JAMMING AND SPOOFING DETECTION ON OBSERVATION LEVEL

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DLR

LEAS

Landseitige Entscheidungsempfehlungen für Verkehrslagen mit hochautomatisierten / autonomen Schiffen

DLR

GEFÖRDERT VOM
Bundesministerium für Bildung Forschung

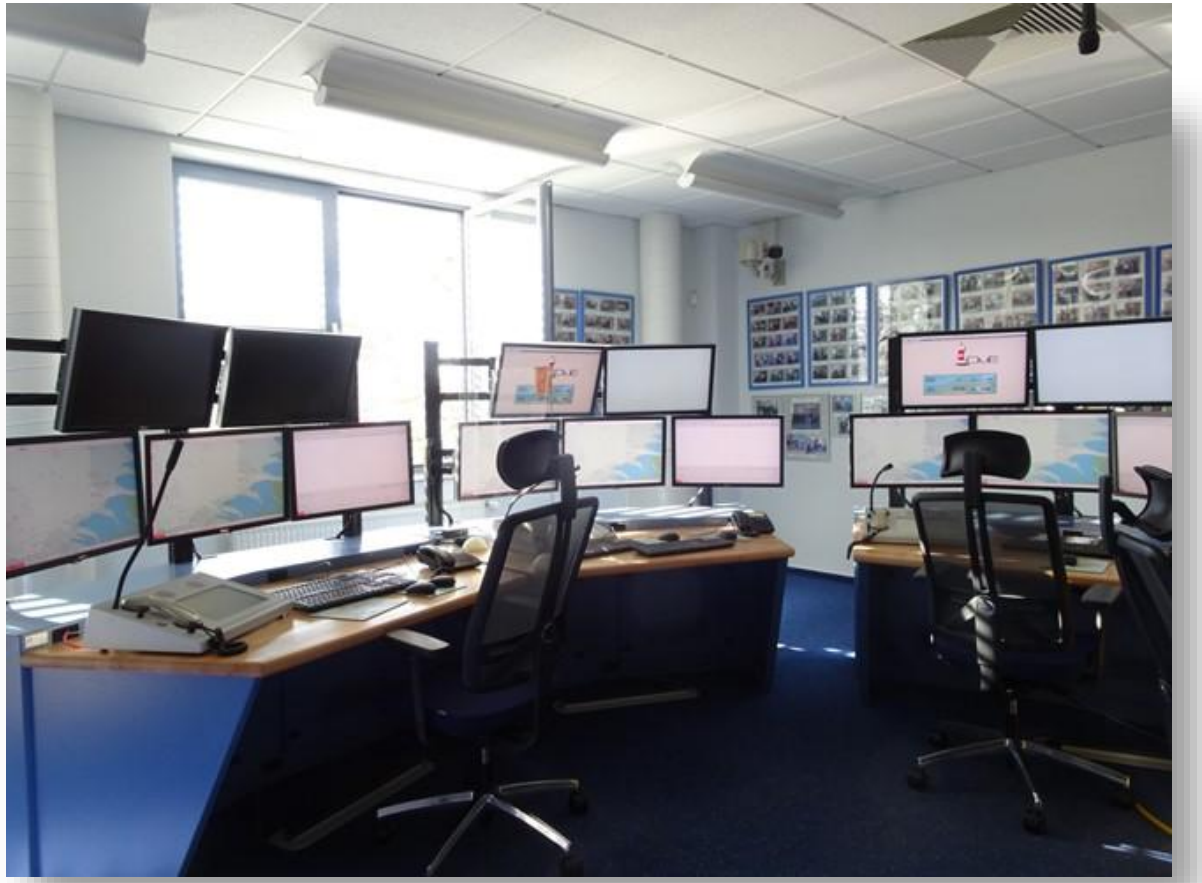
AI-BASED DECISION SUPPORT FOR VESSEL TRAFFIC SERVICES

- Decision support for selection of PNT data
- Movement prediction
- Anomaly detection
- Risk escalation

DURATION: 2022 – 2025

CONSORTIUM

- Fraunhofer (FKIE, CML)
- DLR (KN, MI)
- HS Wismar: Department of Maritime Studies
- JDS
- Bergmann Marine



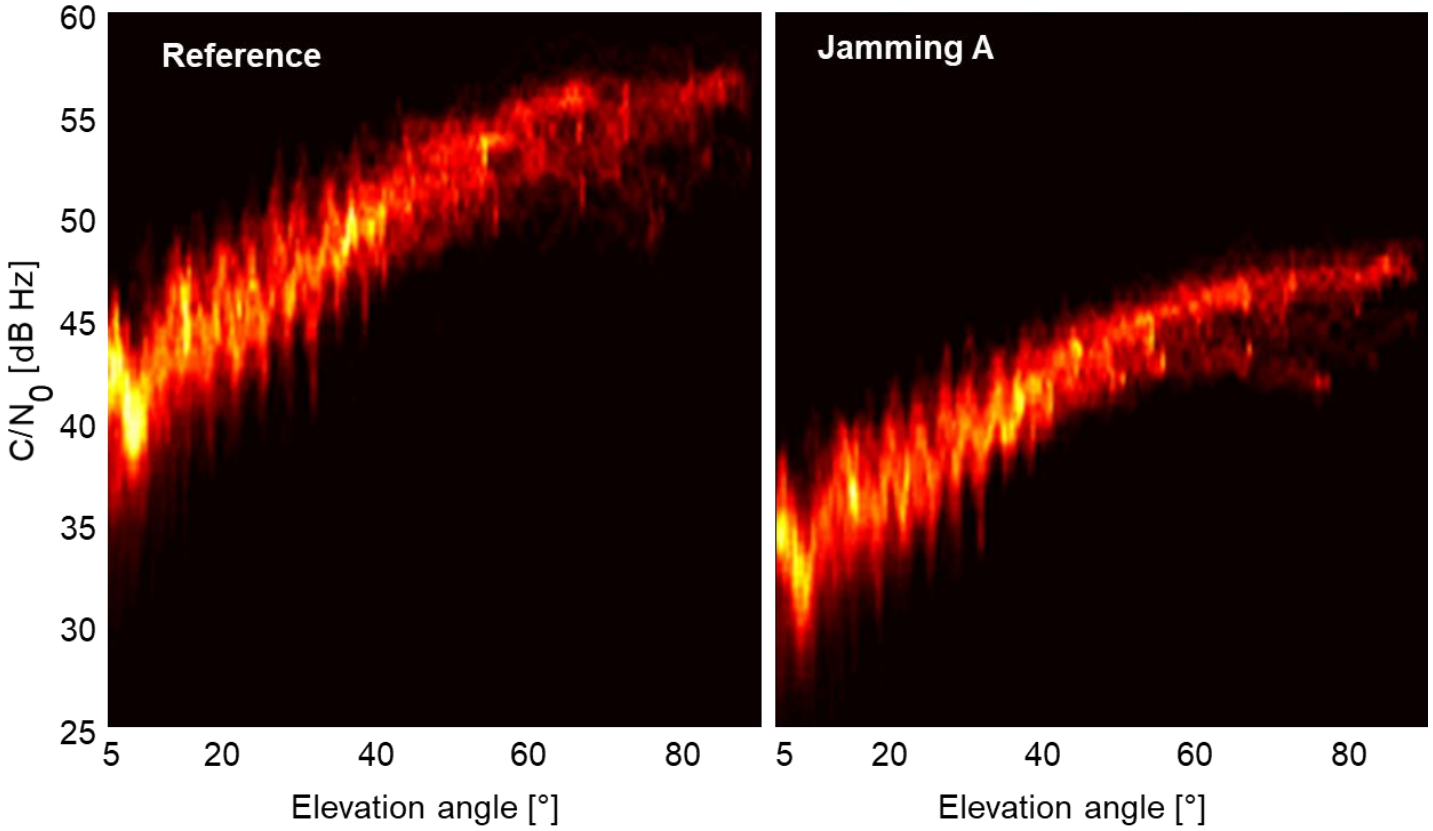
GNSS AI module

GOAL

- Learn nominal relation between data features to be able to detect
  - Decrease of GNSS accuracy
  - Abnormal behaviors in the GNSS data, i.e. Jamming and Spoofing

HOW

- Observations
- Different detectors for each type of threat / interference



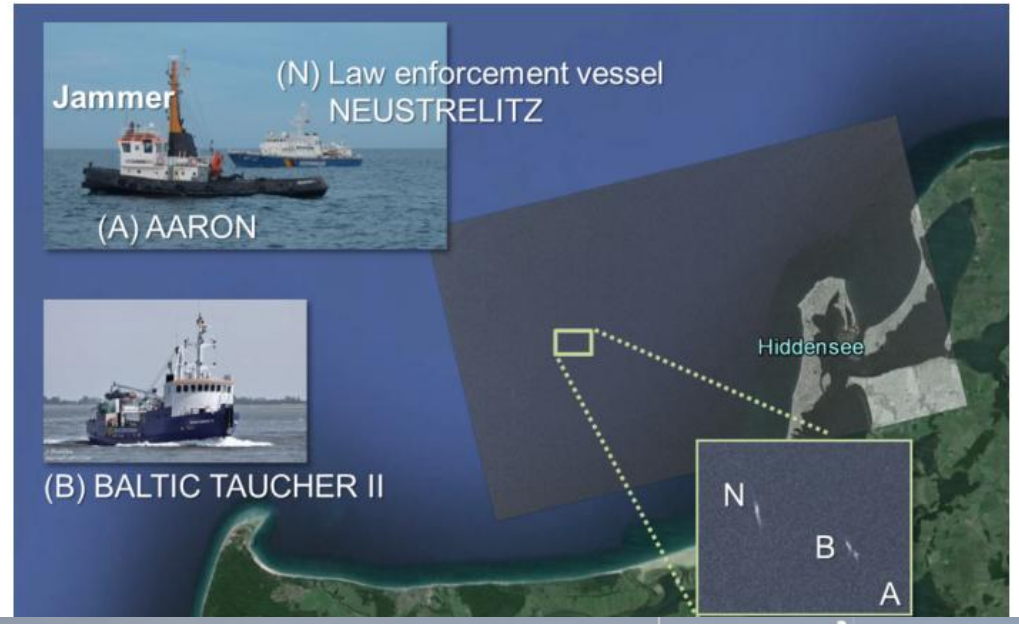
Jamming detector: Input data

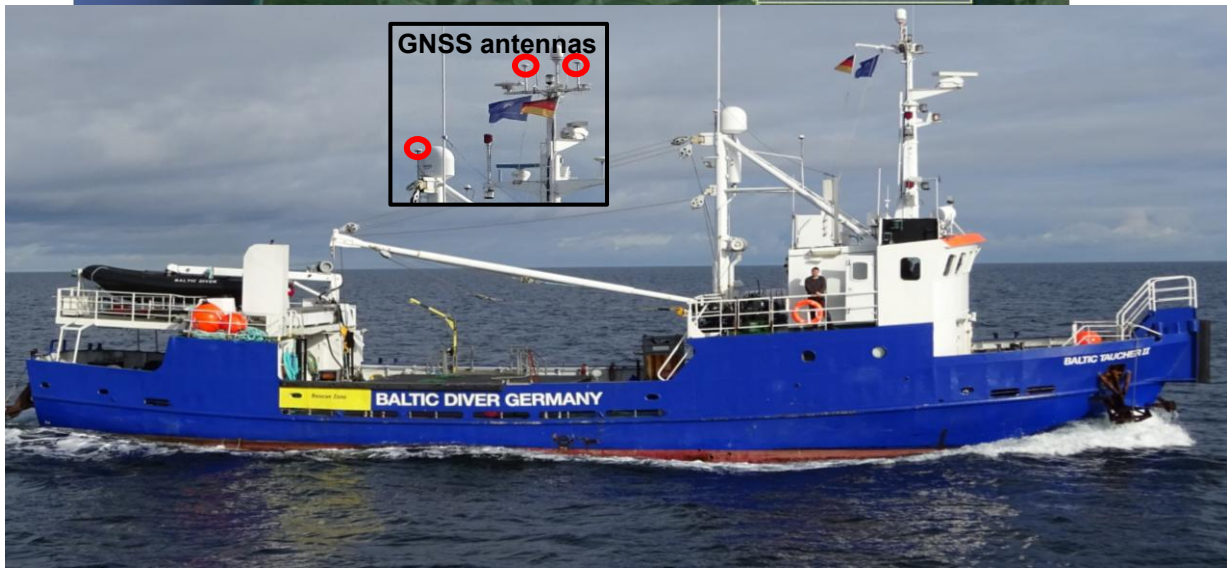
WHAT

- Continuous GNSS raw data: Code, phase, doppler
- Meta data: C/N0, elevation, azimuth, constellation

REAL DATA

- **Static**: Lab experiment → Roof antenna at DLR site in Neustrelitz
- **Dynamic**: Measurement campaigns → Jamming test area in the Baltic with Baltic Taucher II

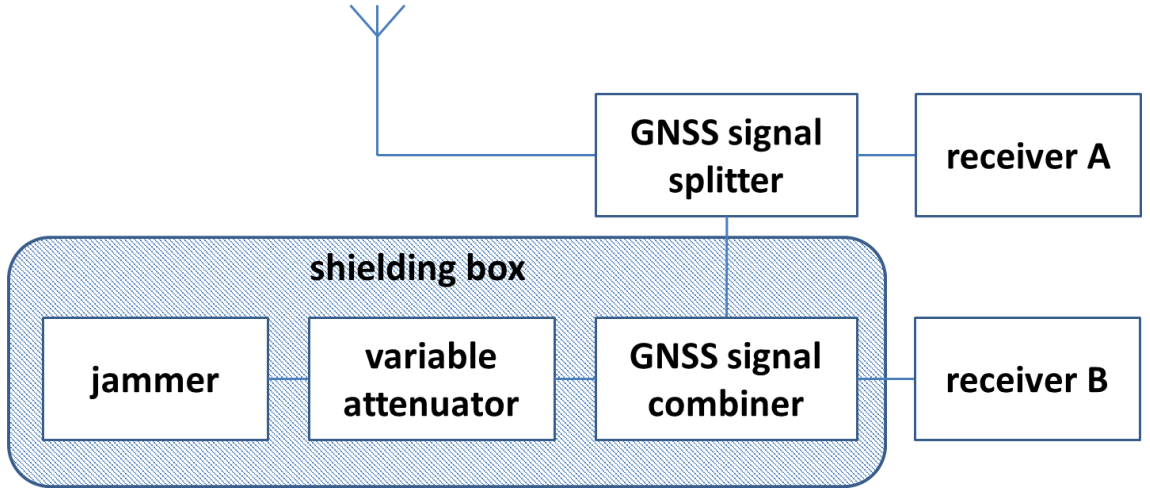


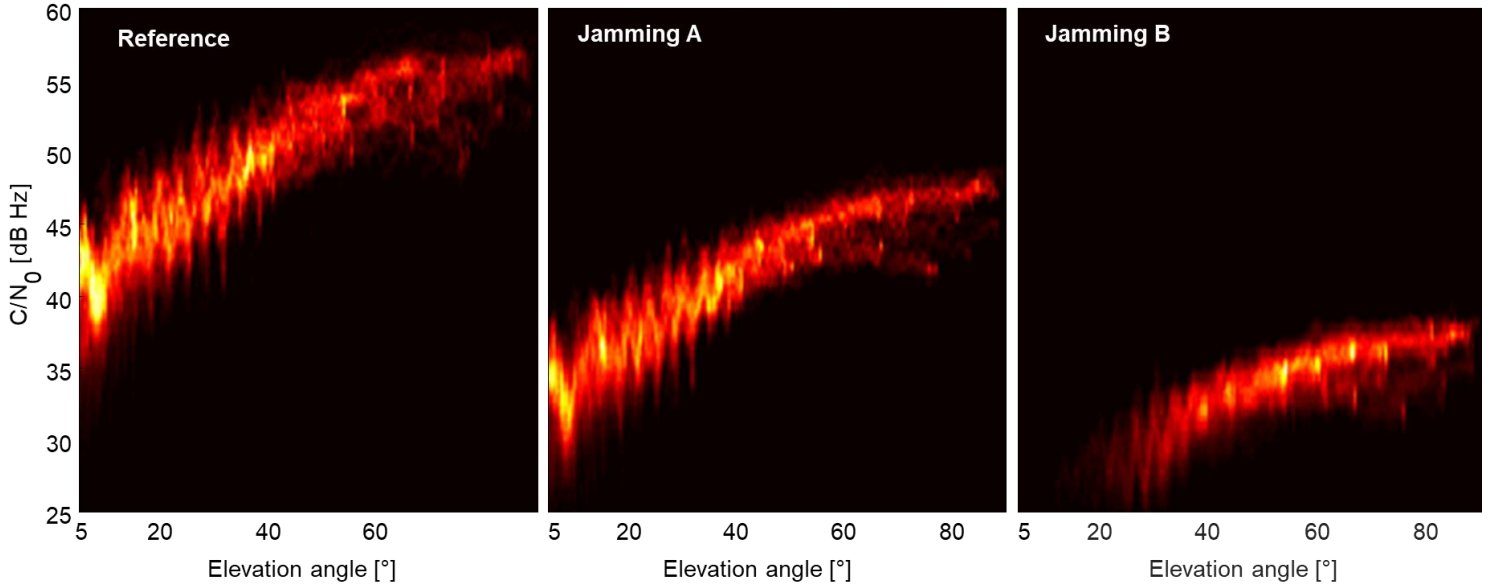


Jamming detector: Static scenario

STATIC SCENARIO

- GNSS signals from one antenna is split into two Javad Delta receivers → Reference is not jammed and the second receiver is always jammed
- Multiple 48 h measurement campaigns with different jamming settings
- Datasets from 2018 → Not many Galileo satellites, but a lot of data for GPS





Jamming detector: Classifiers

- **Objective:** Learn nominal state in order to detect any abnormal behavior

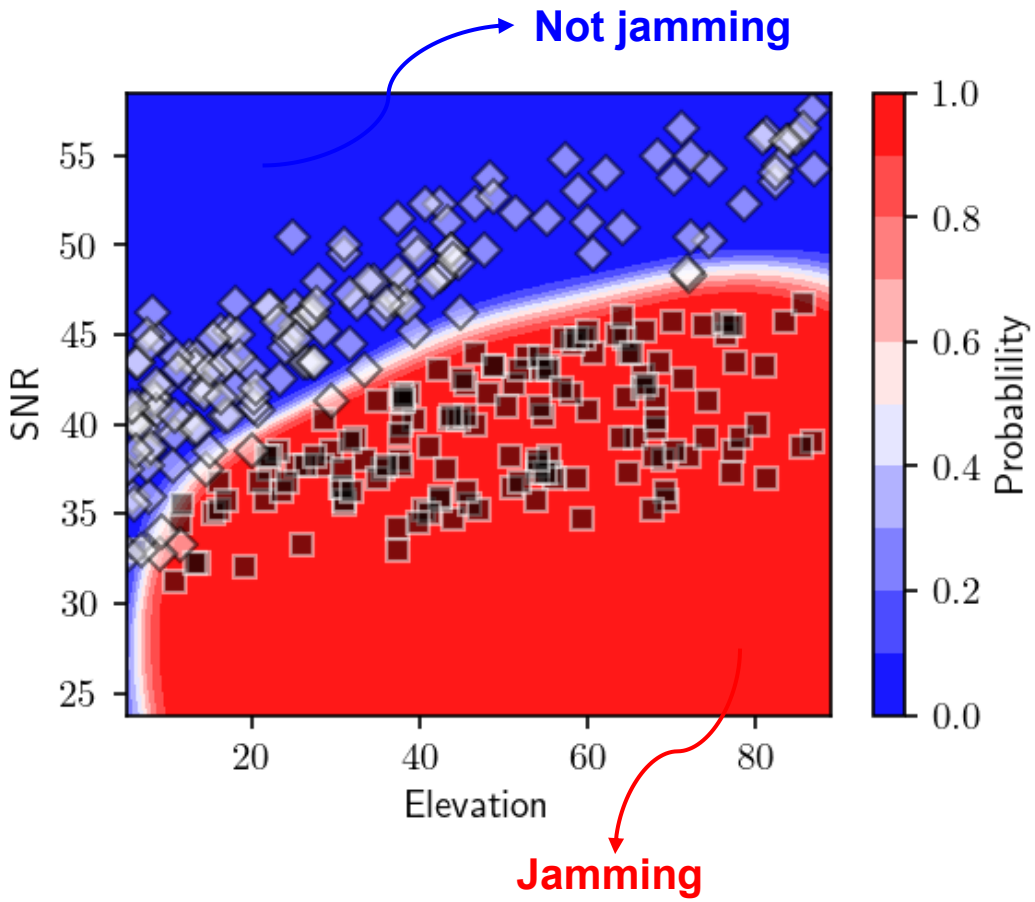
- **Tested classifiers:**
  - Support Vector Machine (static data)
  - Random Forest (dynamic data)
  - XGBoost (dynamic data)

- **Performance evaluation:**
  - Classification accuracy and F1 score
  - Confusion matrix

- **Explainability**
  - Feature importance (where applicable)

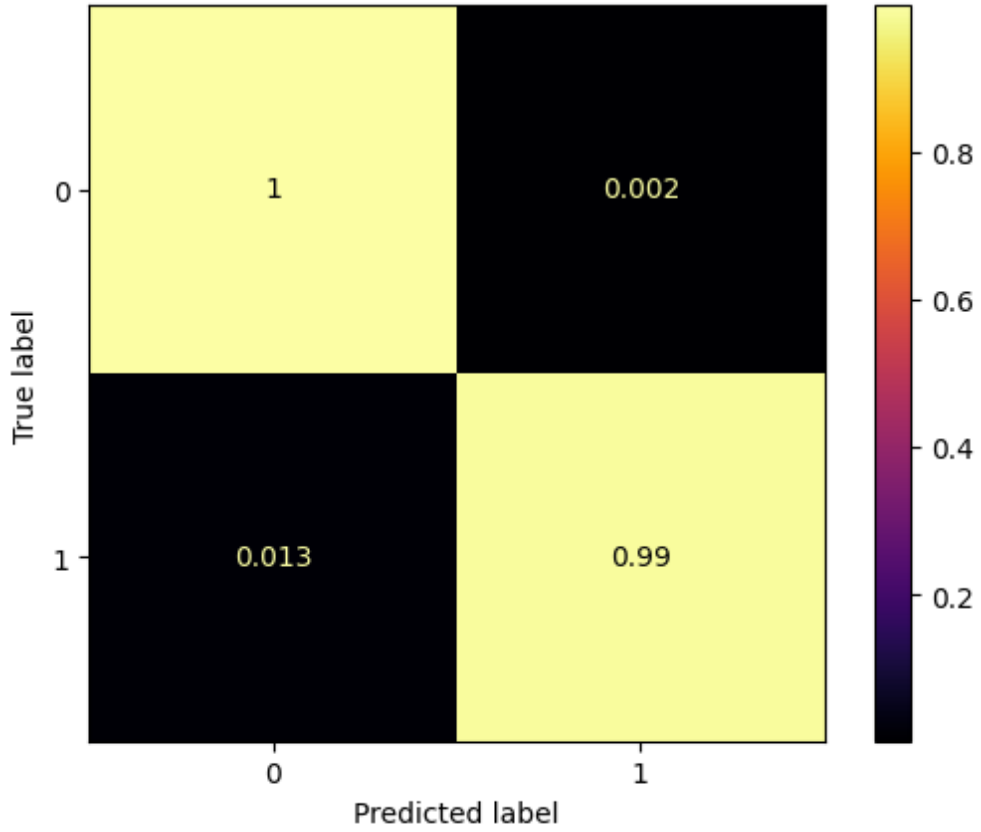
Jamming detector: Results for static scenario

Support Vector Machine

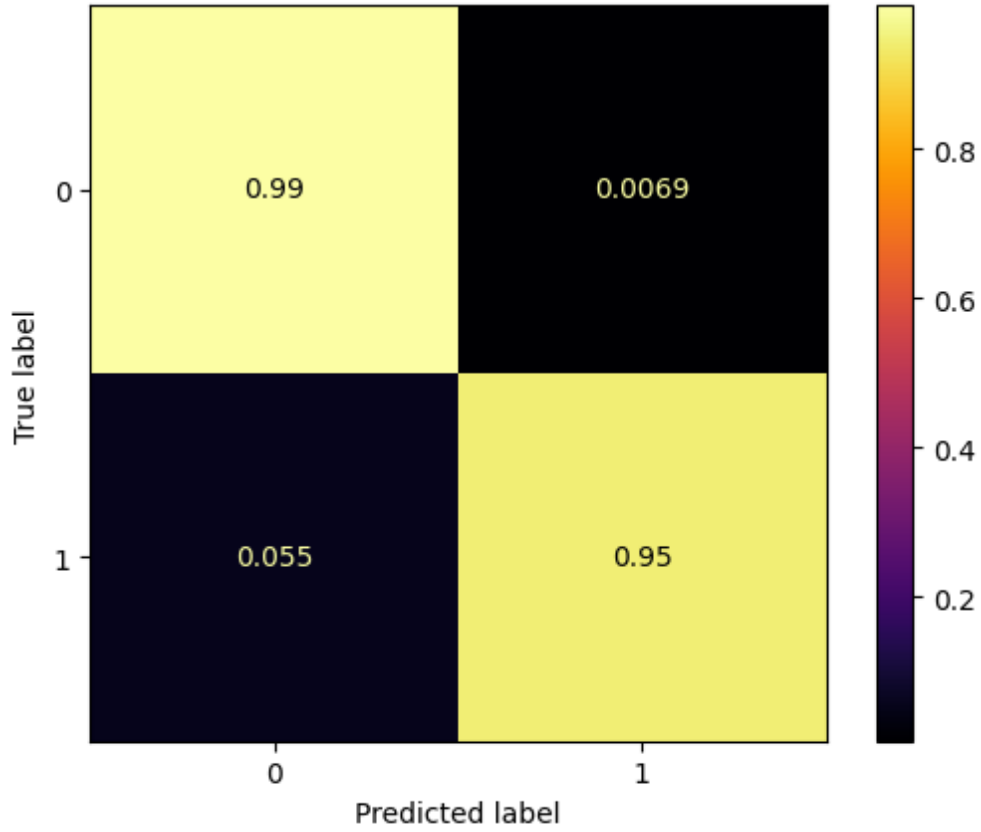


Jamming detector: Results for dynamic scenarios

Random Forest Classifier



XGBoost Classifier



0: Not jamming 1: Jamming

ESA Resilient GNSS Challenge 2024

WHAT

- Open-air GNSS/PNT resilience campaign in Norway on island Andøya over several days in September 2024
- Live jamming, meaconing, and spoofing trials against real receivers and systems

HOW

- Open, international competition
- Winner was announced at navitec 2024 conference at ESA ESTEC in Noordwijk, NL

INPUT

- GNSS observations as RINEX files

AIM

- Promote international collaboration
- Share best practices
- Develop common solutions mitigating the impact of emerging GNSS threats

Photos: David Jensen

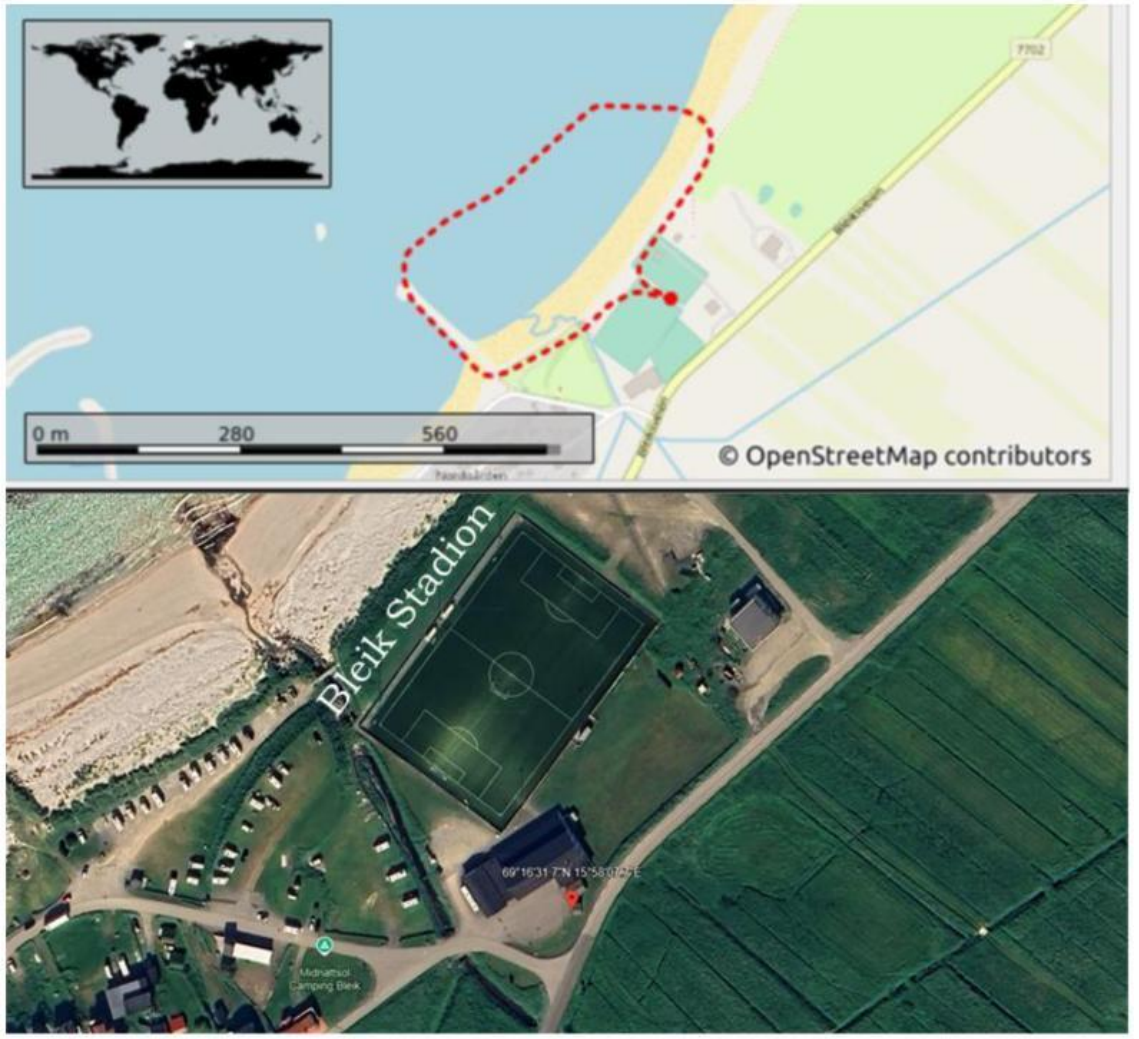
Scenario 1 – Spoofing in static scenario

WHAT

- Static receiver position
- Coherent spoofing emulates drone trajectory (red dashed line)

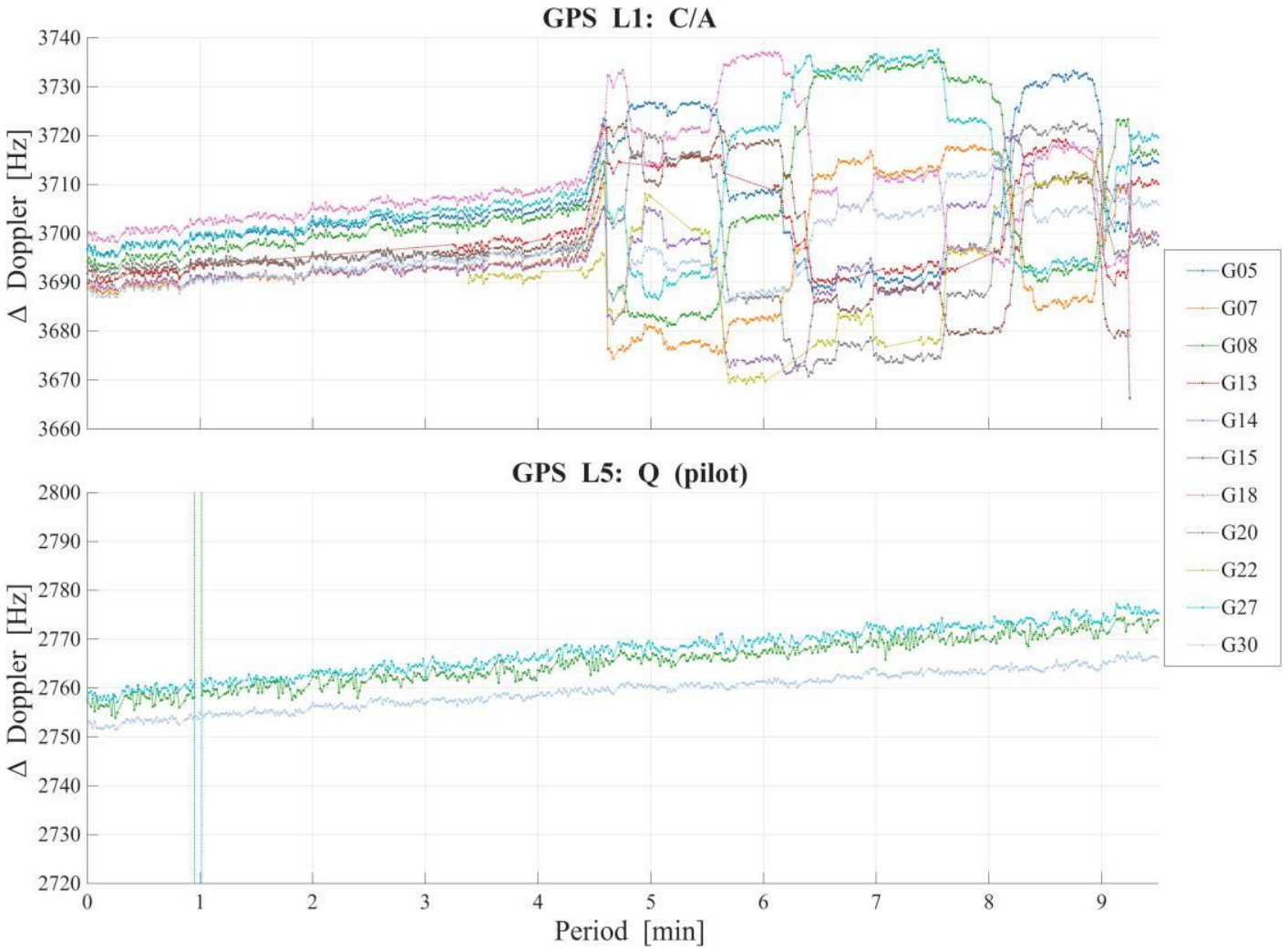
GOAL

- Determine true receiver position



Analysis

- Inconsistencies in Doppler differences (rover – nearby base station) wrt. different frequencies
- Code and phase measurements of all bands affected due to receiver clock relying on L1
- Doppler of non-L1 bands not affected

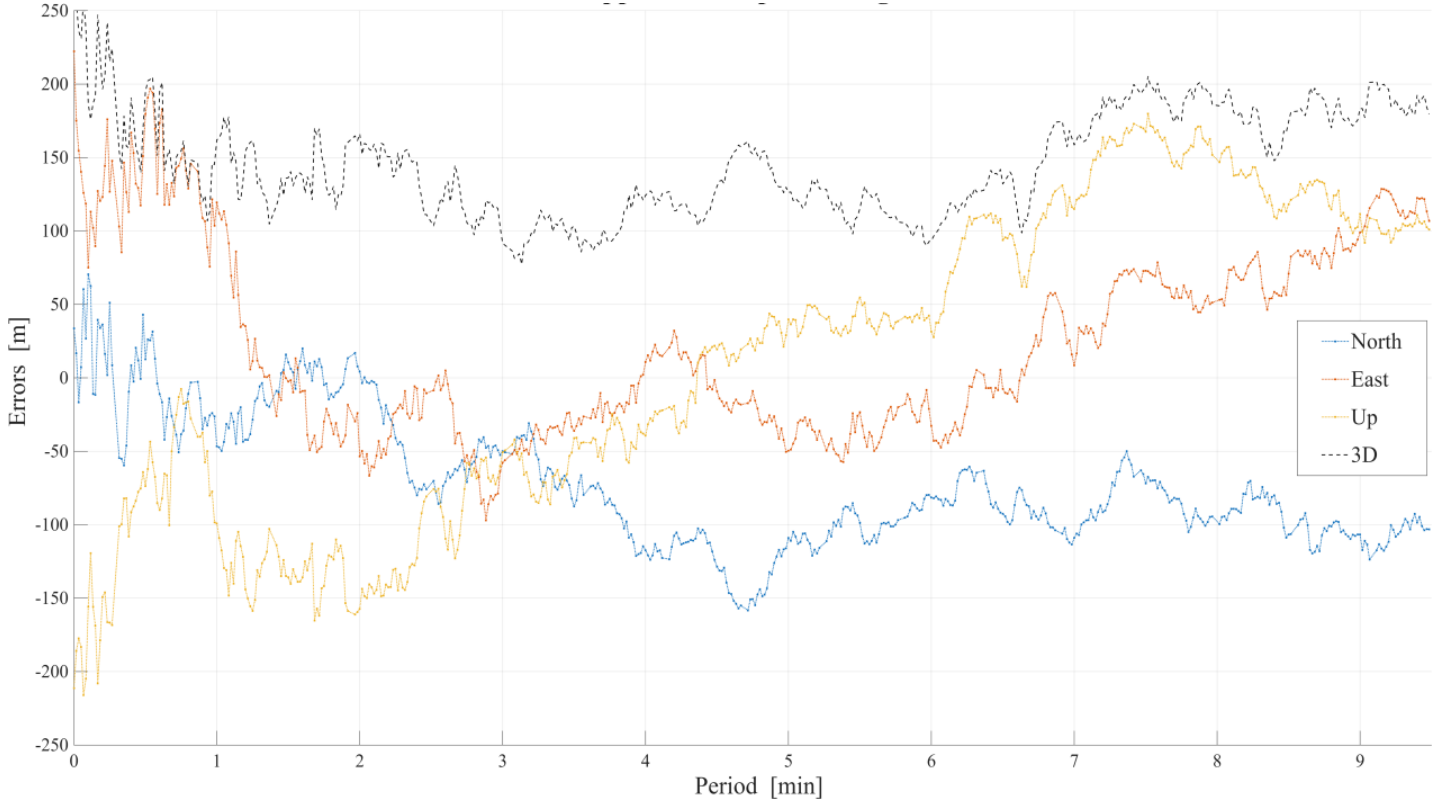


Doppler-based kinematic positioning

- Based on publication by Psiaki (2021) using Kalman Filter

- Measured Doppler shift using accumulated Doppler range

$$D^s = -\frac{1}{\lambda^s}\frac{d\Delta\rho^s_{ADR}}{dt_R}$$

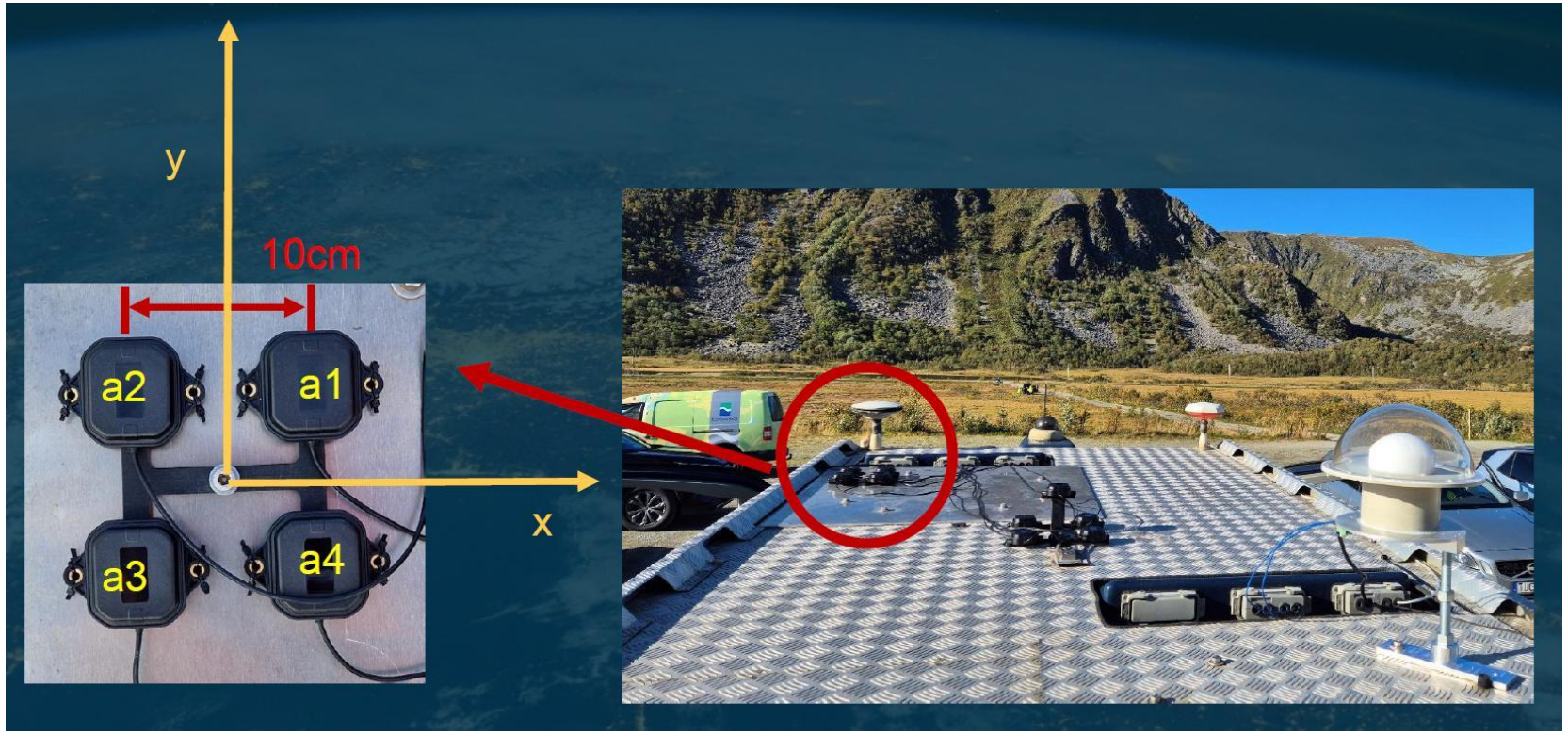


Psiaki, M. L. (2021) Navigation using carrier Doppler shift from a LEO constellation: Transit on steroids. *NAVIGATION*, 68(3):621–641.

Scenario 2A – Spoofer azimuth estimation

WHAT

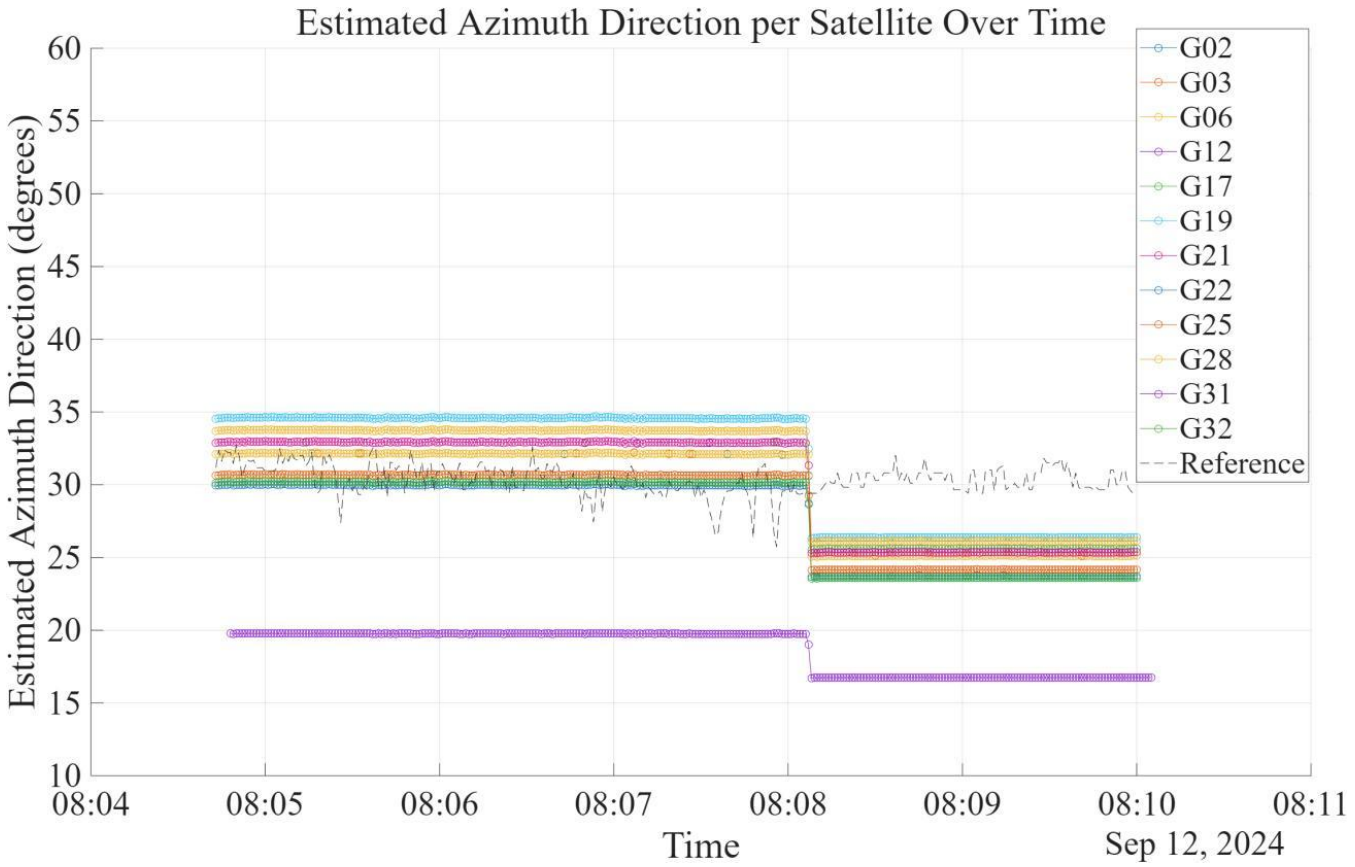
- 2x2 patch antenna array tracking GPS L1 C/A
- 4 sets of observations



GOAL

- Determine spoofer angle-of-arrival

Solution



- Use antenna-differenced phase carrier observations:

$$\Delta\Phi_{ab}^{s} = \Phi_{a}^{s} - \Phi_{b}^{s} = \frac{2\pi}{\lambda^{s}} \mathrm{b}_{ab}^{\mathsf{T}} \boldsymbol{u^{s}} + B_{ab}^{s} + \varepsilon_{ab}^{s}$$

- Baseline b^{T} between antennas is known
- Unknown $\boldsymbol{u^{s}}$ is normalised direction vector (2D) from spoofer to antenna, B_{ab}^{s} are biases and single-differenced ambiguities
- Solution was improved by weighted (C/N_0) average over all satellites

Result of competition

- DLR team from Neustrelitz won ESA challenge
- 13 international teams (e.g. TU Delft, ESA, Correlation Semiconductor, DLR, …)
- Paper about this in ION GNSS+ 2025: ***„Results and Lessons Learned from the NAVITEC 2024 Resilient GNSS Challenge“*** together with 2nd and 3rd best team

THANKS FOR THE ATTENTION!

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Impressum

Topic:	Jamming and Spoofing detection on observation level
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Author:	Christoph Lass
Institute:	KN
Pic credits:	DLR, ESA, TU Delft, Correlation Semiconductor

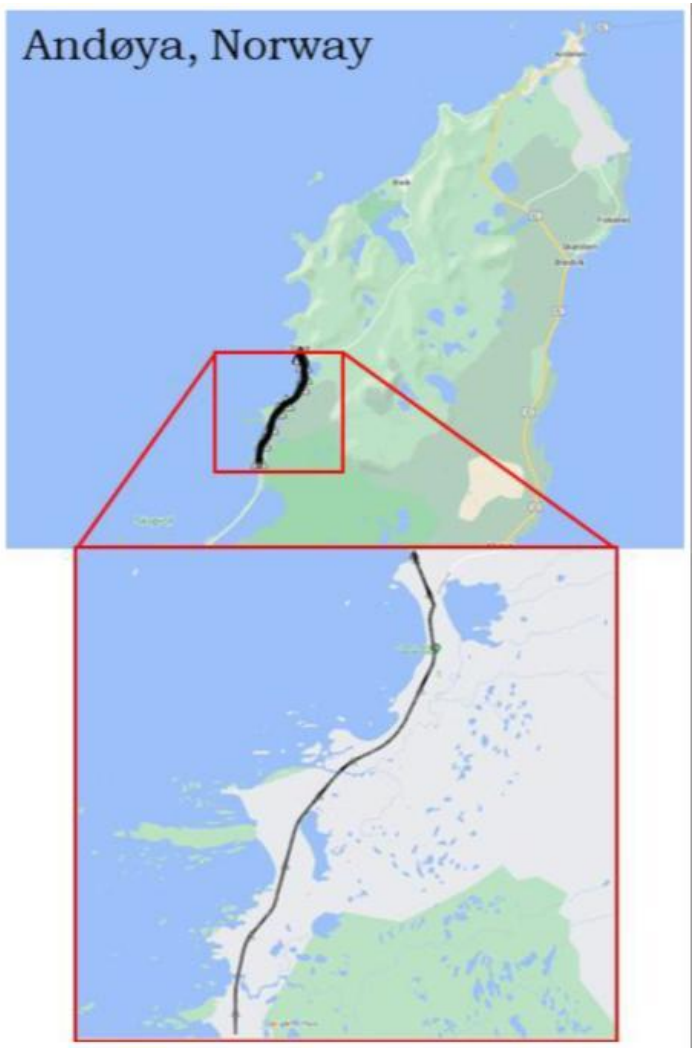
Scenario 2B – Dynamic user spoofing

WHAT

- User is in car, static to moving
- Speed: ~40 km/h
- Spoofing of L1 to static position

GOAL

- Determine true user position

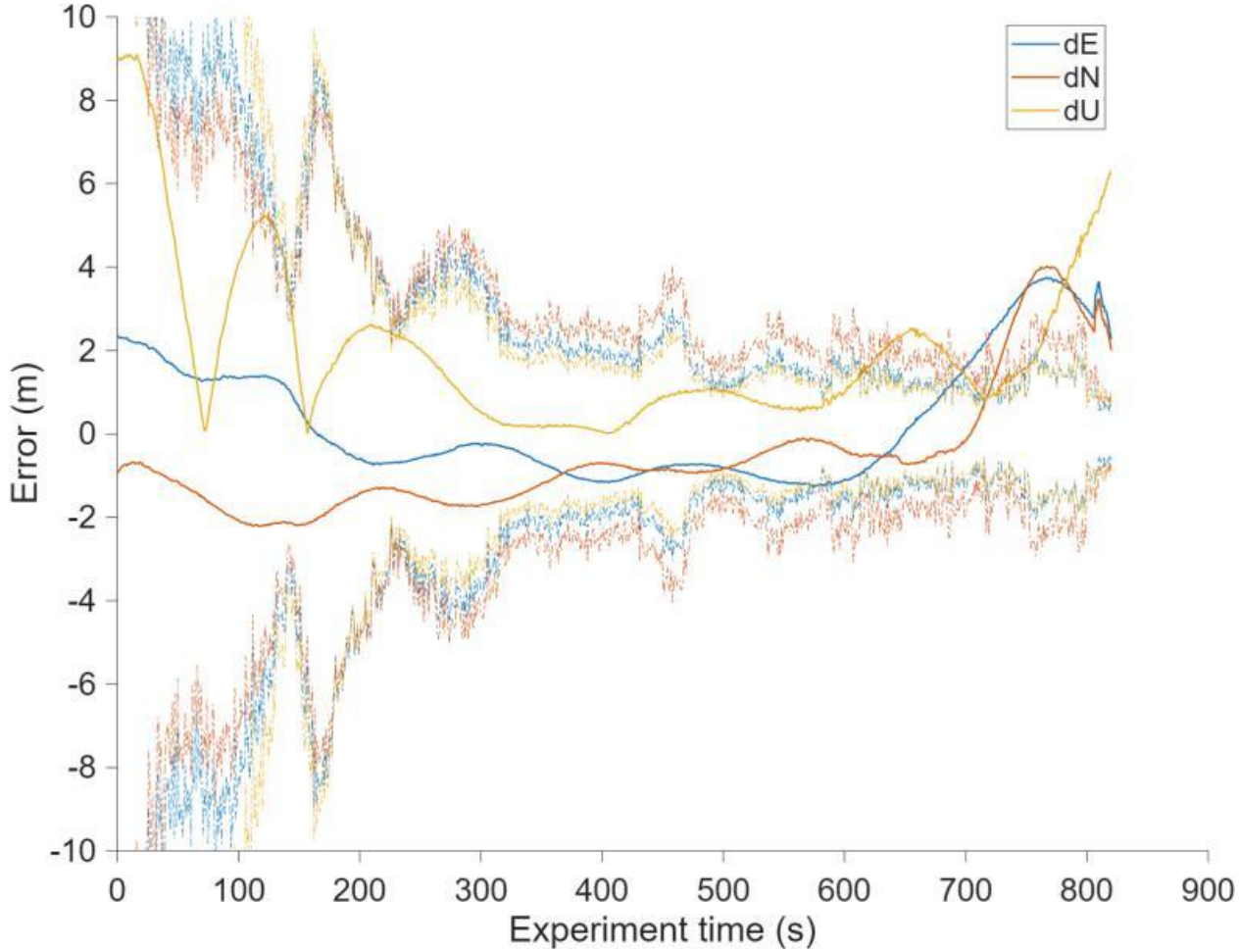


Solution

HOW

- Galileo E5Q, E7Q and E6C signals authentic

- PPP or RTK using nearby base station AND100NOR (~17.5 km distance) with float ambiguities



PPP solution with 3σ curves