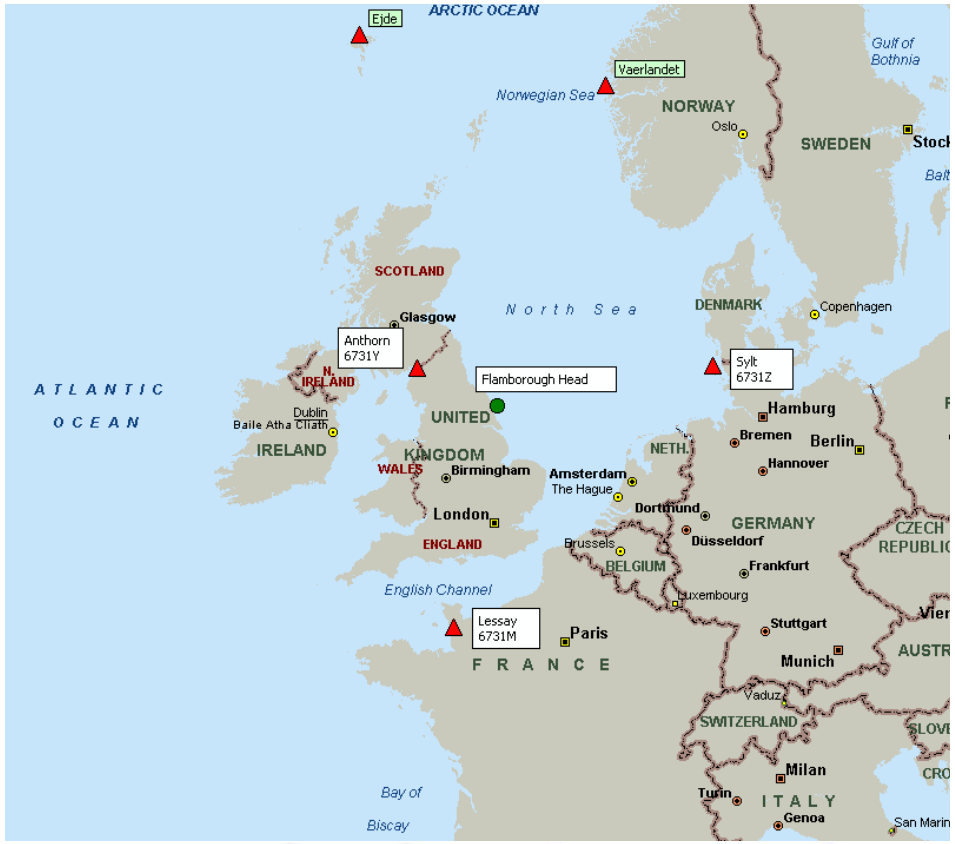
- eLoran receiver has built in GPS receiver
  - Integrates in position domain

- Computes position according to precedence:
  1. DGPS using Eurofix
  2. Stand-alone GPS
  3. GPS calibrated eLoran
  4. ASF corrected eLoran
  5. Stand-alone eLoran

- As various services and data becomes unavailable, the receiver's positioning mode moves down this list



Map showing the Loran stations most highly weighted in the Loran position solution.

eLoran Setup

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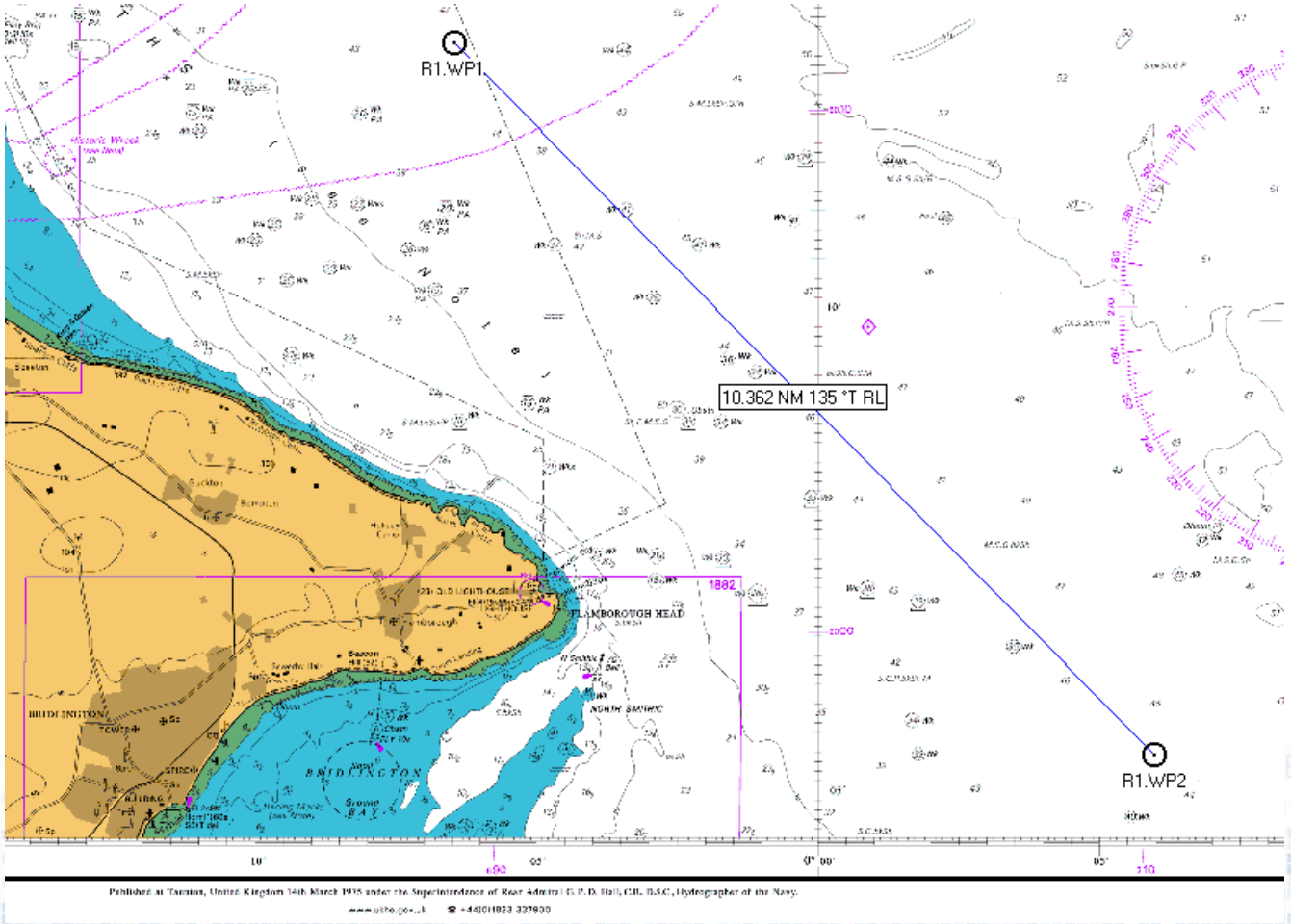
- For periods of GPS jamming Loran was used to provide “ground truth”
- Assess the accuracy of Loran in the area

  -Performed first run along the route comparing Eurofix derived DGPS against Loran

  -Measure ASFs



Measure ASFs

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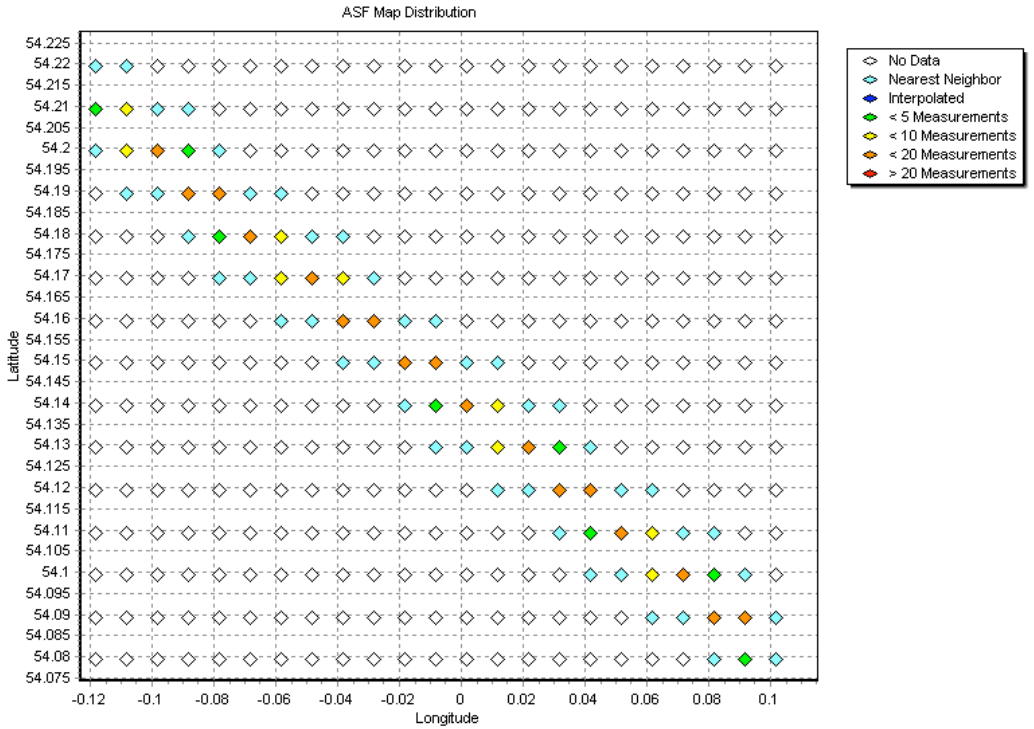
- Should we lose GPS calibration capability we measured ASFs
  - -Effectively GPS calibration parameters
  - -Measured with respect to a strong station: differential-ASFs
- Measured on the morning of the first day (Run 1)
- Stored within receiver in grid format (0.01° resolution)

Station	Mean DASF (μS)	Standard Deviation of DASF (nS)
Lessay 6731M	-0.1422	23
Anthorn 6731Y	0	0
Souston 6731X	0.9397	22
Sylt 6731Z	-1.3624	17



eLoran Position Accuracy

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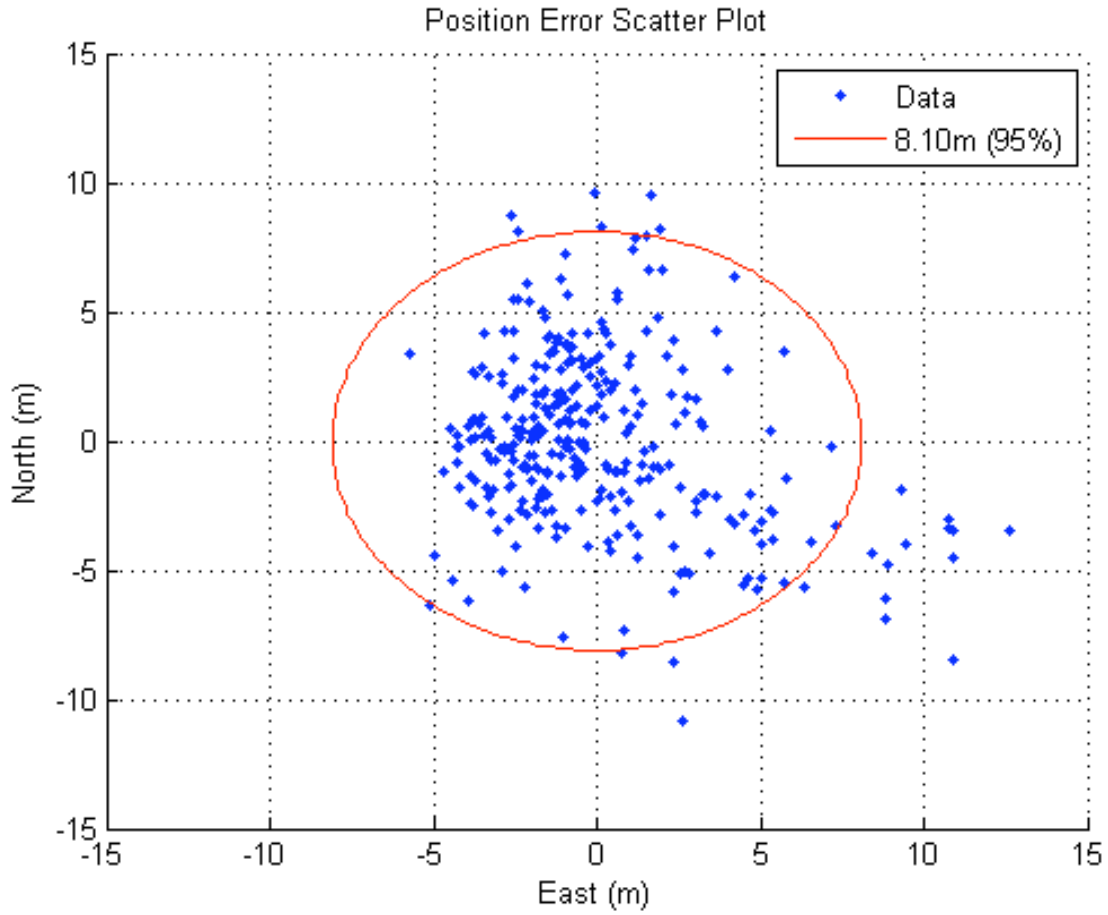

Loran v DGPS positions shows a Loran accuracy of 8.1m(95%).

eLoran Under GPS Jamming

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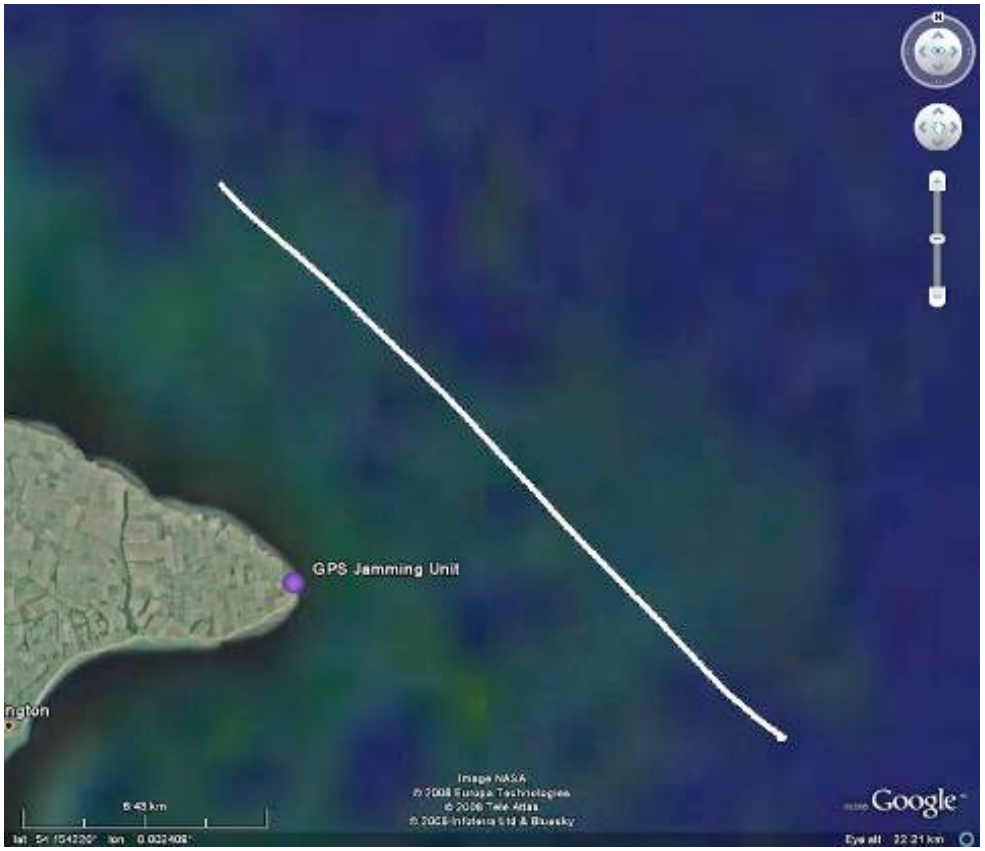
Reported position from eLoran receiver operating in Eurofix corrected GPS mode during control run with no jamming



Reported position from eLoran receiver operating in Calibrated eLoran mode with jamming enabled

All Google Earth Pictures: Michelle De Voy, GLAs

GPS vs. eLoran

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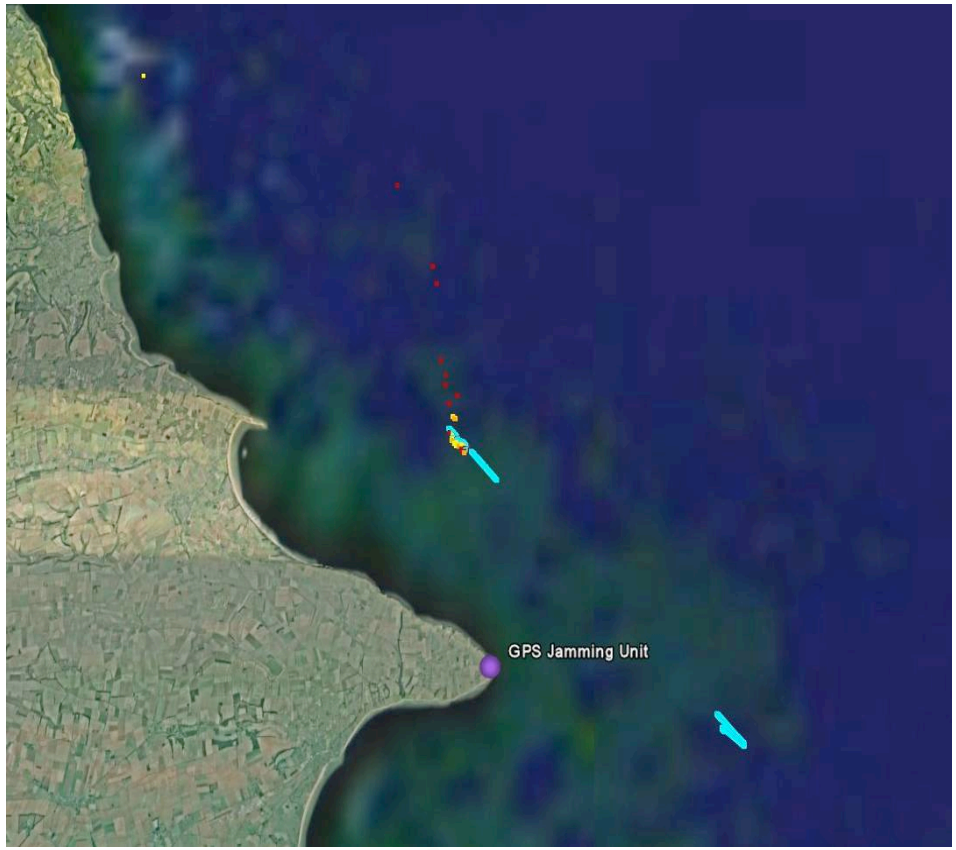
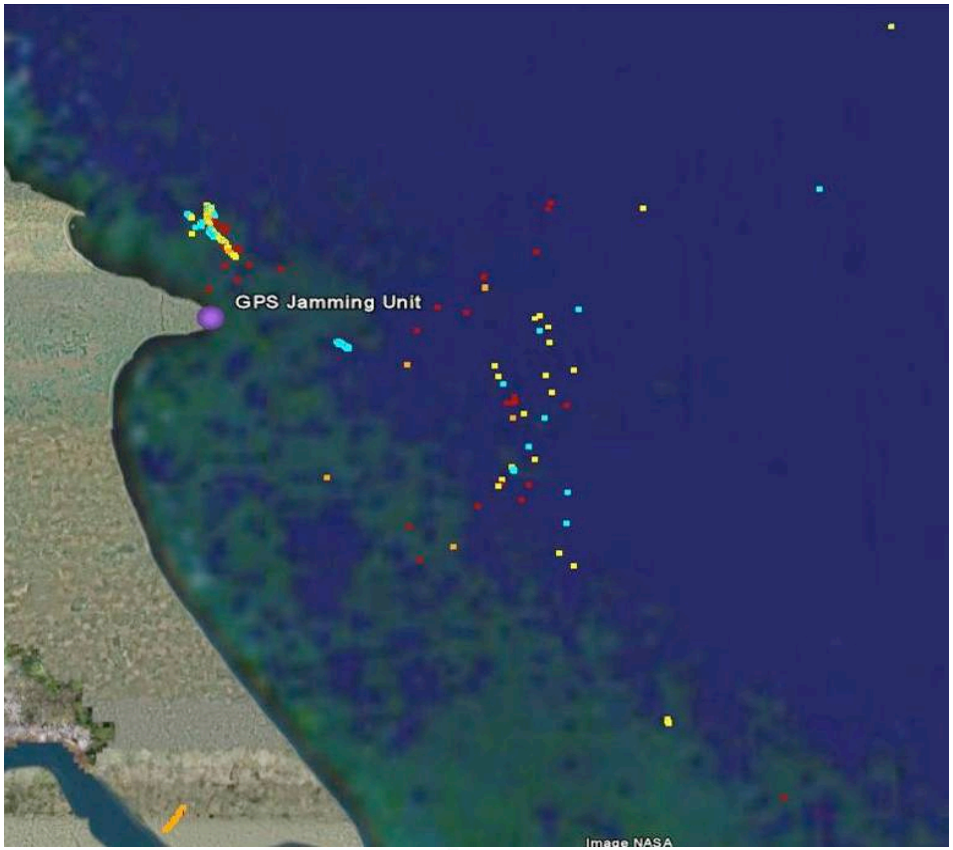


Plot of recorded positions identified as valid, from Receiver A during a GPS jamming run.



Plot of recorded positions identified as valid, from GPS Receiver B during a GPS jamming run.

The colours of the dots represent the reported vessel speed: blue <15knts, yellow< 50knts, orange <100knots and red >100knts.

GPS vs. eLoran

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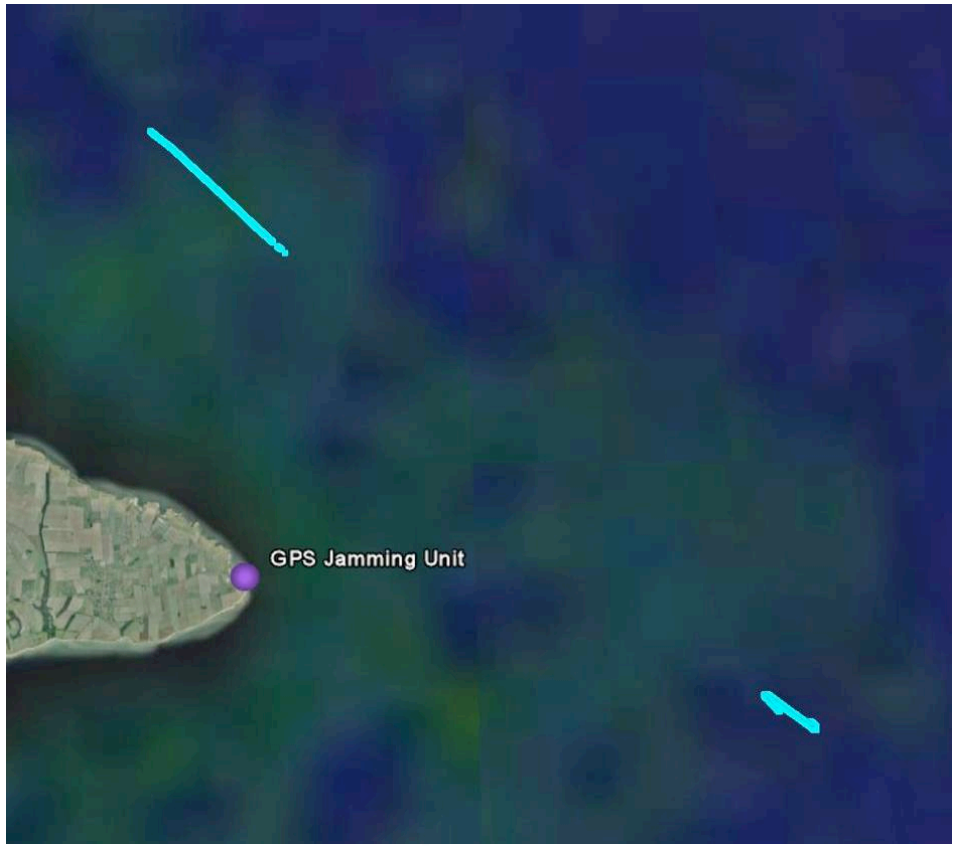

Plot of recorded positions identified as valid, from high-end GPS Receiver C during a GPS jamming run.

Plot of recorded positions from the eLoran receiver during a GPS jamming run.

Position Error

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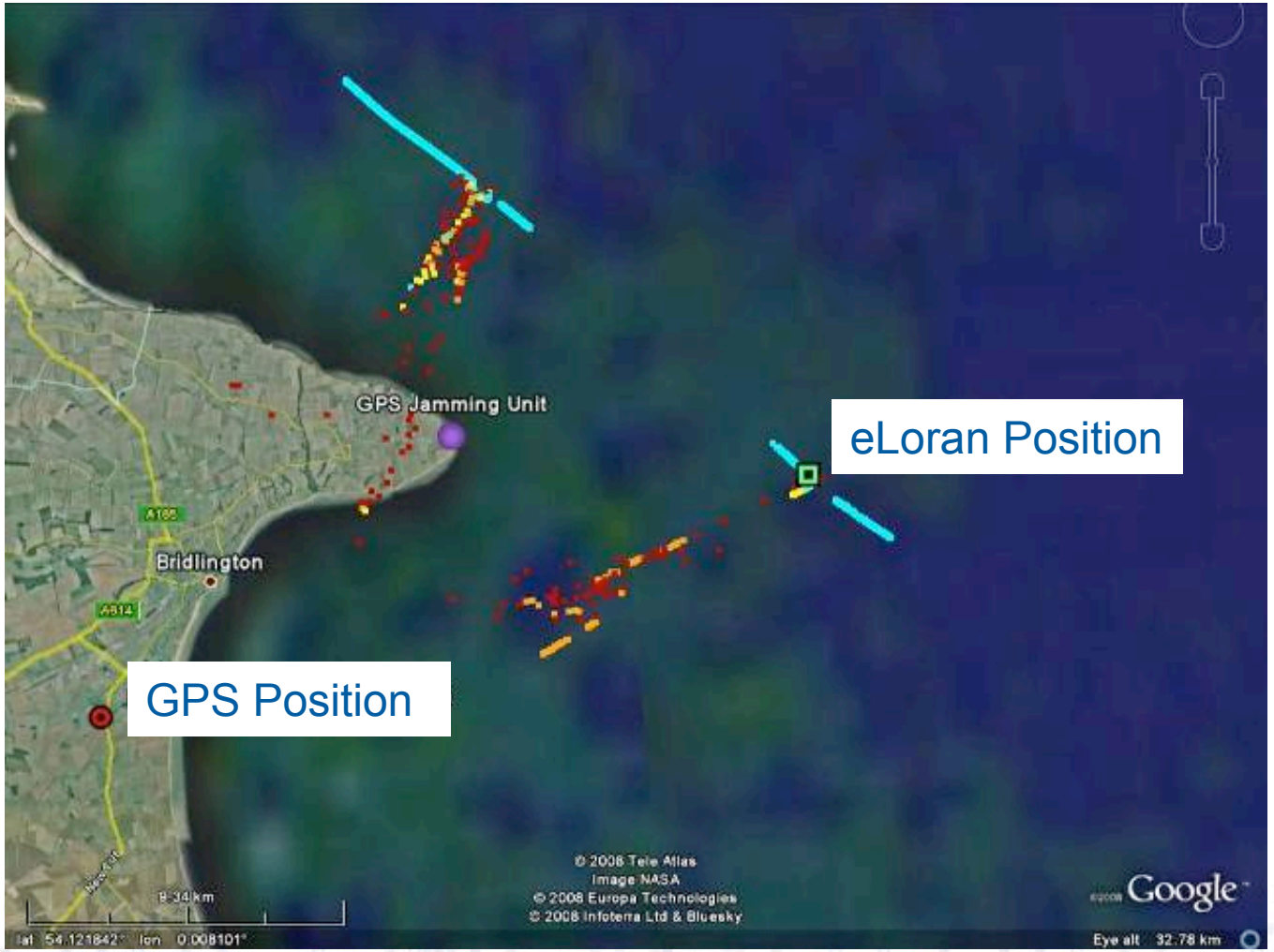
GPS reported position is inland and 22km away from true position (eLoran).



Colours indicate reported speed: blue <15knts, yellow< 50knts, orange <100knots and red >100knts

eLoran Performance

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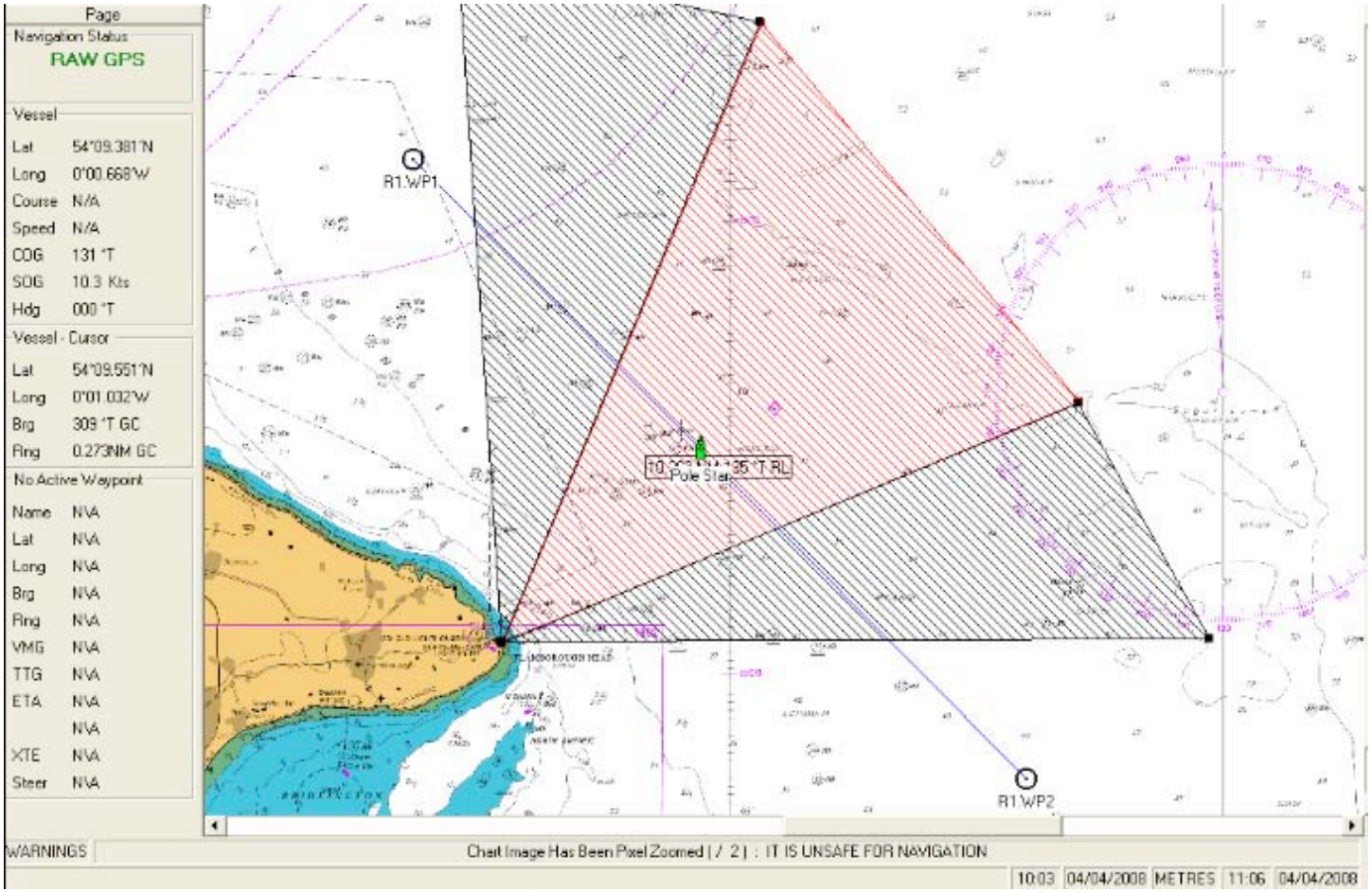

Vessel is in the area of strongest jamming signal and eLoran continues to provide positions.

Static Tests - Differential GPS

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The GLAs operate 14 DGPS stations

Static Tests - Differential GPS

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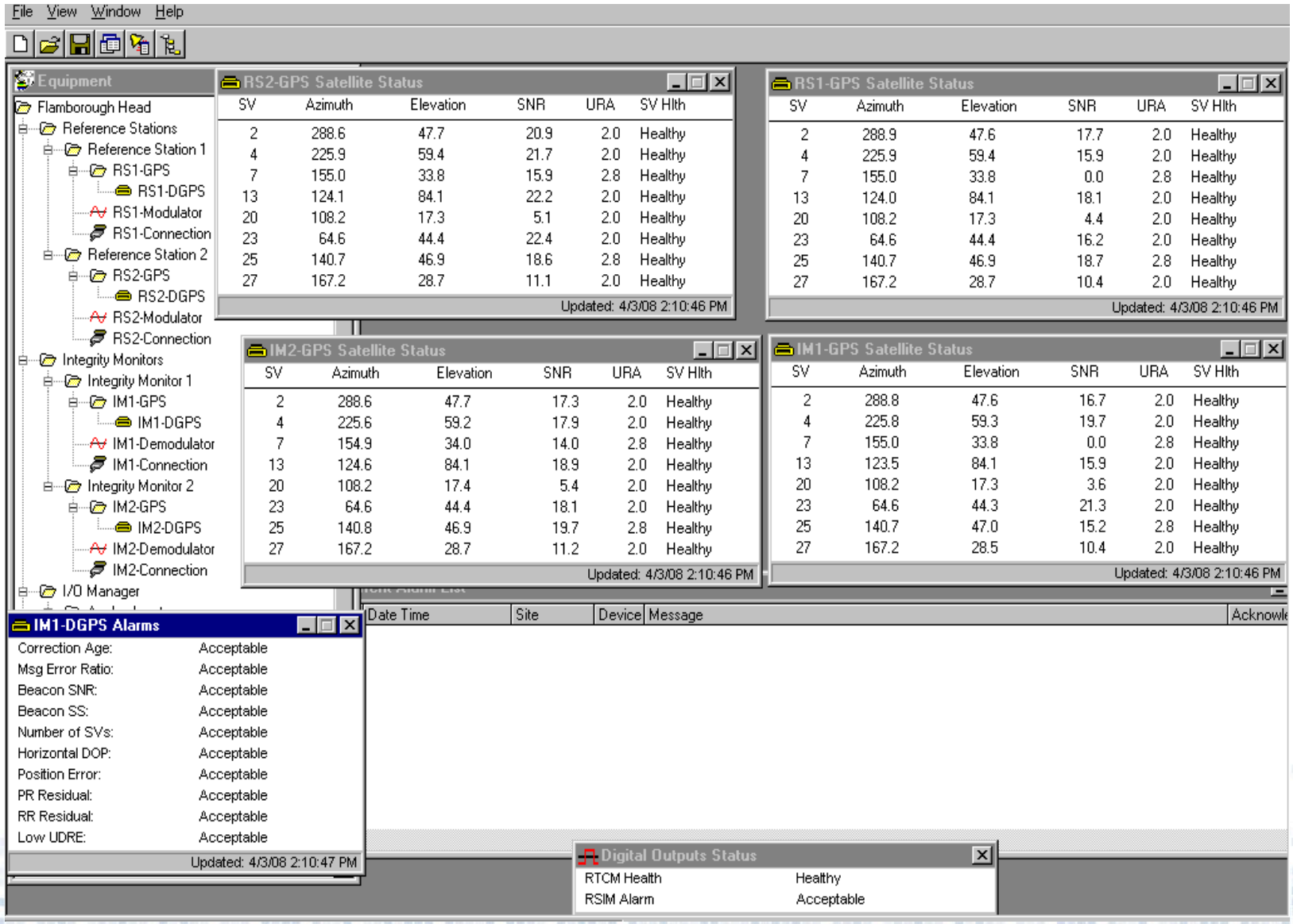

Static Tests - Differential GPS

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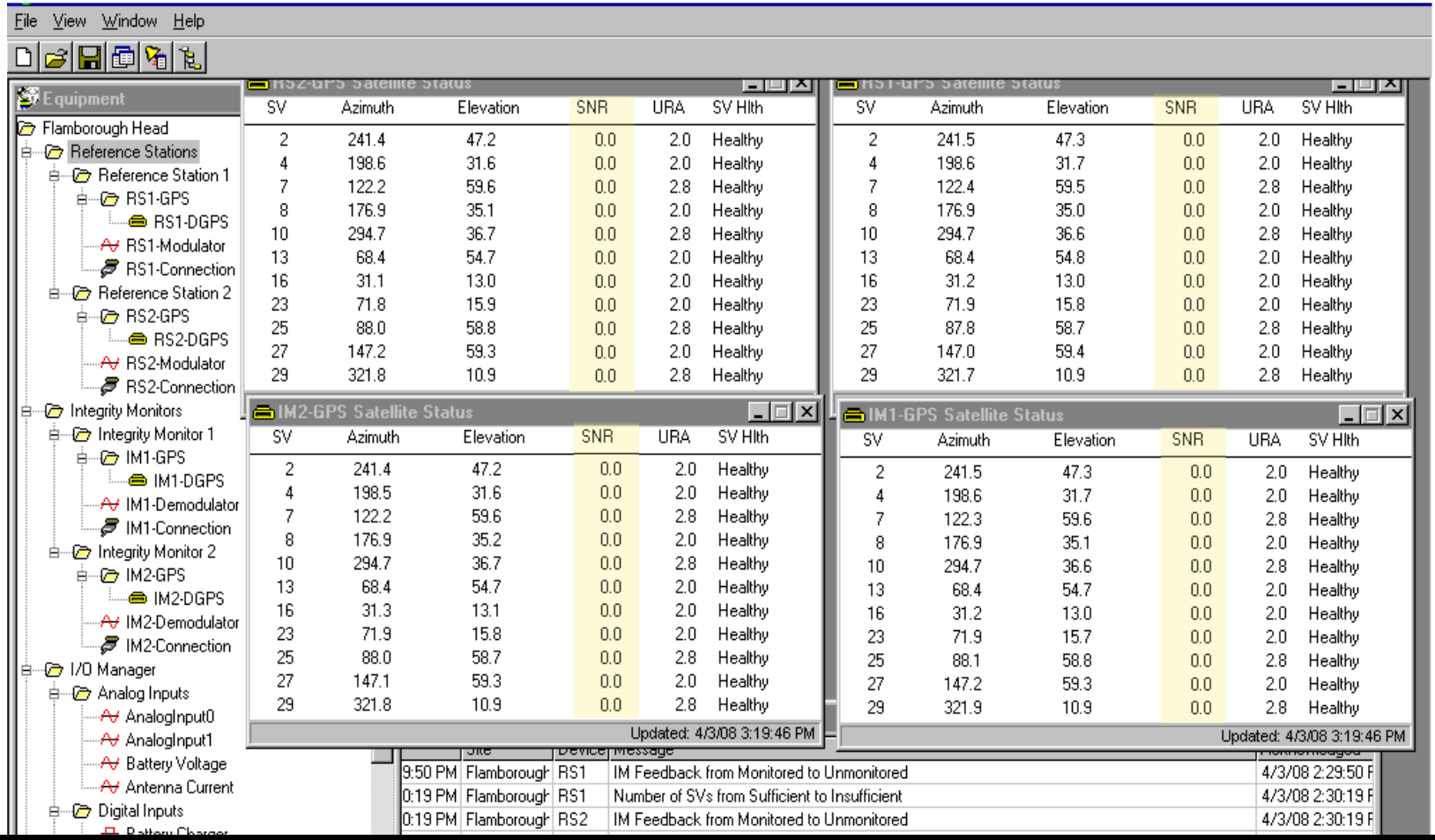

DGPS reference stations can be jammed resulting either in the absence of or faulty DGPS corrections and integrity information broadcast to users over a very large geographical area.

Static Tests - Synchronised Lights

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- Synchronised lights simulating a port approach
- Lights use GPS as a common timing source

Static Tests – Synchronised Lights

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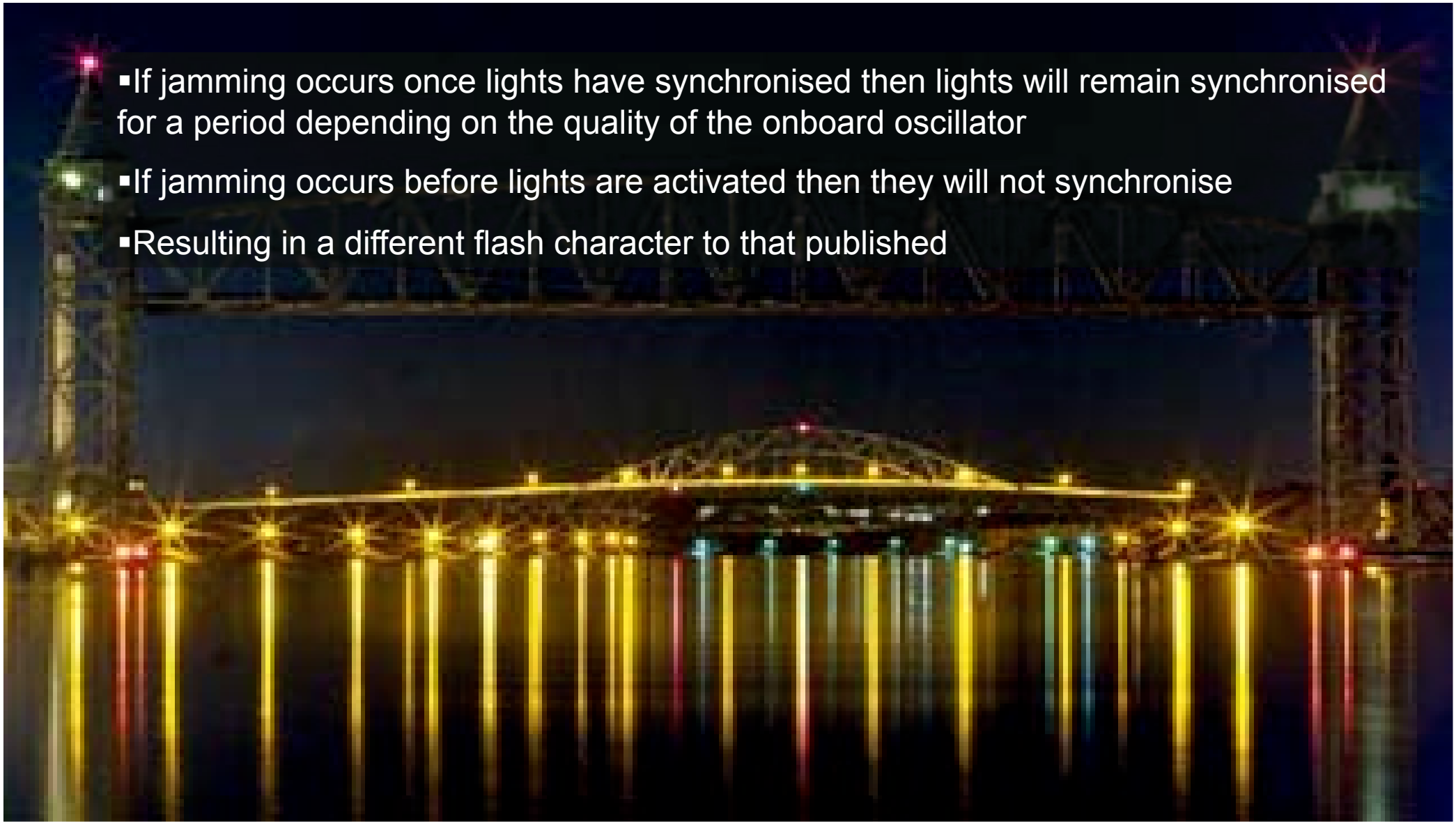

- If jamming occurs once lights have synchronised then lights will remain synchronised for a period depending on the quality of the onboard oscillator
- If jamming occurs before lights are activated then they will not synchronise
- Resulting in a different flash character to that published

AIS: Effect on Ship & Shore

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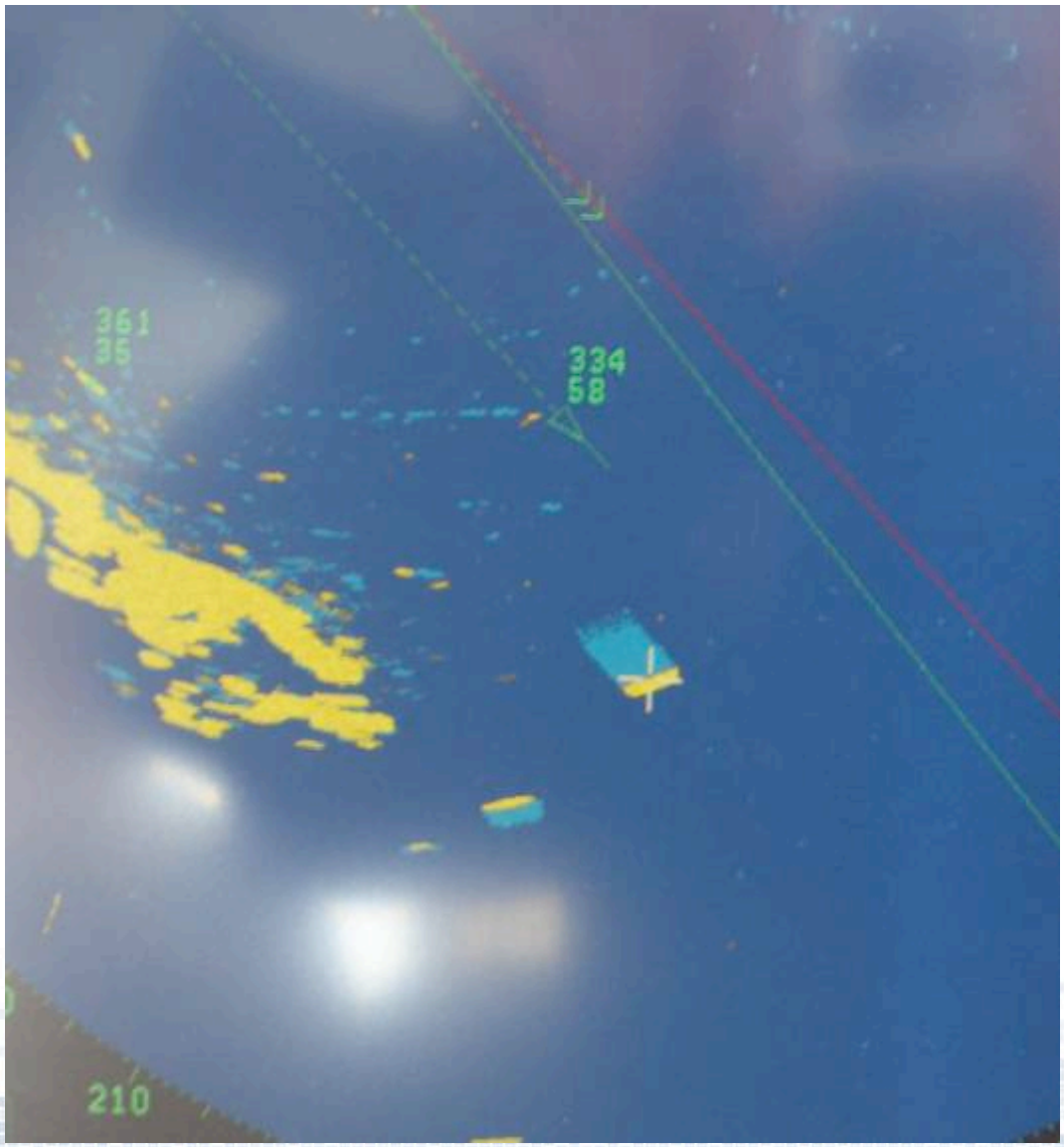
The effect of GPS jamming on AIS was observed by:

- *NLV Pole Star's* AIS alarmed when GPS was lost.
- Without GPS it could not provide a range or bearing to surrounding vessels or AtoNs.
- Some AIS returns included erroneous positions.



AIS: Effect on Ship & Shore

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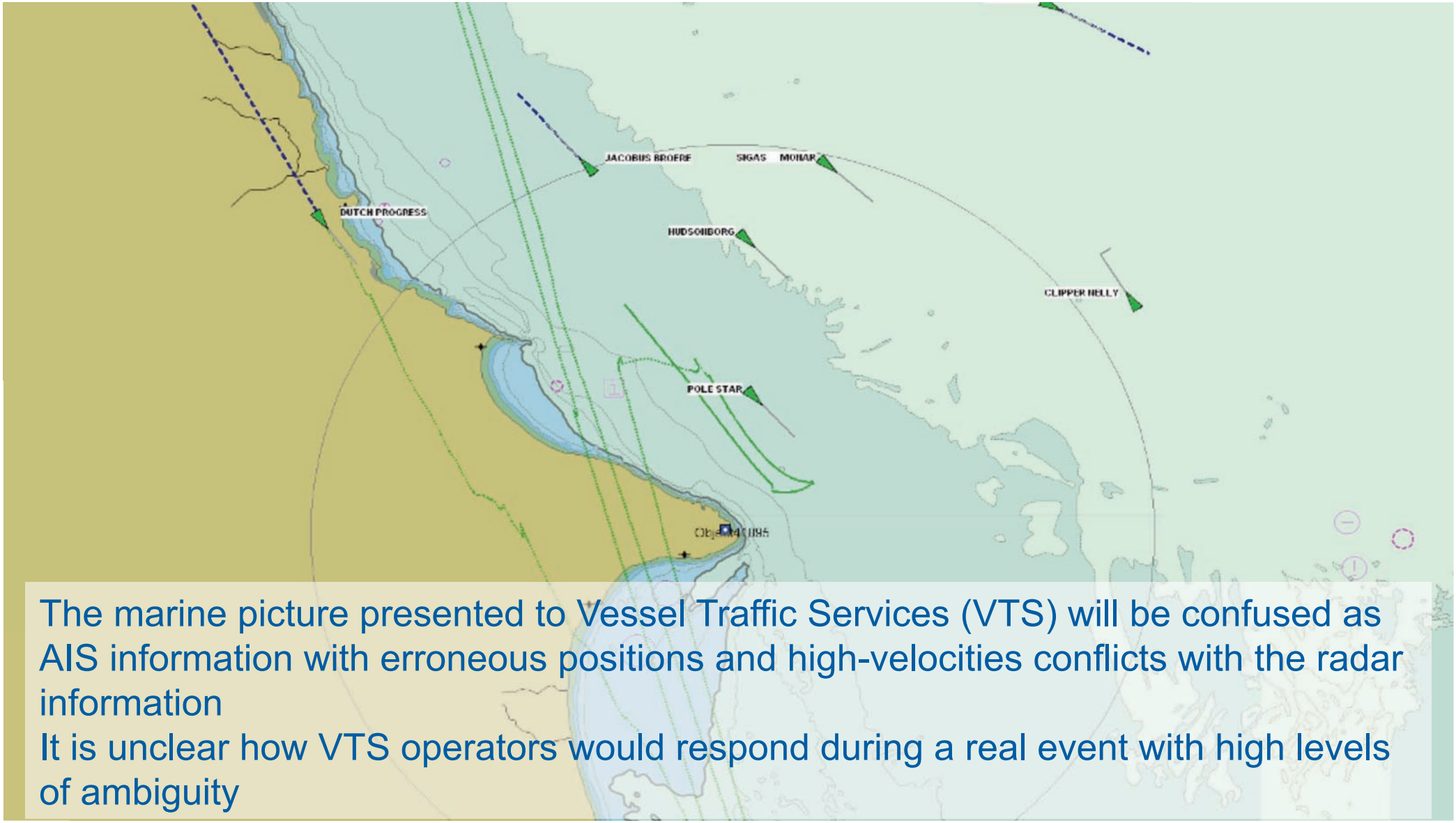

The marine picture presented to Vessel Traffic Services (VTS) will be confused as AIS information with erroneous positions and high-velocities conflicts with the radar information

It is unclear how VTS operators would respond during a real event with high levels of ambiguity

People and Safety

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NLV Pole Star's crew were able to navigate safely during GPS outage.

However, it should be noted:

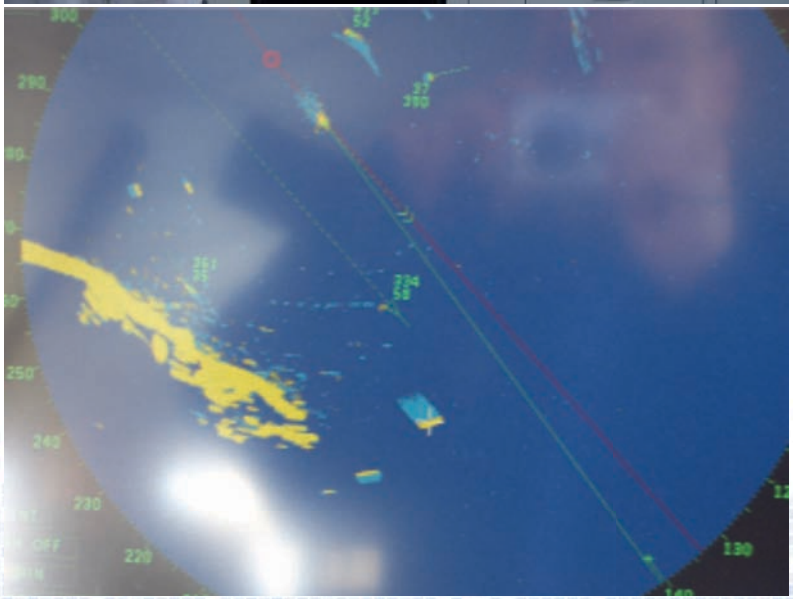
- Vessel's crew had advance knowledge
- Parallel indexing on radar
- Switched ECDIS screen off

Severity of GPS denial depends on:

- Ability of crew to use traditional means
- Availability of traditional means

During entry and exit of the jamming region system alarms sounded for around 5 minutes:

-DGPS Units
-INS Calibration
-Dynamic Positioning System
-VHF Digital Selective Calling



Conclusions

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These results can be extended to GPS service denial by unintentional interference, including:

- spurious harmonics from active TV antennas
- damaged GPS antenna cables
- ionospheric effects (e.g. due to the eleven-year sun-spot cycle)

Conclusions

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The main conclusion from this trial is that GPS service denial has a significant impact on maritime safety!

<u>On Aids-to-Navigation</u>

DGPS reference stations can be jammed and the impact may result in the absence of DGPS corrections and integrity information over a large geographical area.

AIS used as an AtoN may broadcast incorrect information.

Synchronised lights may not synchronise leading to a flash character different to that published.

Conclusions

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The main conclusion from this trial is that GPS service denial has a significant impact on maritime safety!

On ships

Navigation, situational awareness, chart stabilisation and DSC emergency communications will be significantly affected if they are based solely on GPS.

Vessels with integrated bridge systems (autopilot) could, depending on the system design, see the vessel's course and heading change without informing the watch-keeper. Who watches the watcher?

When experiencing jamming, navigational safety is dependent on mariners' abilities to recognise that GPS service is being denied and to operate effectively using alternative techniques (e.g. radar parallel-indexing).

Conclusions

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On shore

Vessel Traffic Services/Management (VTS) marine imaging system will be confused as AIS information with erroneous positions and high-velocities conflicts with the radar information.

Further study is needed to determine how VTS operators will respond.

Conclusions

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On people

People are conditioned to expect excellent GPS (GNSS) performance.

Loss of familiarity with alternative methods of navigation or situational awareness may make a significant impact on safety and security.

In this trial, despite the fact that the *Pole Star's* crew was forewarned, problems were experienced with reliance on the ECDIS.

The number of alarms that can sound on the bridge can be distracting.

Moving to other navigation techniques can cause an increase in bridge workload.

Conclusions

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The main conclusion from this trial is that GPS service denial has a significant impact on maritime safety!

On eLoran

eLoran was unaffected by GPS jamming.

Any loss of GPS calibration compensated for by storing ASF data.

Demonstrated an accuracy of 8.1m (95%) vs. DGPS.

Can be used to detect GPS errors and provide independent position, navigation and timing information (PNT) to maritime systems.

With e-Navigation, the combination of GPS, Galileo and eLoran will provide robust and resilient PNT in order to reduce the impact of human error and to improve the safety, security and protection of the marine environment.

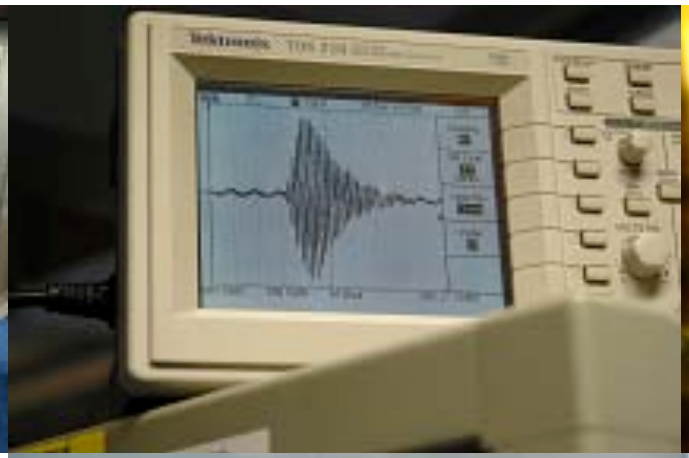
The GLAs welcome the recent US policy announcement on their use of eLoran and will continue their eLoran programme of work!

Thank you!

The authors' would like to thank:

- The crew of *NLV Pole Star* for their patience and assistance;
- Maritime and Coast Guard Agency for their support; and
- DSTL for providing and operating the GPS jamming unit.

Pictures: Loran Station Anthorn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