European Sea Trials of Kalman-filtered Loran-C System

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Project Background

- Cooperative effort of STN Atlas and Locus, Inc.

- Locus:
  - provided SatMate Loran technology (here with E-field antenna)

- STN Atlas:
  - major service/system provider to German Navy
  - integrated GPS and SatMate systems
  - developed Kalman filter
  - developed track controller system
  - performed sea trials

- Both companies contributed to system optimization and data analysis

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Two Major Trials

- Helgoland - September 27-29, 2001
  - Test navigation filter and control system for:
    - Single track steering of drone vessel
    - Transit steering of drone vessels
    - Multitrack steering of 4 drone vessels

- Kiel Canal - August 27, 2001
  - Did not include nav filter or track control system
  - Evaluated Loran and GPS performance
  - Loran performance illustrated with and without ASF corrections (supplied by University of Wales - Last and Williams)

- Important Qualification to Both Trials and All Loran Data:
  - the European Loran infrastructure is incomplete, so capabilities demonstrated here will be considerably enhanced when the system is completed.

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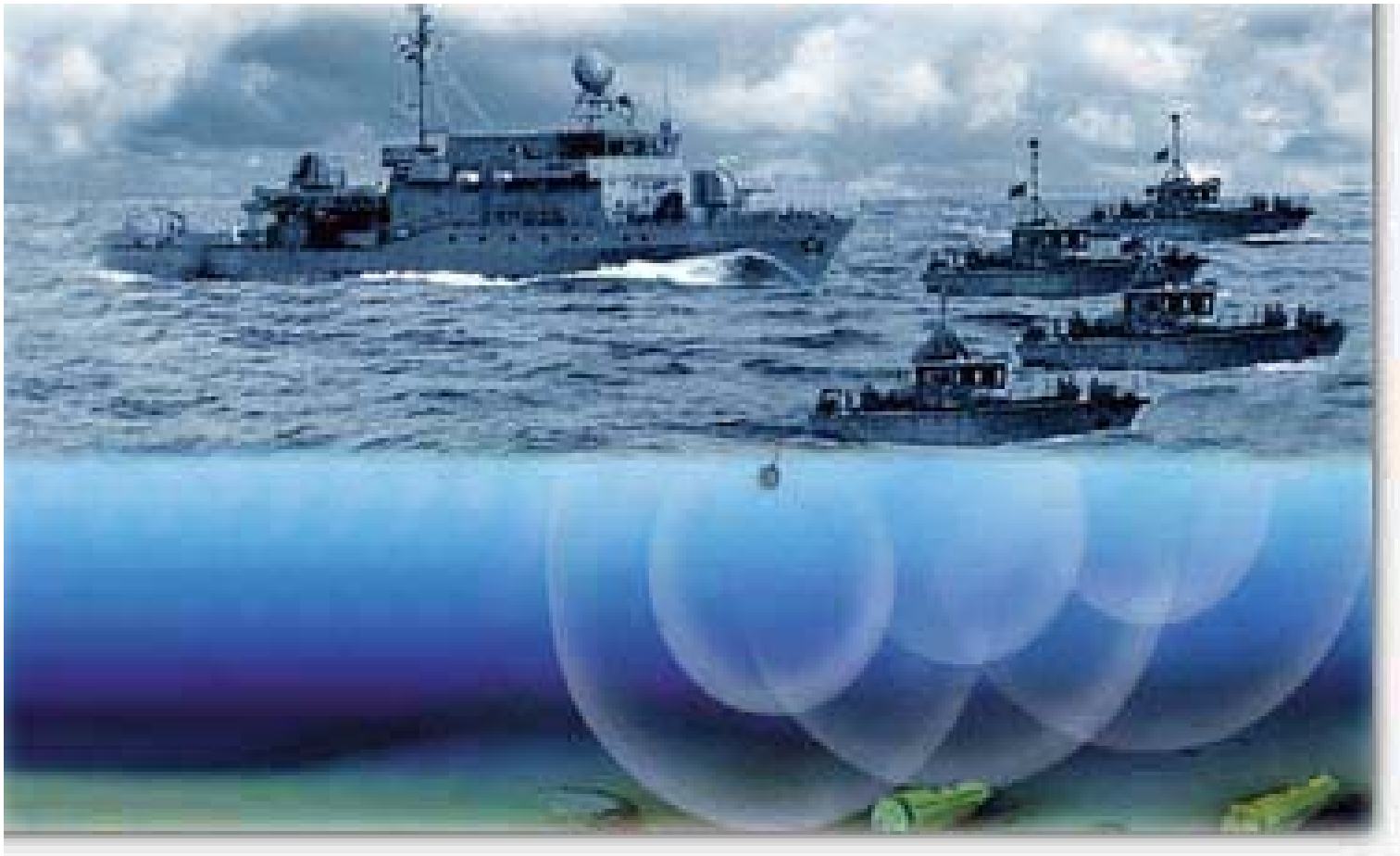
Overview of Helgoland Project



- Main vessel remotely controls 4 drone vessels
- System must function independently if GPS denied

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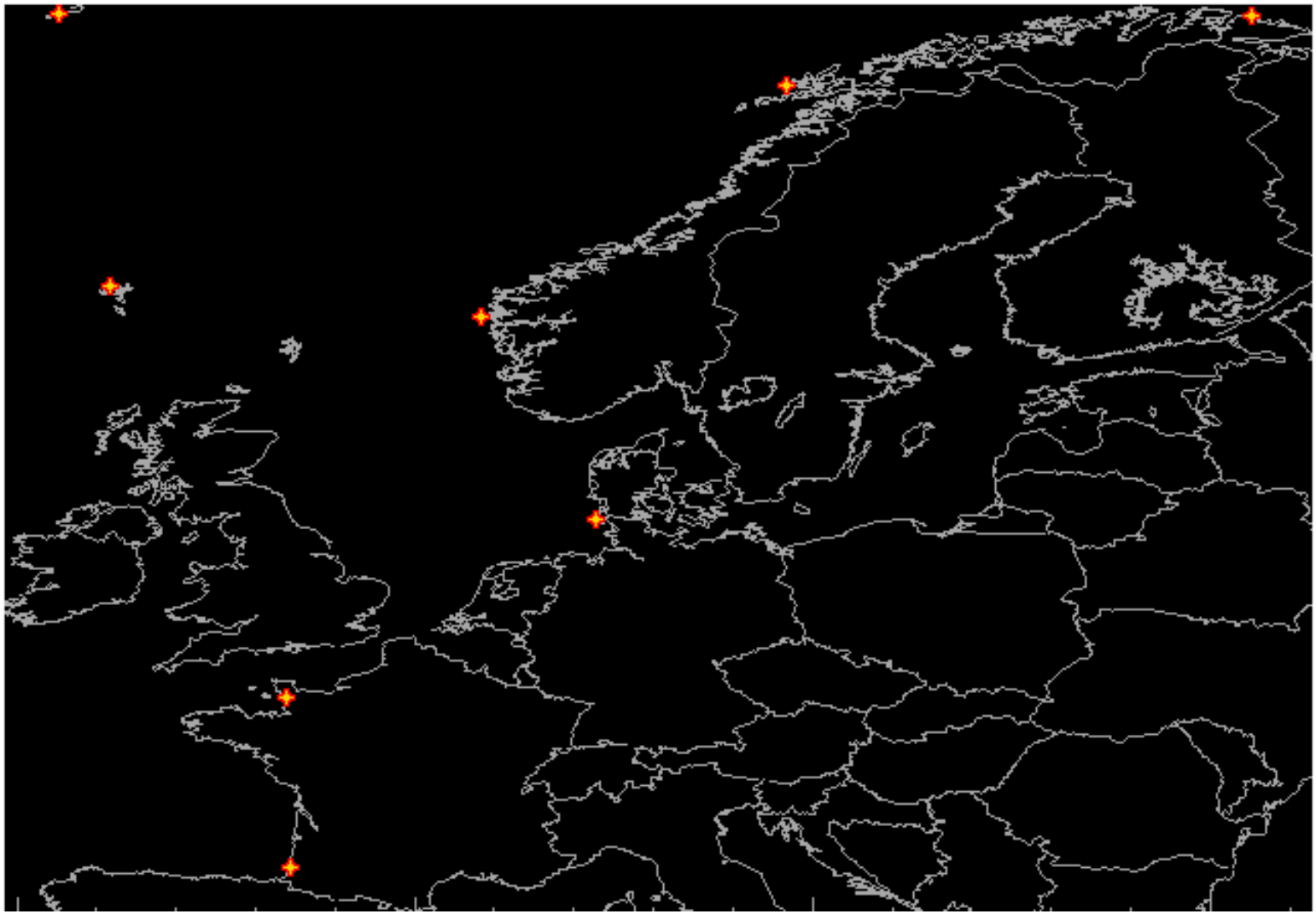
Loran-C Coverage in Test Area



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Nav Filter and System Overview

• Navigation filter takes GPS data for ~ 30 seconds, and then GPS input to filter and track controller turned off by software switch on control vessel

• GPS shown throughout for reference only

• After GPS removed, raw Loran with no ASF corrections becomes the only sensor to provide input to the nav filter and track controller system

• SatMate used general conductivity of 5 millisiemens

• System functions automatically, i.e. without human intervention

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Helgoland Sea Trials Overview

• Three types of trials:

1. Single Track Steering - one drone, commanded to go between 2 waypoints at set speed, then into a waiting circle.

2. Transit Steering - system automatically controls speed, course, and specified separation of 4 drones along a single track either in front of or behind the main vessel.

3. Multi-track Steering - system automatically controls speed, course, and specified separation of 4 drones and main vessel along parallel tracks. *Multi-track steering* performance is the *critical* system test.

• Drones run in “waiting” circles prior to test for system calibration and drone positioning.

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Helgoland Sea Trials Overview

Drone Vessels

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Helgoland Sea Trials Overview

Drone vessel Seehund 7 with SatMate Receiver

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Helgoland Sea Trials Overview

Control Vessel

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Helgoland Sea Trials Overview

2 drone vessels during sea trials

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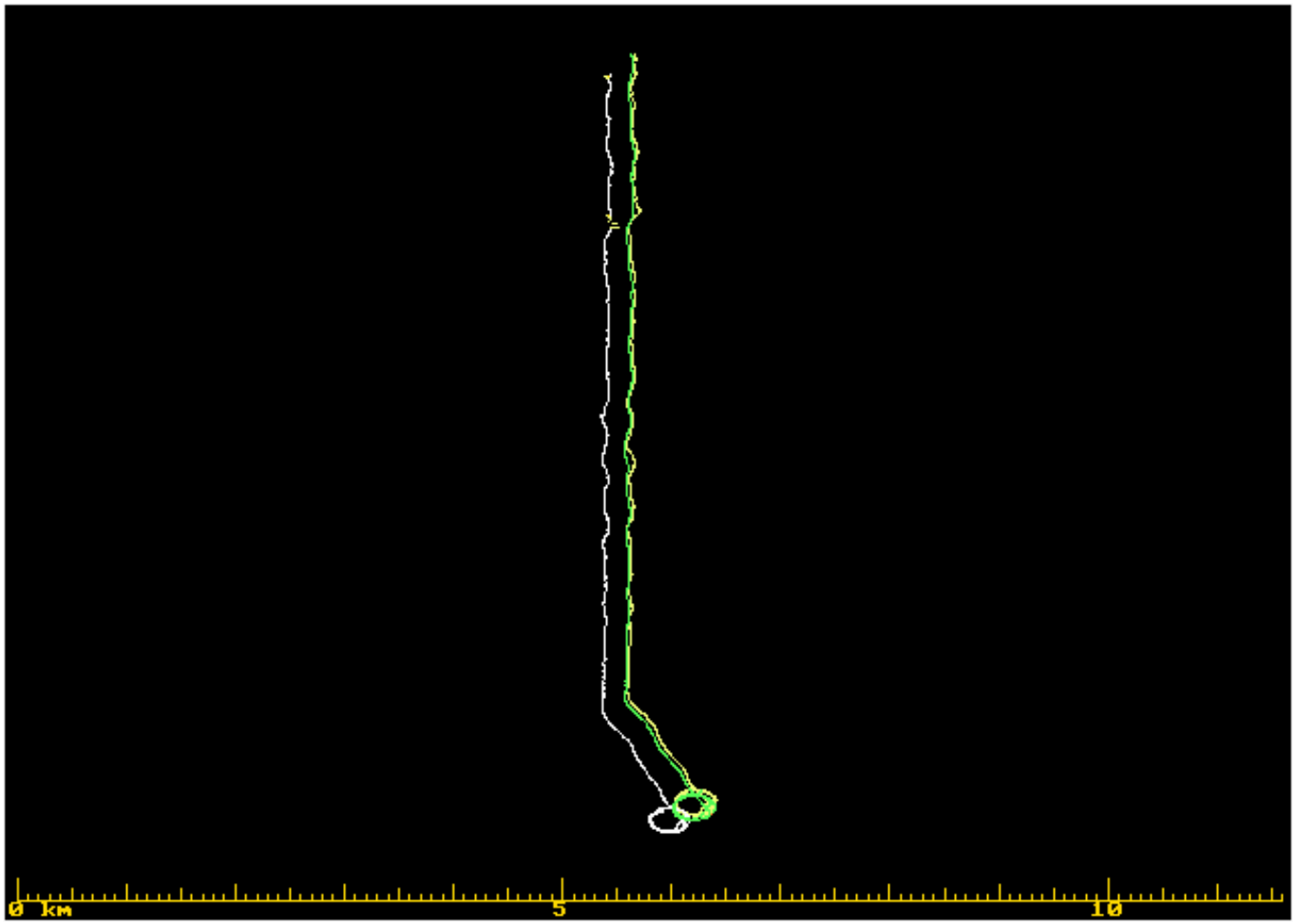
Single Track Steering
North - South Trial

GPS - green
SatMate - white
NavFilter - yellow



- **GPS input to nav filter turned off after initial calibration**
- **Loran losses due to Sylt (7499 and 6731) going off air**

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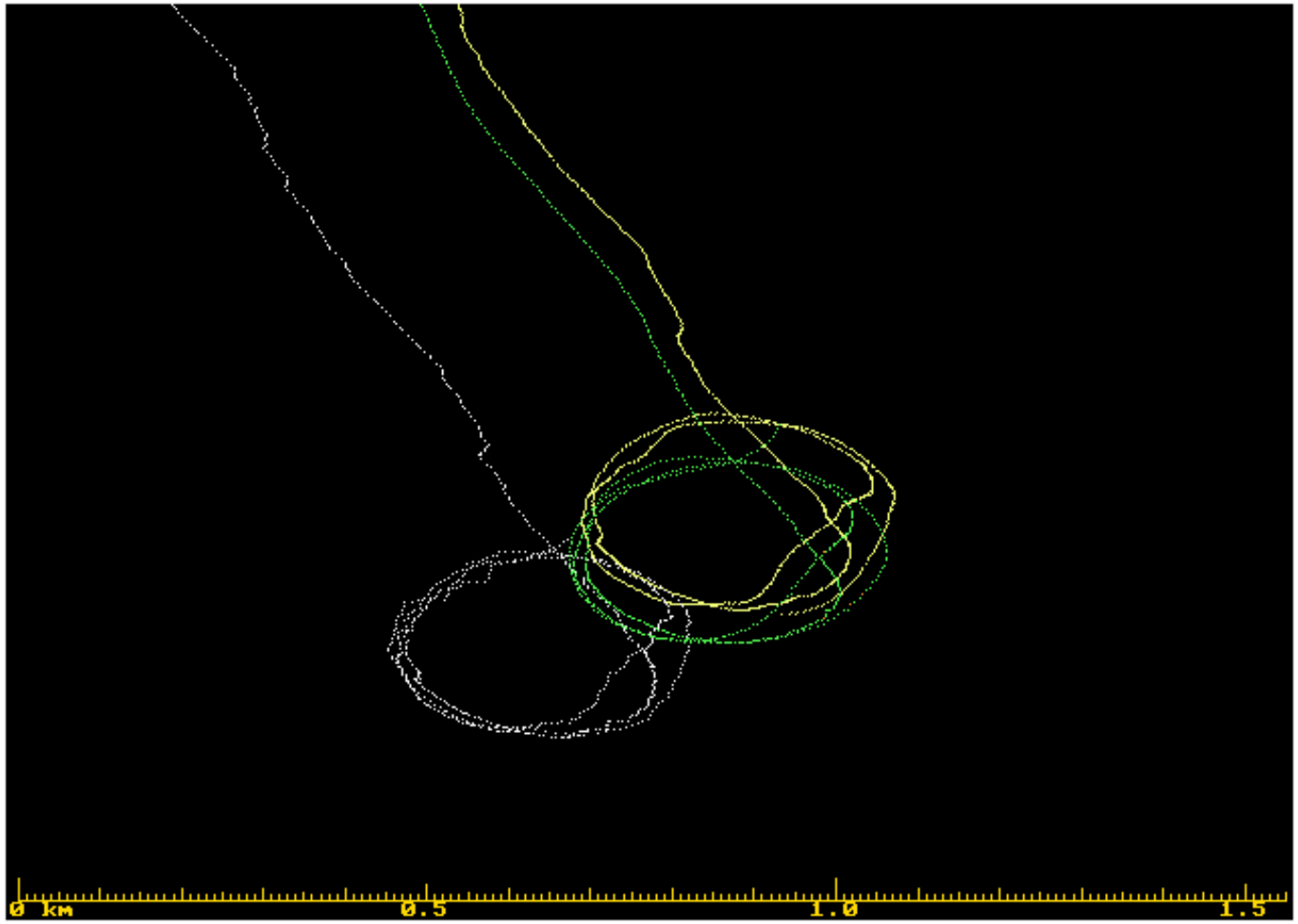
Single Track Steering - Close-up of S Waiting Circle

GPS - green
SatMate - white
NavFilter - yellow



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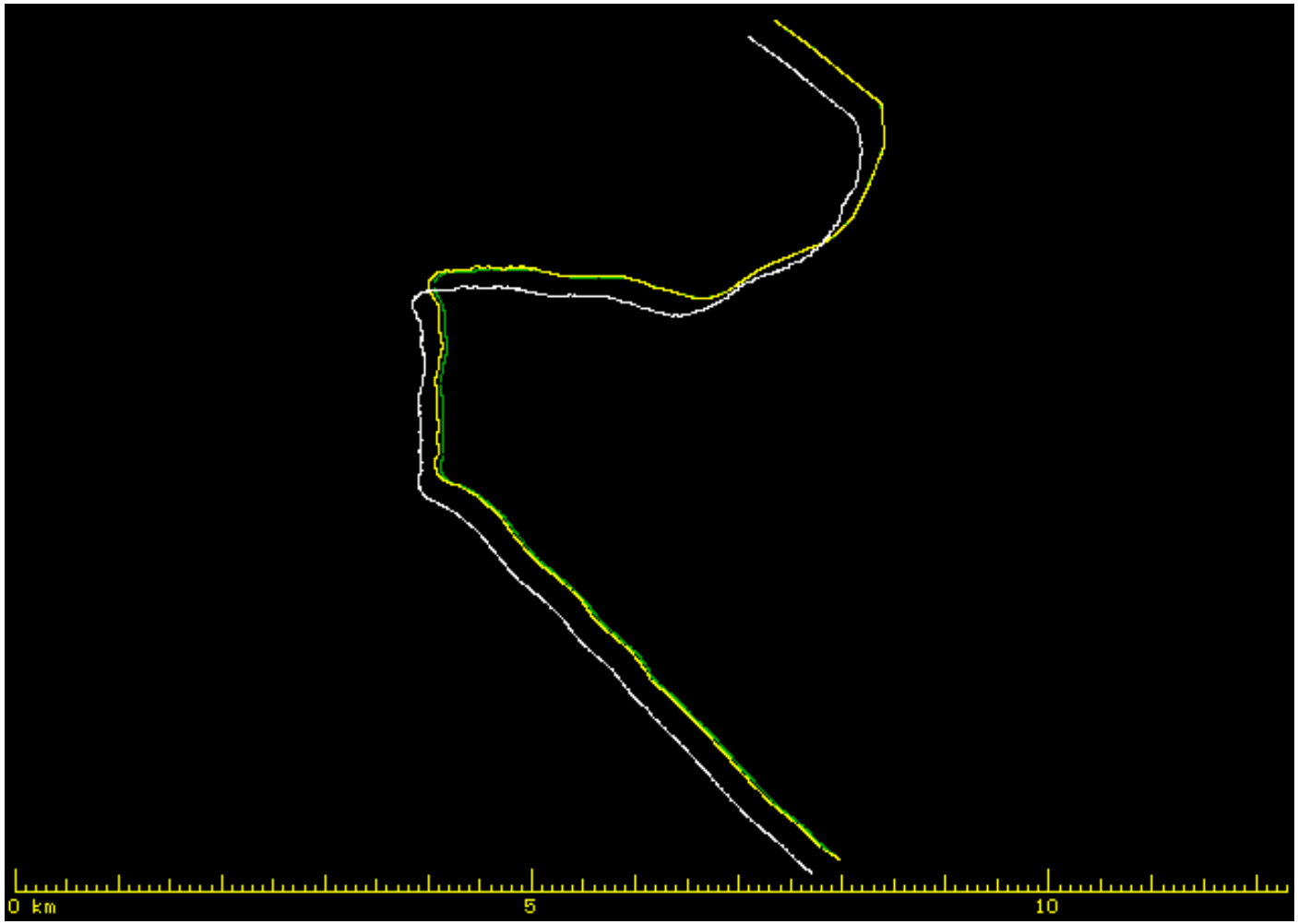
Transit Steering
North - South Trial

GPS - green
SatMate - white
NavFilter - yellow



- Velocity 7-9 knots before 90° turn to South
- Velocity 3-4 knots during due South excursion
- Velocity 8-9 knots after 45° turn to East

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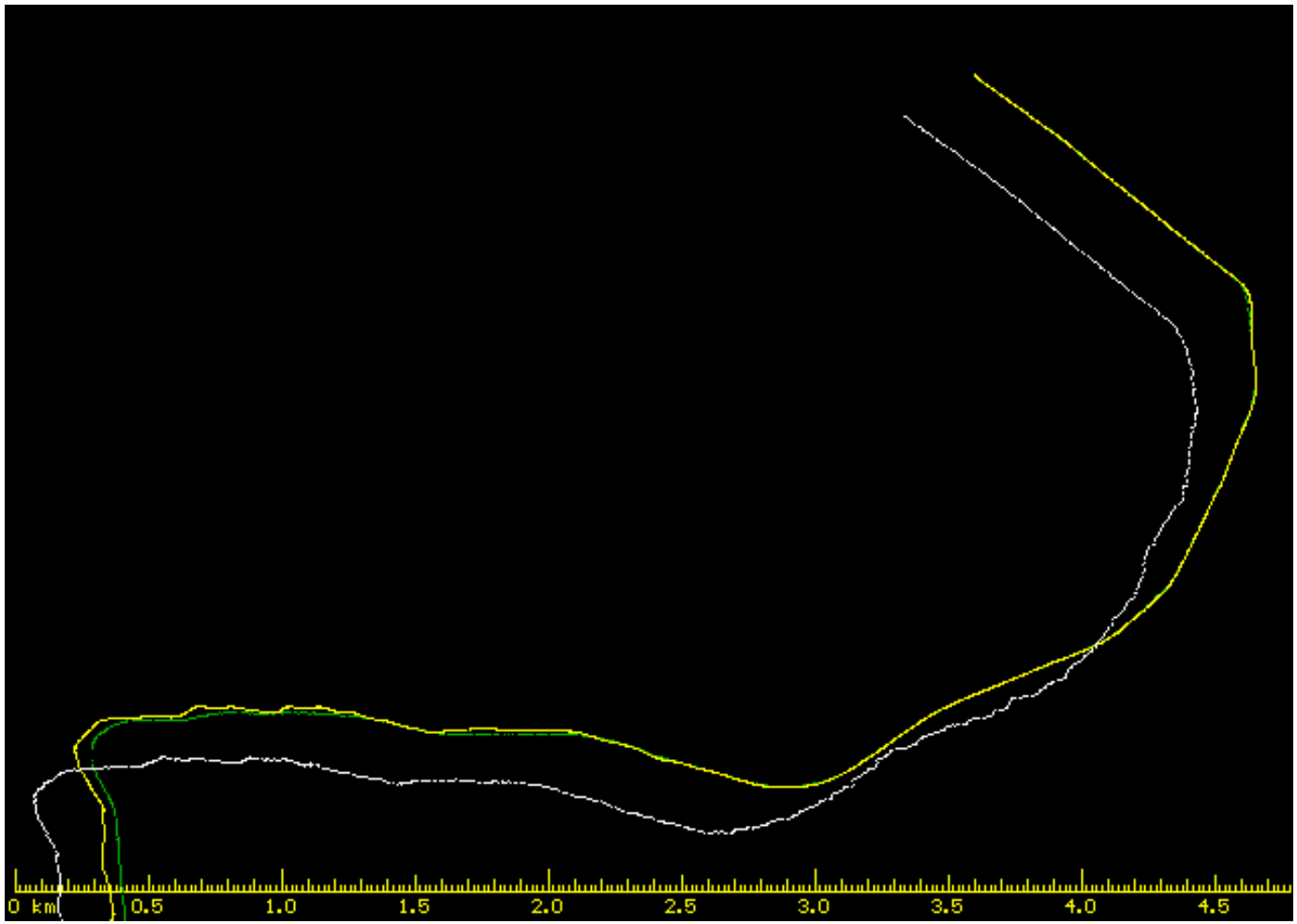
Transit Steering - Close-up

GPS - green
SatMate - white
NavFilter - yellow



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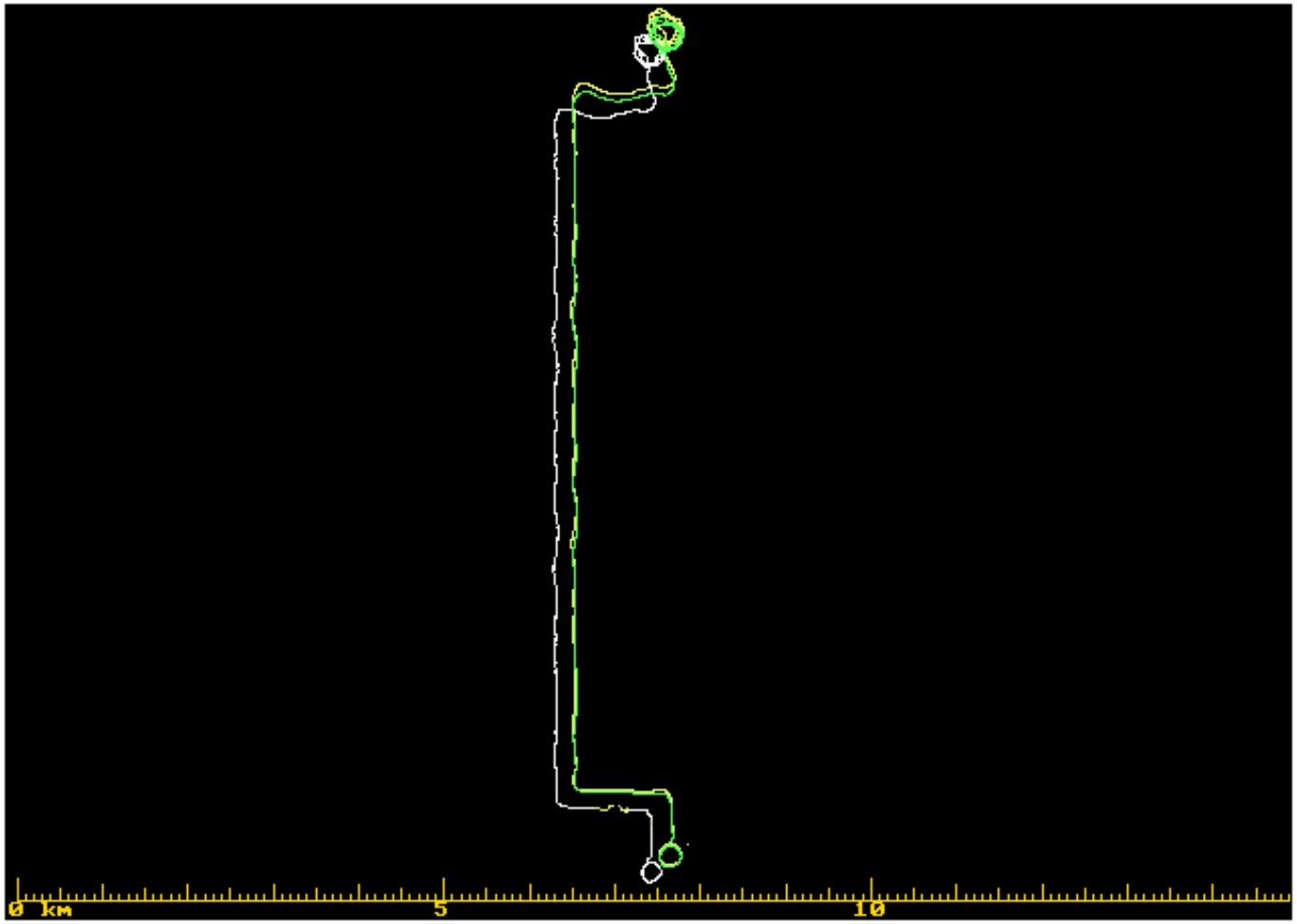
Multitrack Steering,
South - North Track, Waiting Circles Shown

GPS - green
SatMate - white
NavFilter - yellow



- 4 drones and main vessel under automated system control
- Loran gaps due to Sylt (7499 and 6731) going off air

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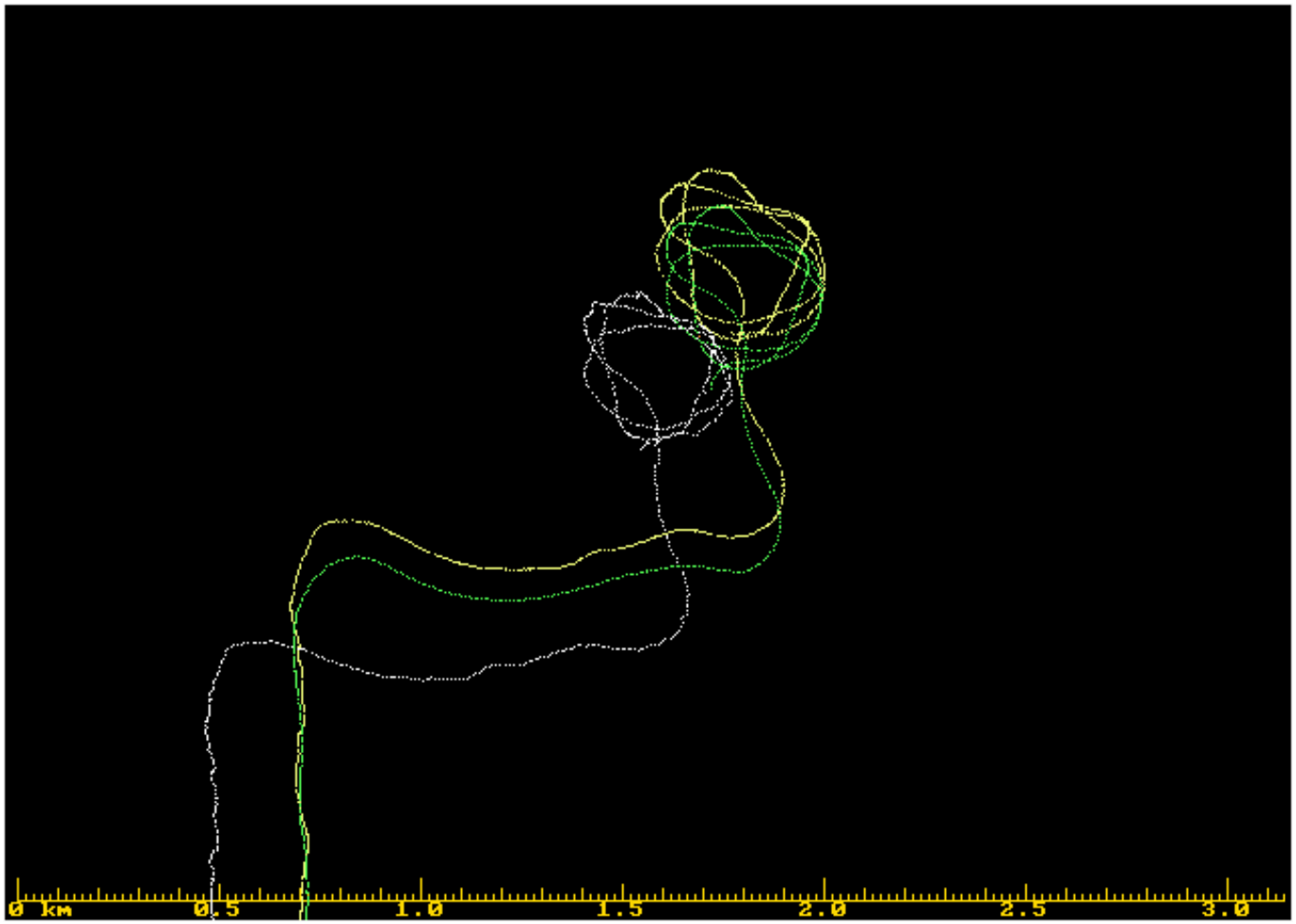
Multitrack Steering - Close-up of N Waiting Circle

GPS - green
SatMate - white
NavFilter - yellow



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Helgoland Sea Trials
- Conclusions -

• a Kalman-filtered Loran and track controller system meet necessary performance requirements for automated operation of up to four drones and one main vessel in minesweeping operations

• the system can operate independent of GPS if that system is denied

• ASF corrections and a complete Loran infrastructure would generate even better results

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Kiel Canal Tests

- August 27, 2001, from Kiel to Brunsbuettel on same test vessel used for Helgoland trials
- Kalman filter not applied to SatMate data
- Simultaneous GPS and SatMate recordings
- SatMate data shown:

  - without ASFs (sea water conductivity)

  - with ASF corrections provided by University of Wales using their ASF model (Last and Williams)
- SatMate nav solution used only 4 stations and 3 baselines (i.e. 7499 MXY and 6731 MXZ)

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Kiel Canal

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Test Vessel near Rendsburg Bridge

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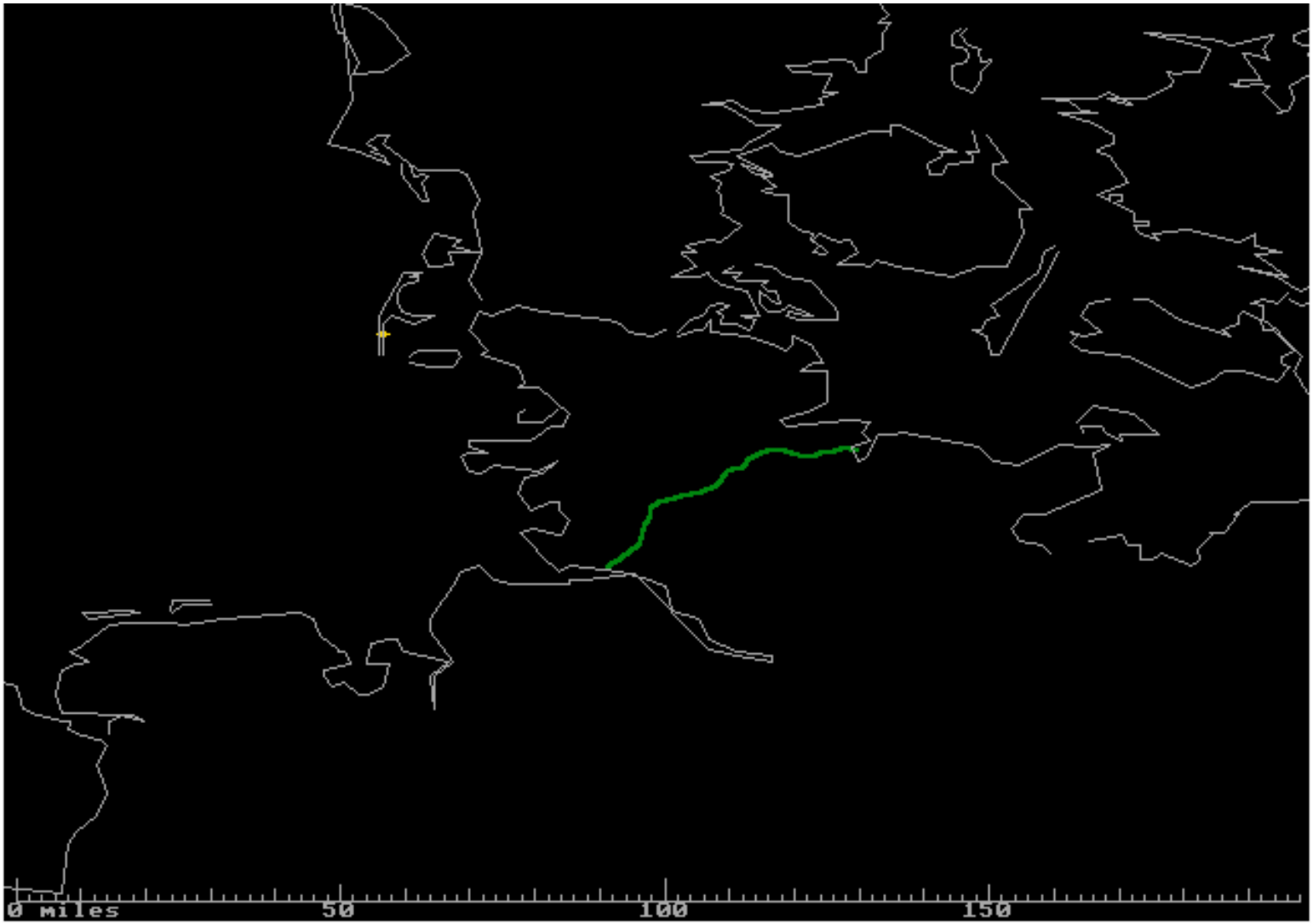
Kiel Canal



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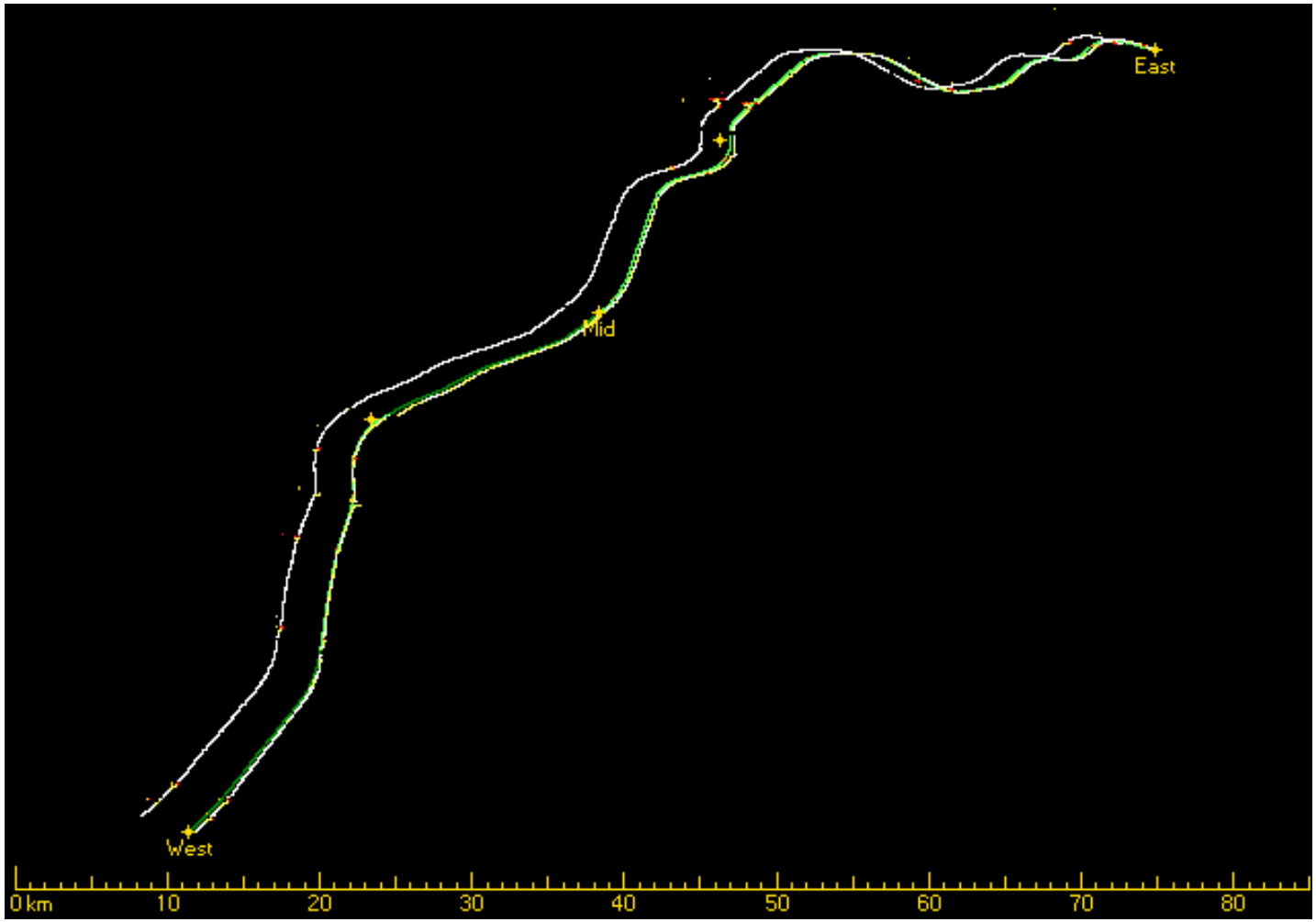
Kiel Canal



GPS - green; SatMate with ASF - yellow;
SatMate with no ASF - white

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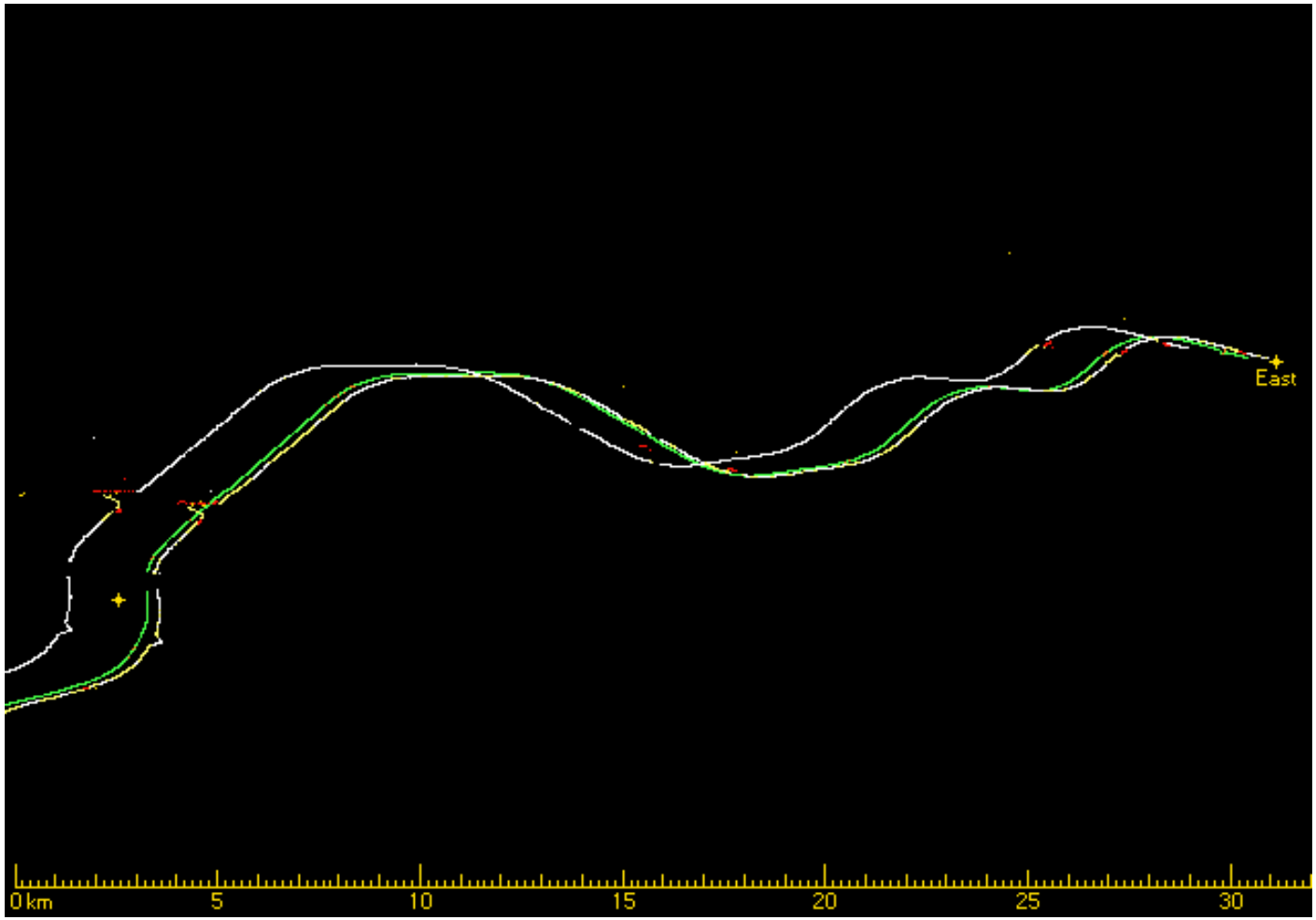
Kiel Canal - Northeast Section



GPS - green; SatMate with ASF - yellow;
SatMate with no ASF - white

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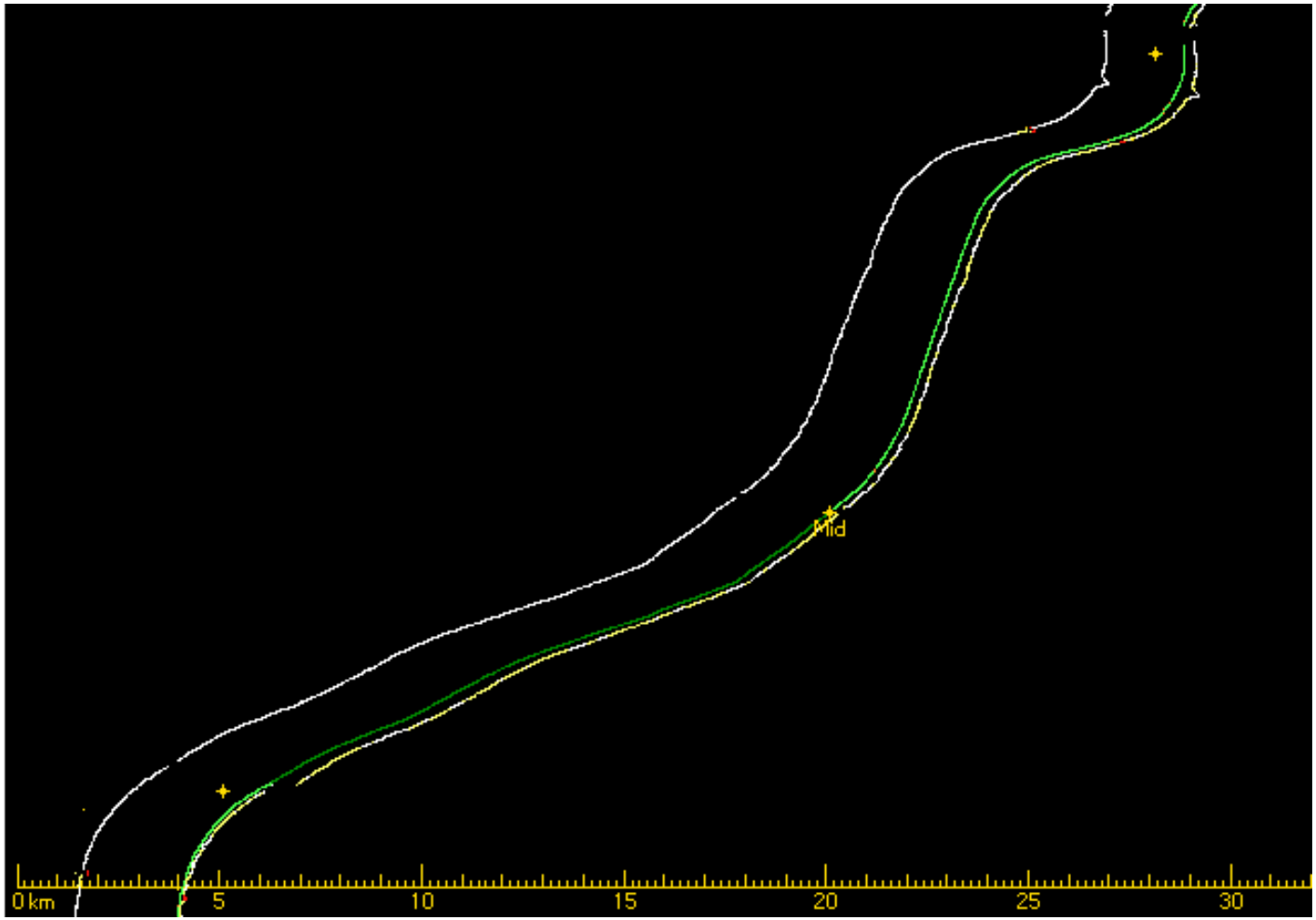
Kiel Canal - Central Section



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SatMate with no ASF - white

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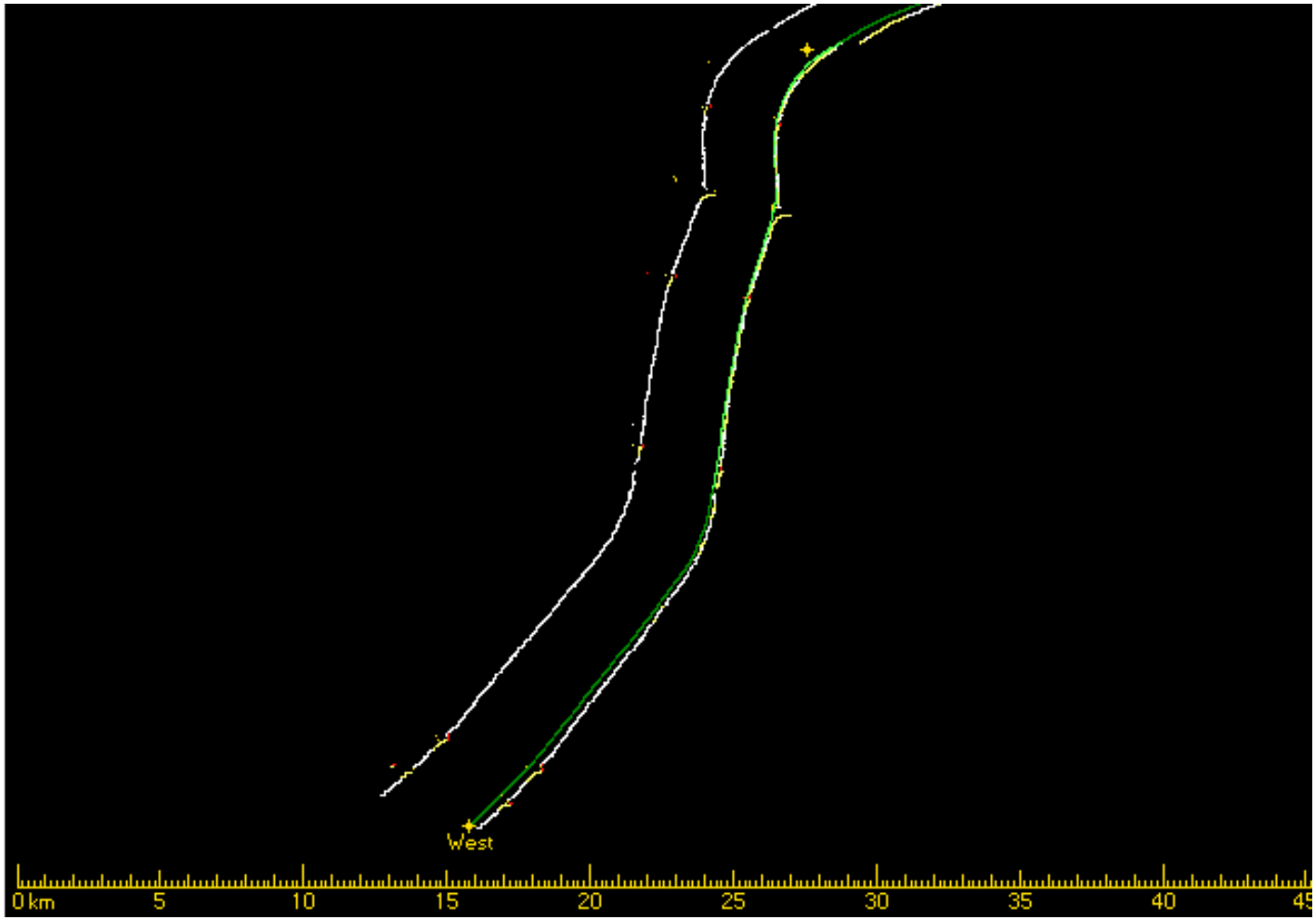
Kiel Canal - Southwest Section



GPS - green; SatMate with ASF - yellow;
SatMate with no ASF - white

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Kiel Canal Trial
- Conclusions

• Loran availability throughout the Kiel Canal is good, even with an incomplete Loran infrastructure

• Even with poor system geometry, Loran positions show consistent offset from GPS

• With ASF corrections, Loran accuracy is very good

• Obviously, overall Loran system performance would be enhanced with a complete infrastructure

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