R-MODE – TERRESTRIAL NAVIGATION FOR MARITIME USERS

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DLR

Agenda

- Introduction R-Mode
- R-Mode Baltic test bed
- Measurement results
- Summary and conclusion

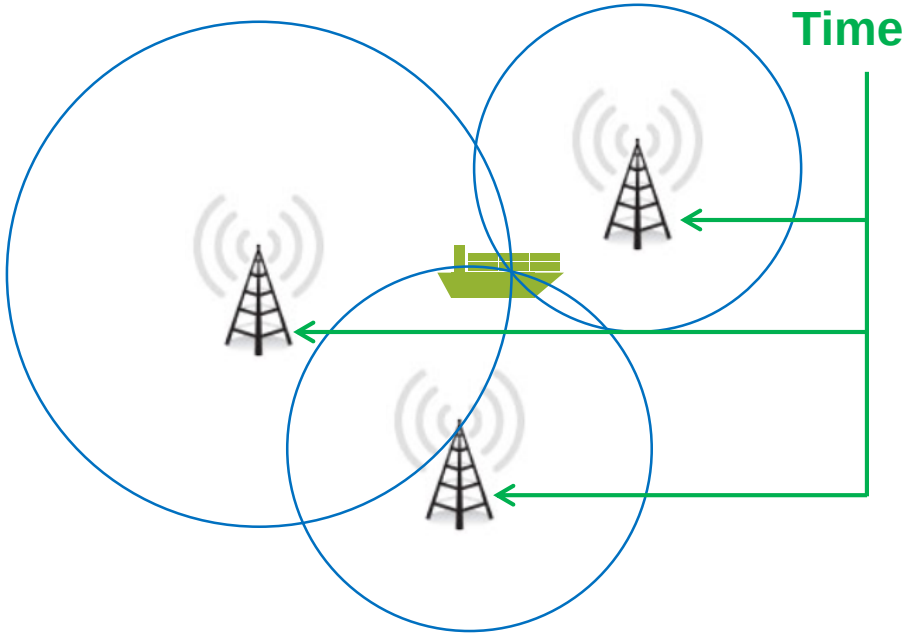
INTRODUCTION R-MODE

Need for an alternative PNT information

- GNSS primary source for PNT information on board of ships
- Used for
  - Own positioning
  - Vessel position exchange (AIS)
  - Vessel data recorder, ship clock
  - Autonomous vessel
- GNSS is vulnerable to system errors
- GNSS is vulnerable to interferences
- Redundant sensors and systems needed
  - IMU, Speed log, RADAR
  - **R-Mode**, eLoran
  - Visual AtoN

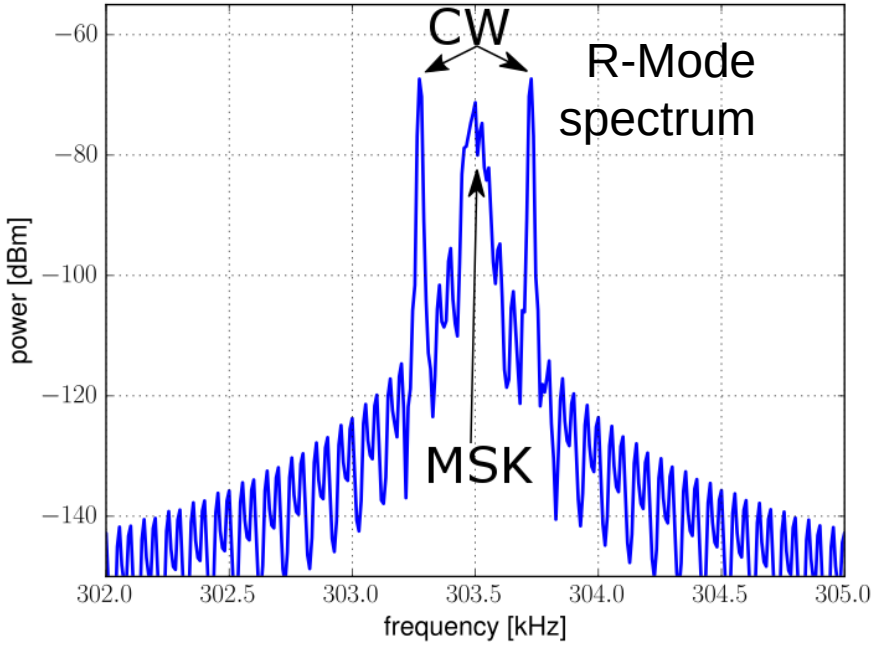
R(anging)-Mode
A terrestrial maritime backup for GNSS

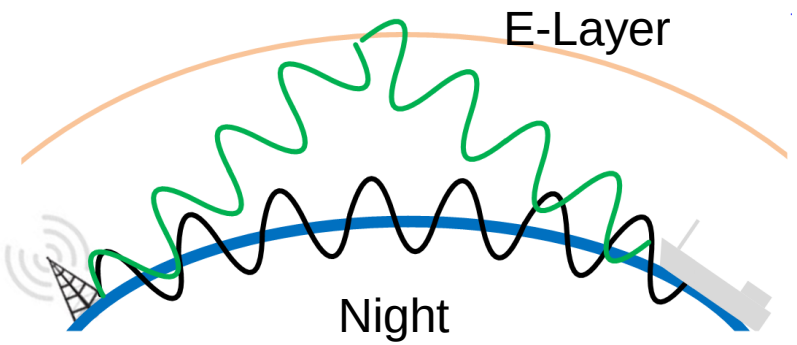
- R(anging)-Mode is a positioning system that
  - transmits timely synchronized ranging signals
  - using the communication channel of existing maritime radio infrastructure
- Cost-efficient way to a backup system
- 2D positioning with Time of Arrival approach - 3 stations have to be in view
- R-Mode signal sources
  - **Medium Frequency (MF)** using maritime radio beacons
  - **VDES** using VHF transmissions



Marine radio beacons as source for R-Mode signals

- Radio beacon provide DGNSS corrections in Medium Frequency (MF) band
- Frequency Division Multiple Access (FDMA) with 500 Hz or 1 kHz channel bandwidth
- Bit length of legacy signal 5 to 20 ms
- R-Mode: two aiding carriers (CW) signals 225 Hz beside carrier of legacy signal





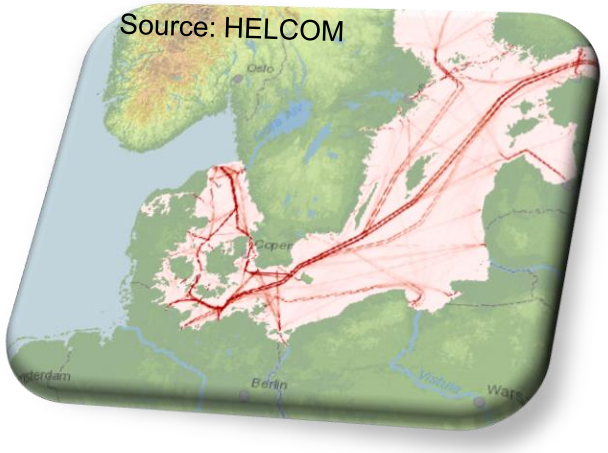
Challenges

- Mitigate sky-wave induced fading
- Land-sea path

R-Mode research and development activities in the Baltic

Presented results are based on two projects (2017 - 2021)

- Research
- Development
- Implementation
- MF and VDES R-Mode validation
- Standardization



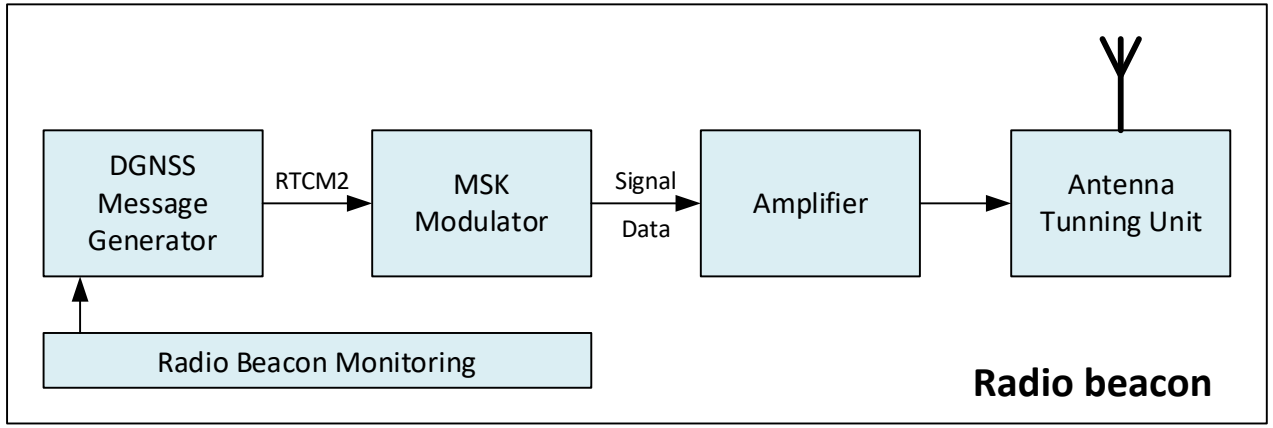
R-MODE BALTIC TEST BED

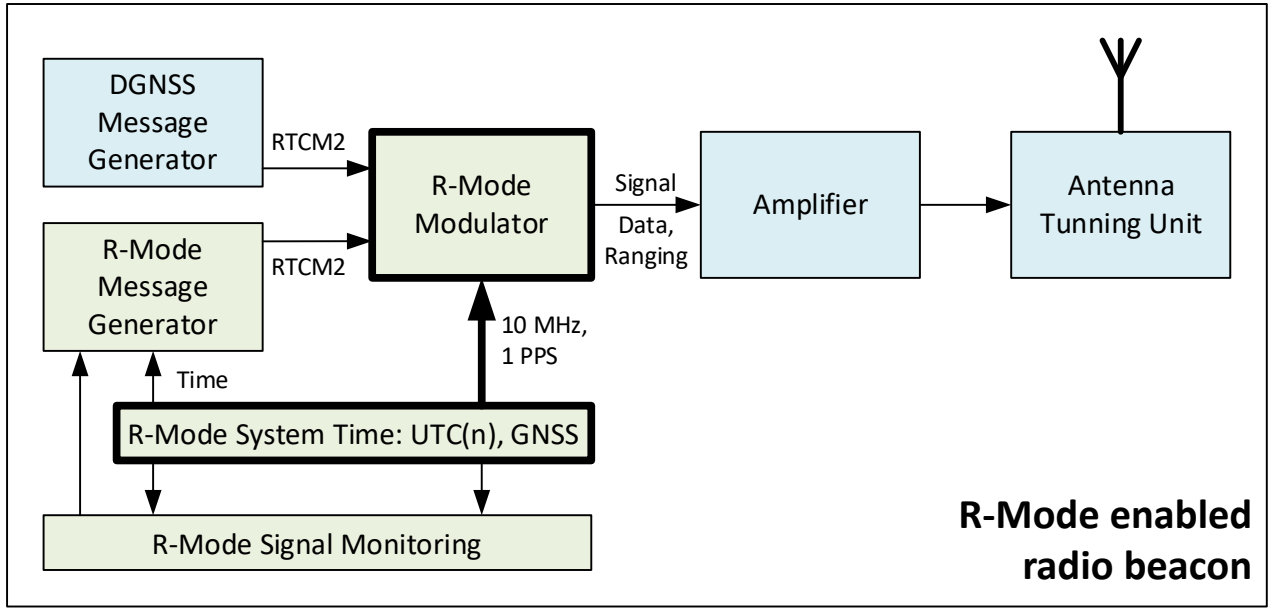
Retrofitting maritime radio beacons to enable MF R-Mode transmission

- Reuse most elements of the transmitter chain
- Replace signal generator (modulator)
- Add time source for R-Mode System Time
- Upgrade signal monitor
- Legacy service is not disturbed

✓ Can be implemented with low to medium effort

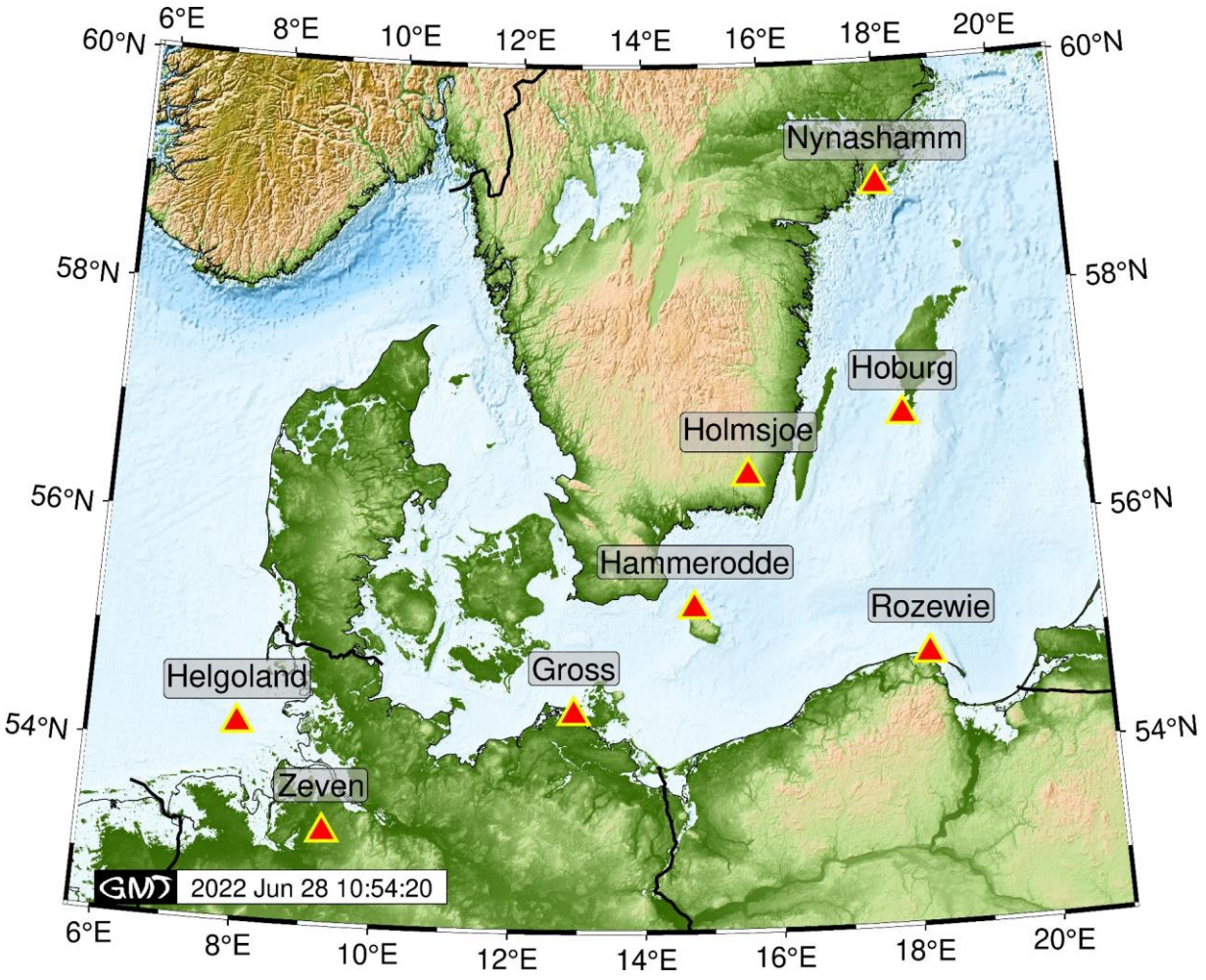
! Transmitter chain not designed for R-Mode signals



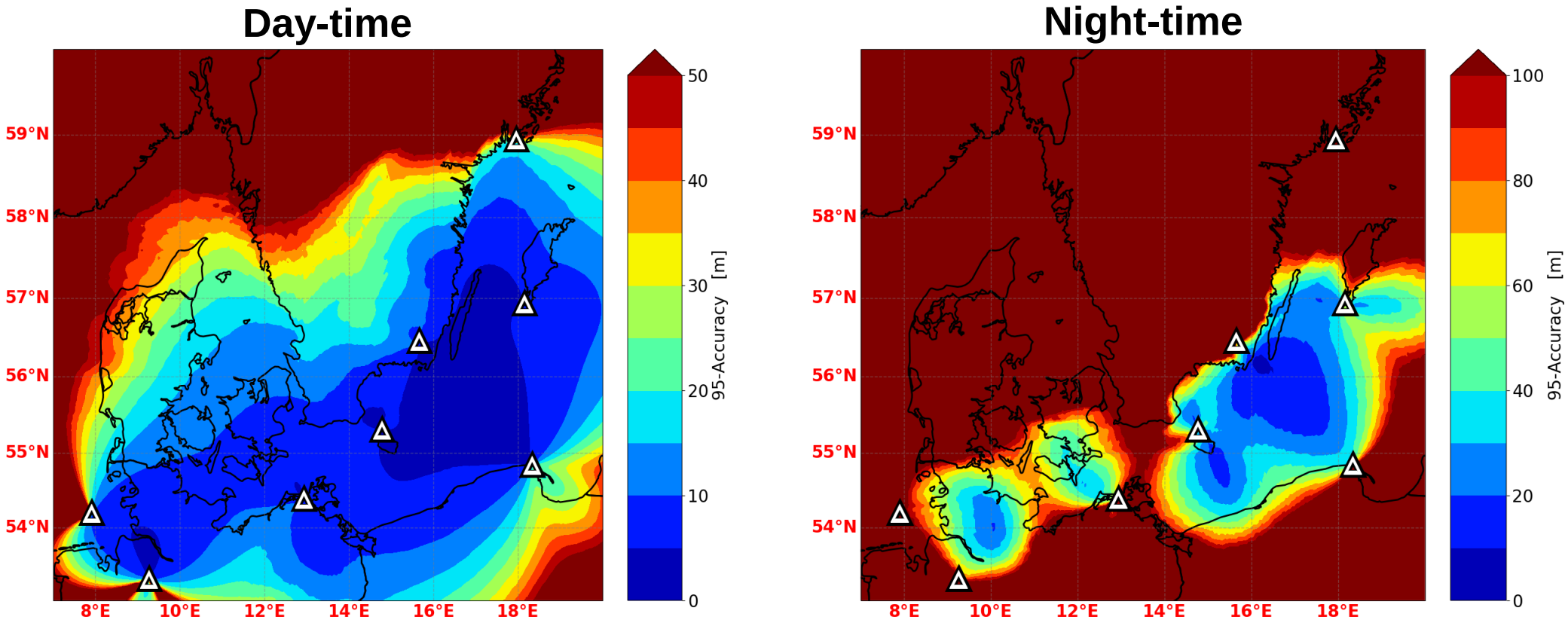


MF R-Mode Baltic test bed

- First large scale test bed
  - 8 transmitters
  - 4 countries (Germany, Poland, Sweden and Denmark)
  - 800 km extension (SW to NE)



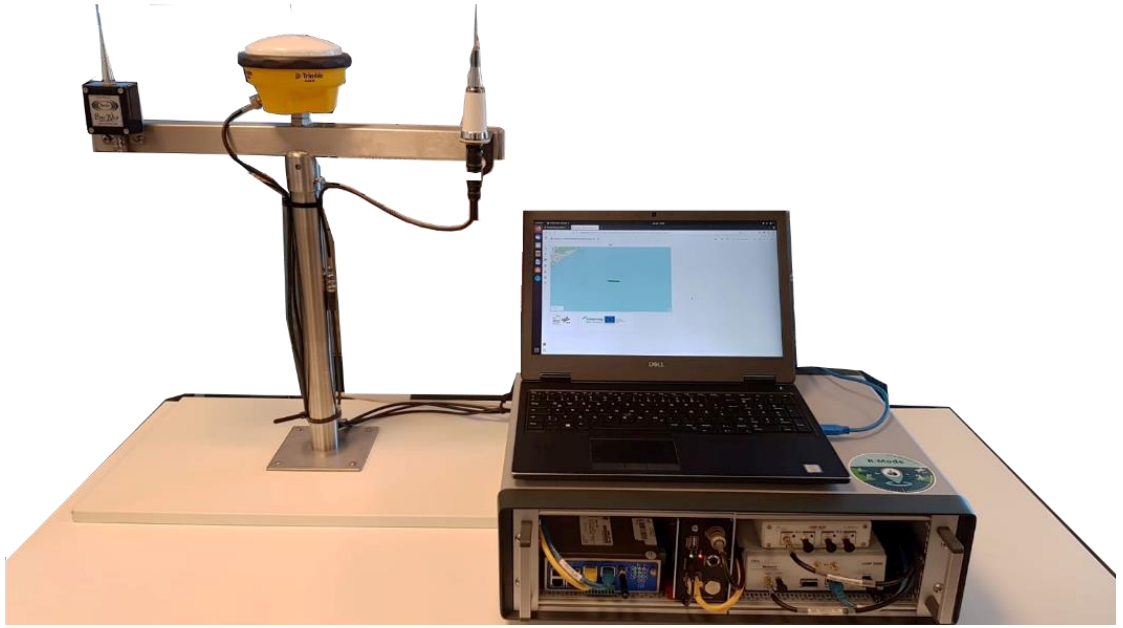
MF R-Mode test bed positioning accuracy prediction (95%)



- Day-time: 10 m accuracy between Helgoland and Gotland
- Night-time:
  - Reduced performance due to sky-wave induced fading and poor geometry
  - Coastal areas are more affected by performance reduction

DLR MF R-Mode receiver

- SDR based prototype
  - All-in-view receiver
  - Enables ranging and position
  - Static and dynamic measurements
  - Calibration in the field



VDES R-Mode

- Replaces AIS base station
- Additional atomic clock needed
- No permanent installation in the R-Mode Baltic test bed

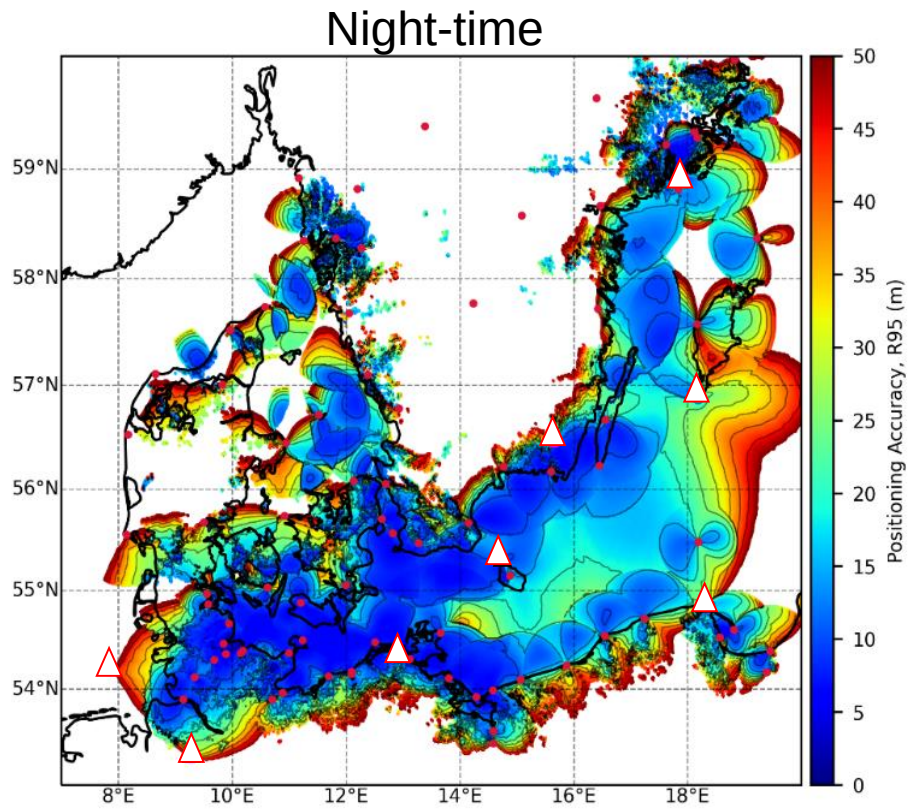
- Receiver
  - SDR based research platforms

Source: Kongsberg Seatex

MF + VDES R-Mode positioning accuracy prediction (95%)

Study conducted by the GLA Research & Development Department for the projects

- Assumption
  - Use all AIS base stations as location for VDES R-Mode transmitters (red dots in the figure)



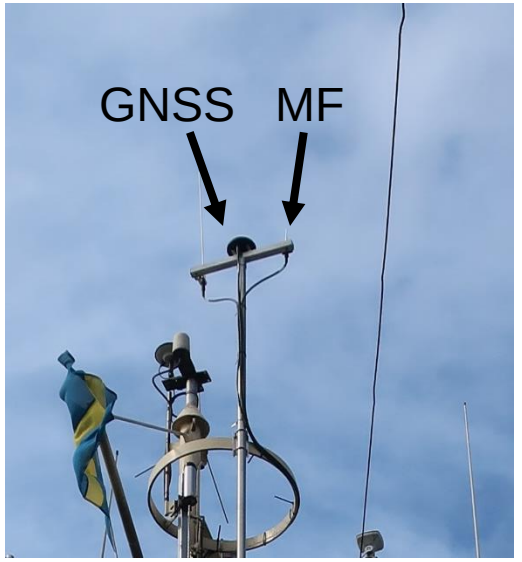
- VDES base stations pure geometry and limited coverage cause difficult conditions
- Combination of MF and VDES R-Mode can cover sensitive coastal areas

MEASUREMENT RESULTS

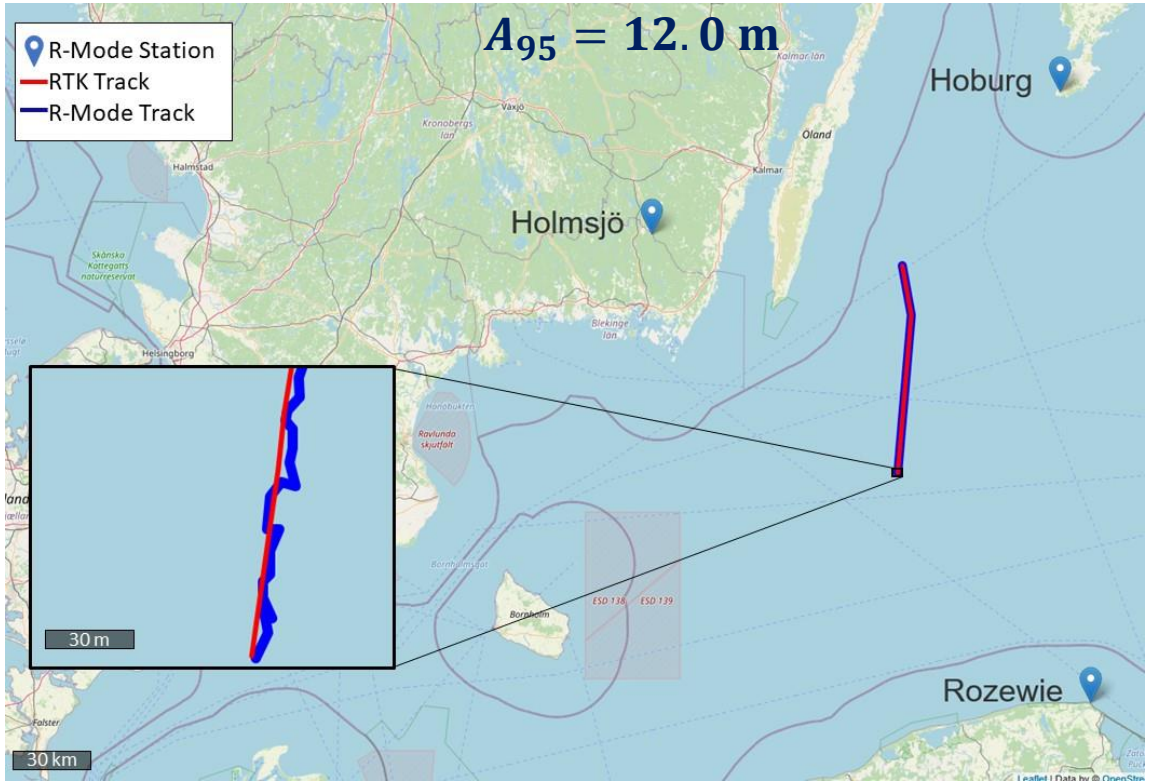
MF R-Mode dynamic measurements

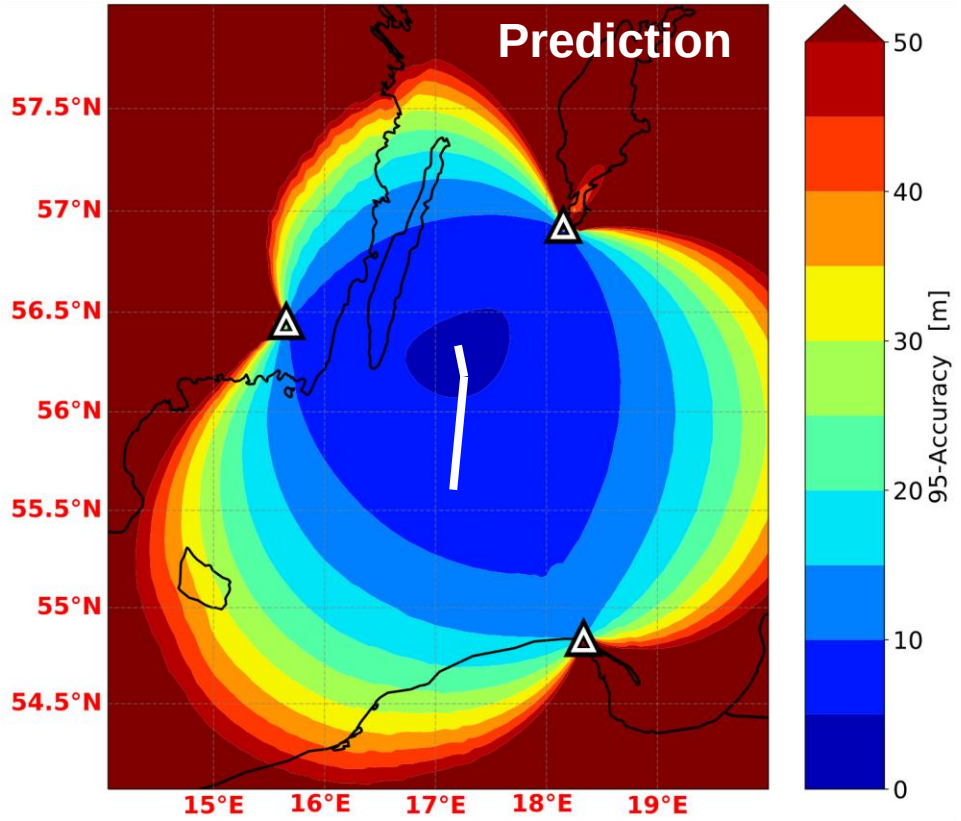
- Sea trials in the Baltic test bed with ships of German and Swedish maritime administration
- All-in-view MF R-Mode receiver of DLR

DLR MF R-Mode receiver



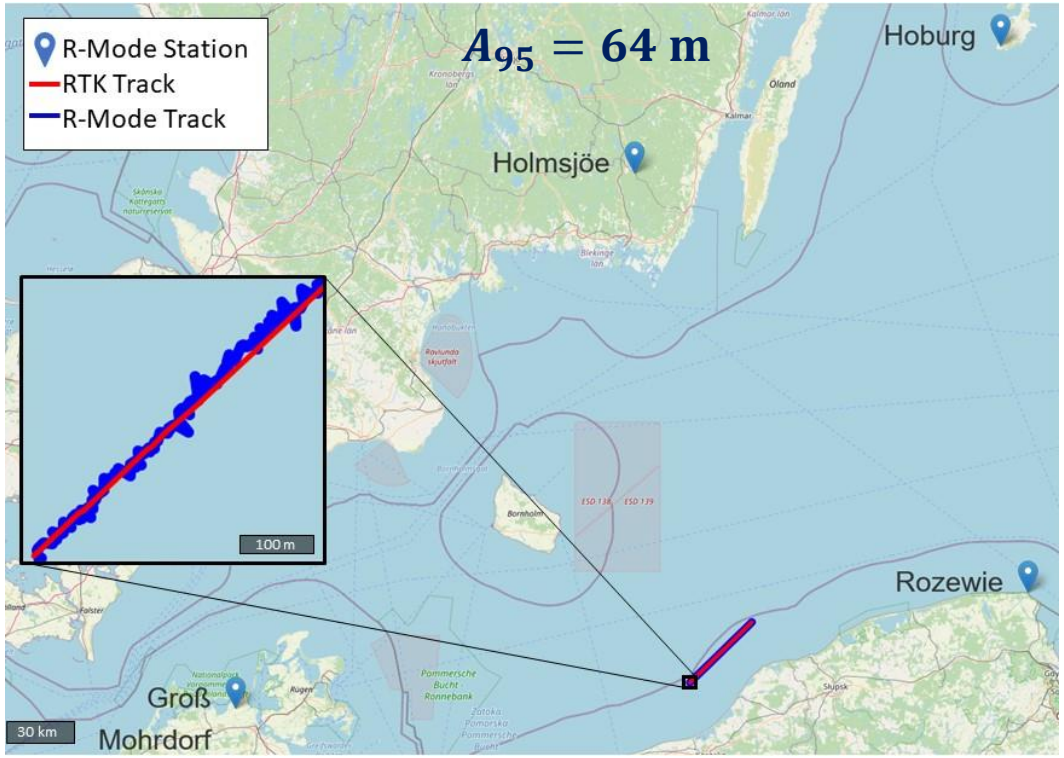
Dynamic day-time positioning performance MF R-Mode

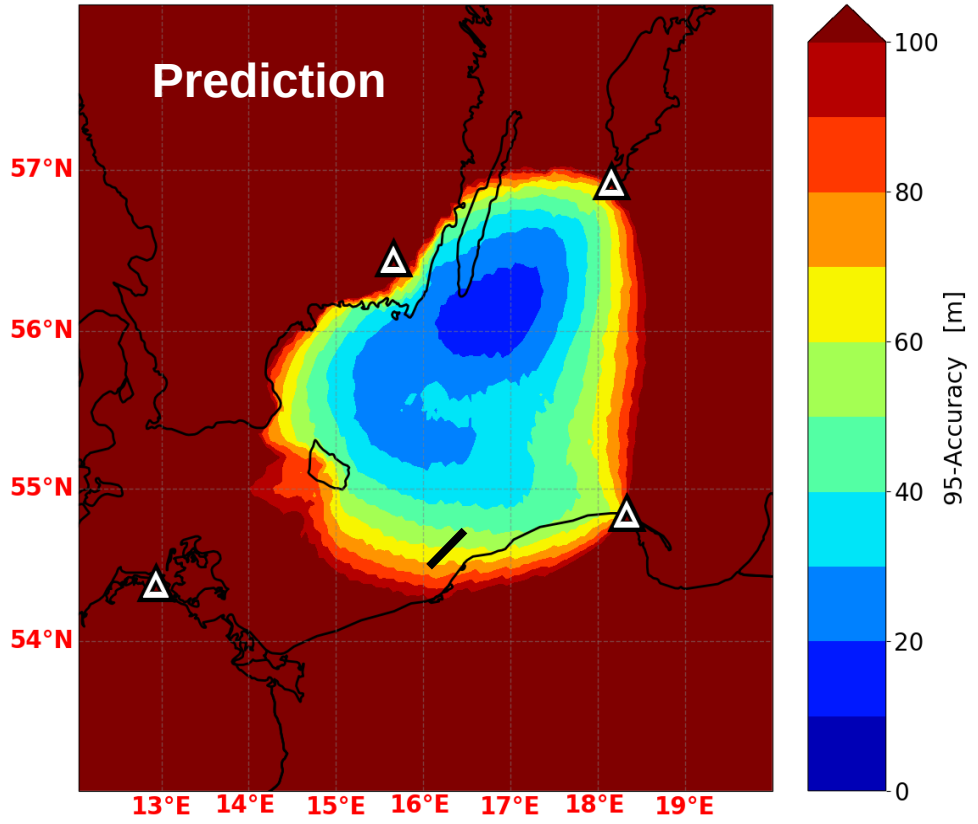




- Good conditions: mostly over sea path, good geometry
- Horizontal positioning error 95% percentile: 12.0 m
- Experiment with slightly lower performance than predicted by theory.

Dynamic night-time positioning performance MF R-Mode

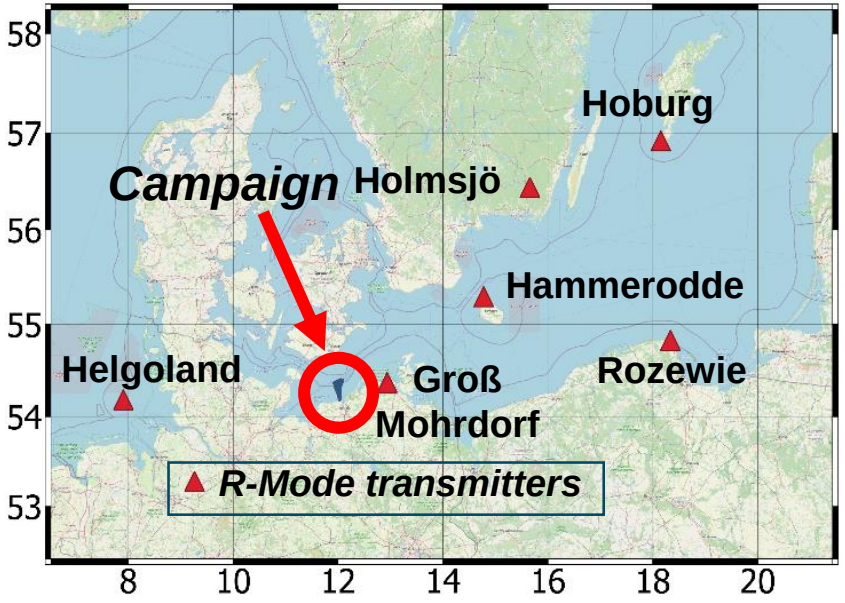




- Conditions: mostly over sea path, not so good geometry, large distance to transmitters
- Horizontal positioning error 95% percentile: 64 m
- Experiment is in agreement with theory.

MF R-Mode campaign in a limited area

Dynamic positioning in the test bed with 6 MF R-Mode transmitters

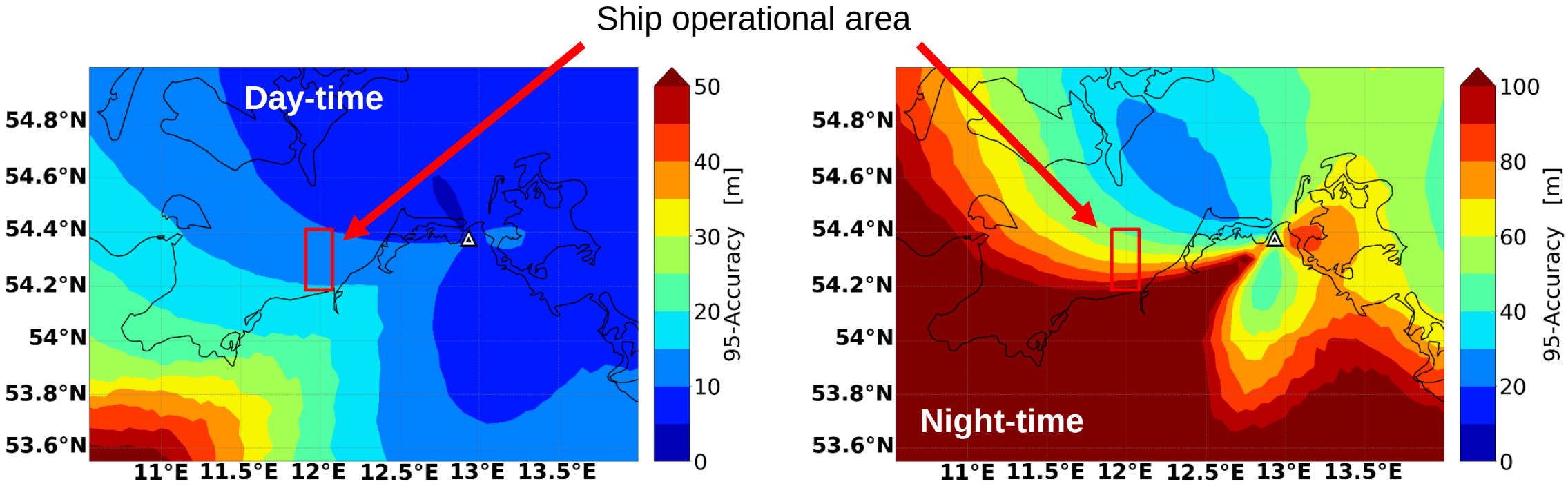


Station	Distance [km]
Hoburg	481
Rozewie	414
Helgoland	266
Hammerodde	207
Holsmjö	328
Groß Mohrdorf	62

- Day-time: Undisturbed conditions - R-Mode signals usable outside DGNSS service area
- Local interferences and instabilities of the transmitters restricted the scope of the usable data

MF R-Mode campaign in a limited area

Positioning performance assessment dynamic conditions

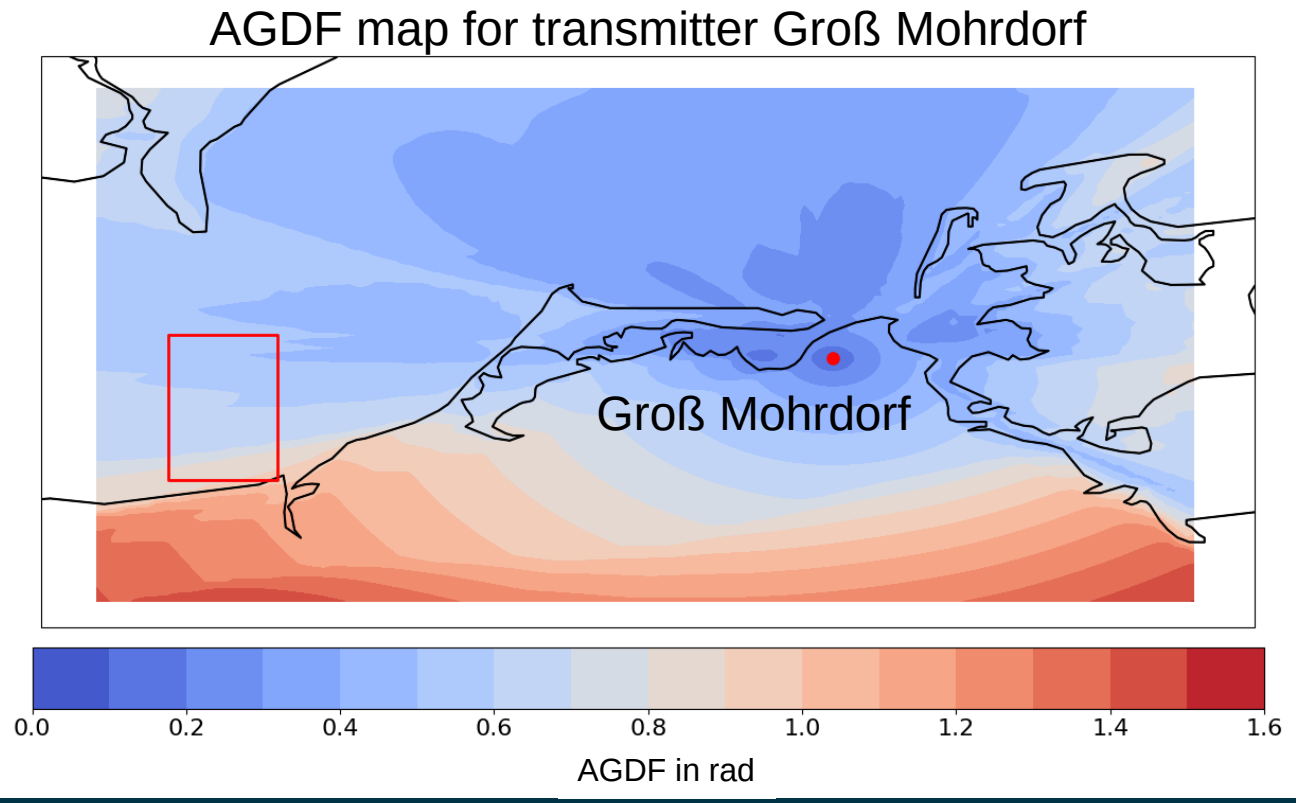


- Day-time 95% percentile: 16 m (6 h)
- Night-time 95% percentile: 51 m (3 h)
- Theoretical bounds are comparable with measured performance
- Satisfies user performance requirements for coastal waters backup system

Atmospheric and Ground Delay Factor (AGDF)

Compensation of electrical properties of the ground

- AGDF – modelled delay based on an integral method for the calculation and ground conductivity maps of ITU-R
- AGDF extension on the impact of terrain possible

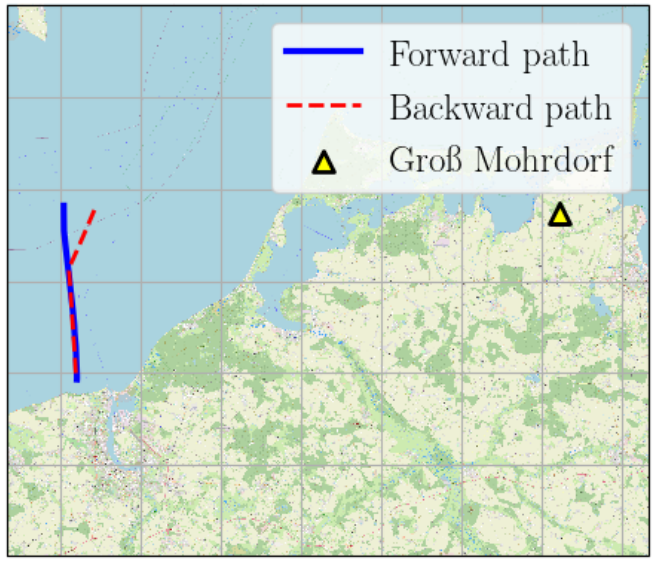


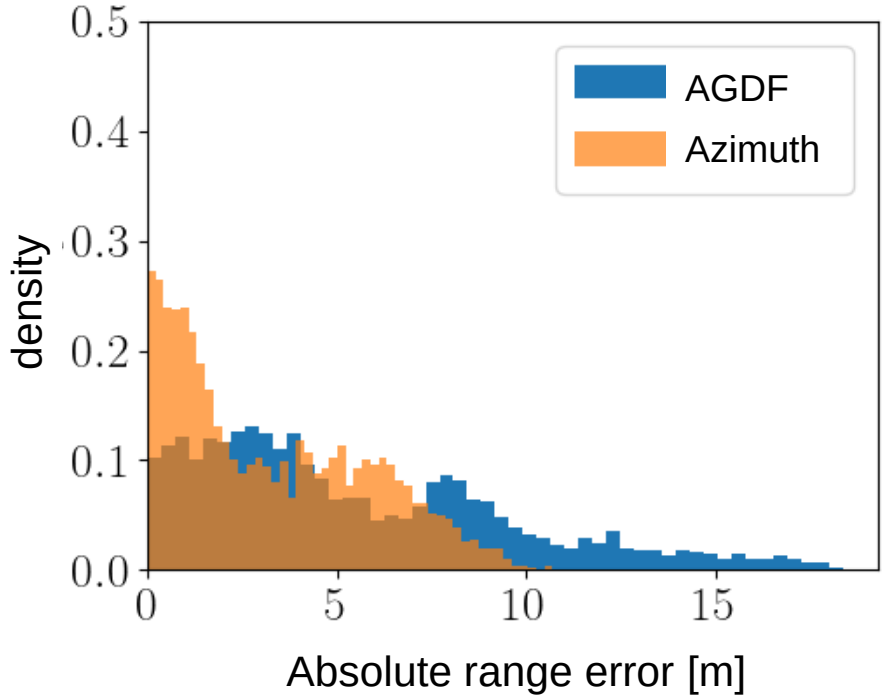
- Measurements showed AGDF can help to improve R-Mode performance
- But remaining systematic errors when ships operate next to land

Azimuth dependent correction function of AGDF maps

Approach

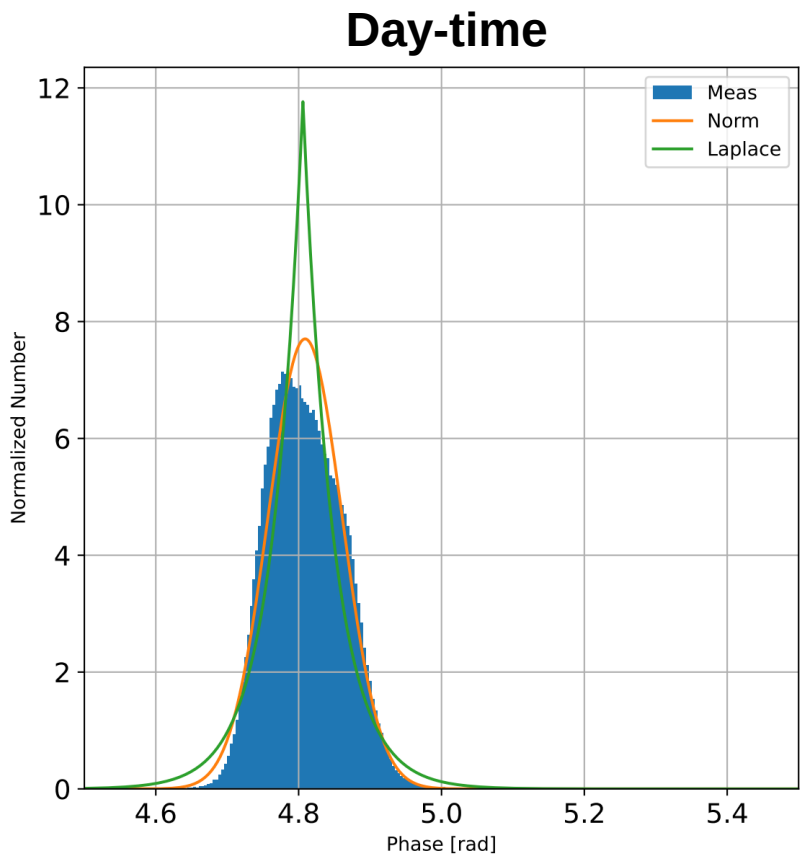
- Measure azimuth dependent correction function with help of known position (RTK/GNSS)
- Apply correction function and AGDF on later measurements in that area

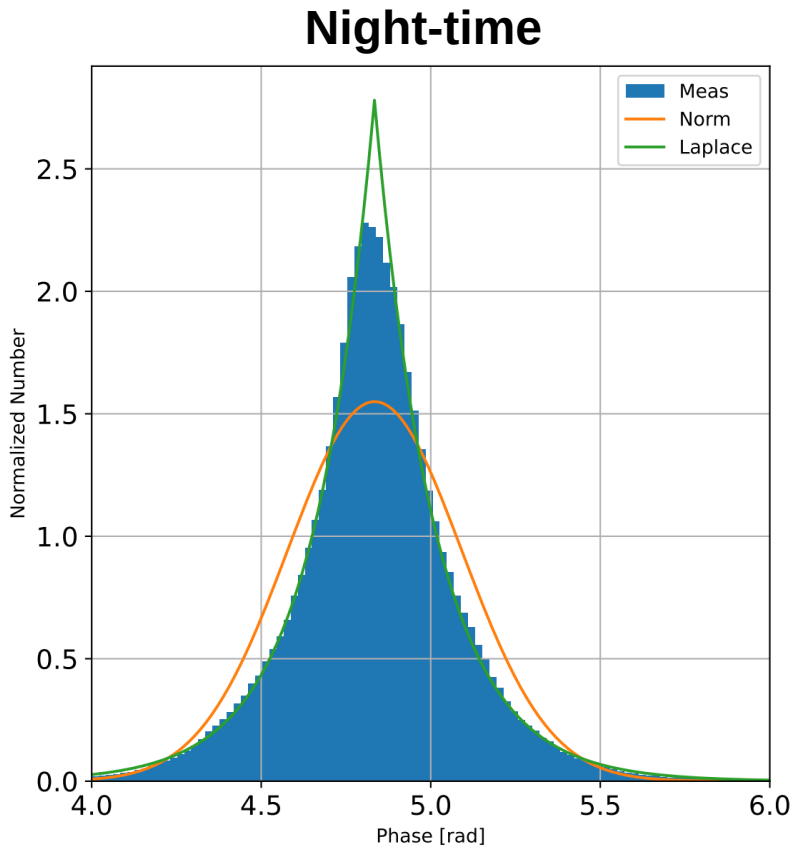




- Reduction of ranging error (95%) from 13.9 m to 8.3 m
- Strong reduction of distribution tail
- Service provider could perform such measurements for each transmitter to correct AGDF maps

Static long-term MF R-Mode ranging

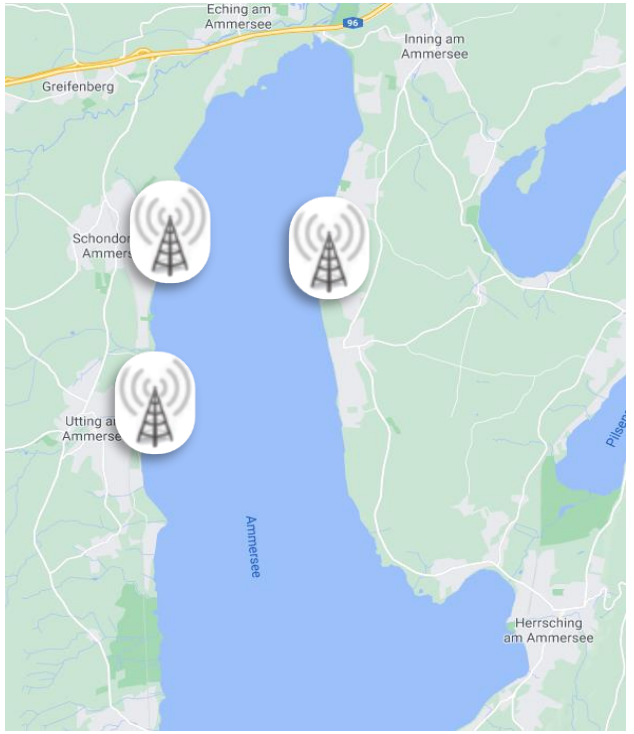




- Day-time: measurements follow Normal distribution
- Night-time: measurements follow Laplace distribution
- Consideration in future estimation of R-Mode performance and weighting of measurements in the positioning algorithm

VDES R-Mode performance

- Experiments in bay of Gdansk (Poland) and on lake Ammer (Germany)
- Ranging performances with 25 W EIRP
  - ~ 10 m error in favorable conditions and port approaches (Line of sight (LOS) in the bay of Gdansk)
  - < 100 m error in less favorable conditions (Mixed Path)
- Small scale positioning experiment with 1 W EIRP in up to 3.5 km distance
  - Position tracking using a Kalman Filter and doppler measurements
  - 10 m positioning performance achievable



SUMMARY AND CONCLUSIONS

Summary and conclusions

- With R-Mode Baltic a first MF R-Mode large scale test bed exists.
- Radio beacons of four administrations were successfully upgrade to support R-Mode broadcast.
- MF R-Mode system accuracies was determined with a value between 10 m and 100 m.
- This enables R-Mode to support coastal navigation as maritime backup for GNSS.

- Implementation of R-Mode system core operational functionalities is planned for 2023 to 2026.

Thank you for your attention.

Questions?

Imprint

Topic:	**R-Mode – Terrestrial Navigation for Maritime Users**
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