# Modelling the Noise of GNSS Signals under Jamming Conditions

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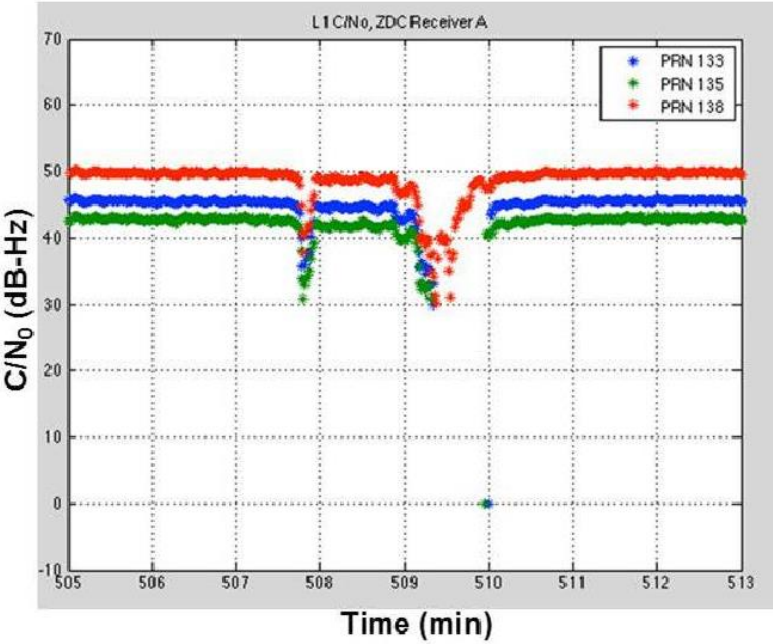
# 1. Motivation

- Positioning, Navigation and Timing information mainly derived from GNSS
- GNSS signals can easily be disturbed by Personal Privacy Devices (PPD)
- PPD of vehicle affecting WRS at Leesburg, Virginia, USA on 9th of April 2011[1]




[1] S. Pullen, G. Gao, et al., “The Impact of Uninformed RF Interference on GBAS and Potential Mitigations”, Proceedings of the 2012 International Technical Meeting of The Institute of Navigation

# Motivation II

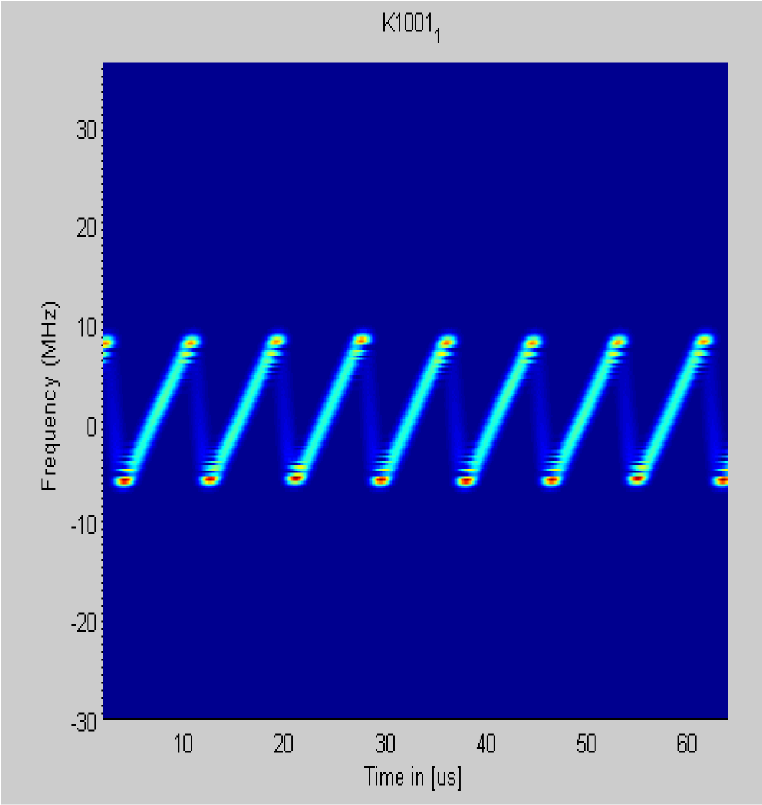
- Measurement campaign in the Baltic Sea using allocated civilian maritime GNSS jamming testbed[2]
- Using GNSS + onboard sensors in Kalman filter
- How to estimate "quality" of GNSS observations?
- Estimating noise of signals without position reference

[2] R. Ziebold, D. Medina, et al. "Performance Characterization of GNSS/IMU/DVL Integration under Real Maritime Jamming Conditions", Sensors 2018, 18(9)

# Jamming on selective frequencies

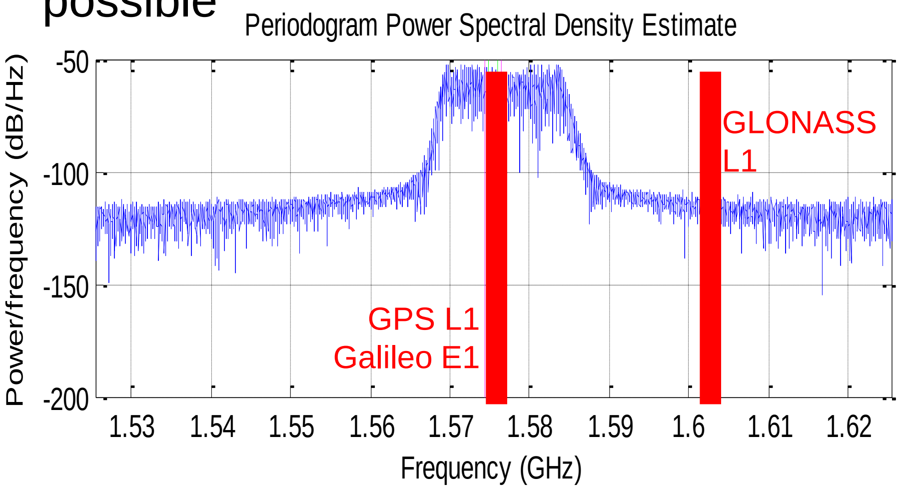
## Jammer K1001 at GPS L1: 1575.42 MHz

Characterization in time domain

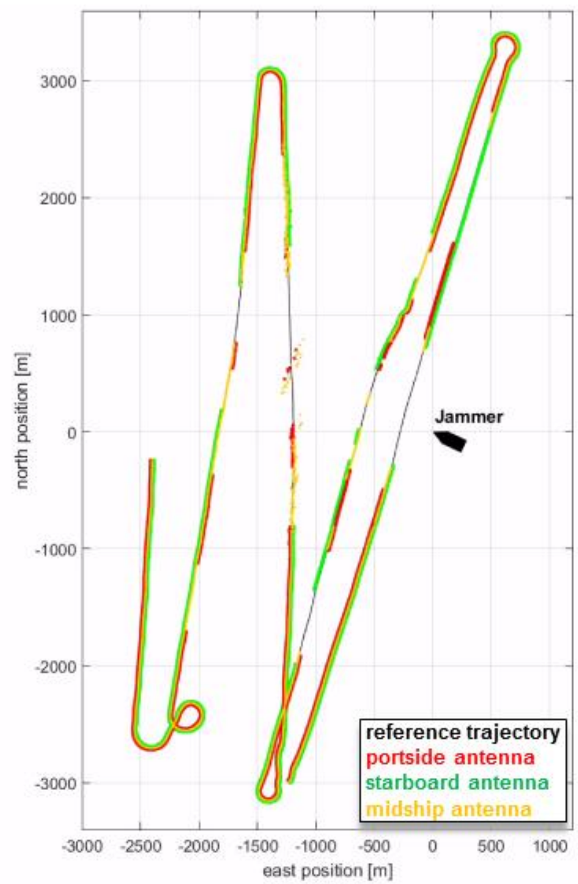


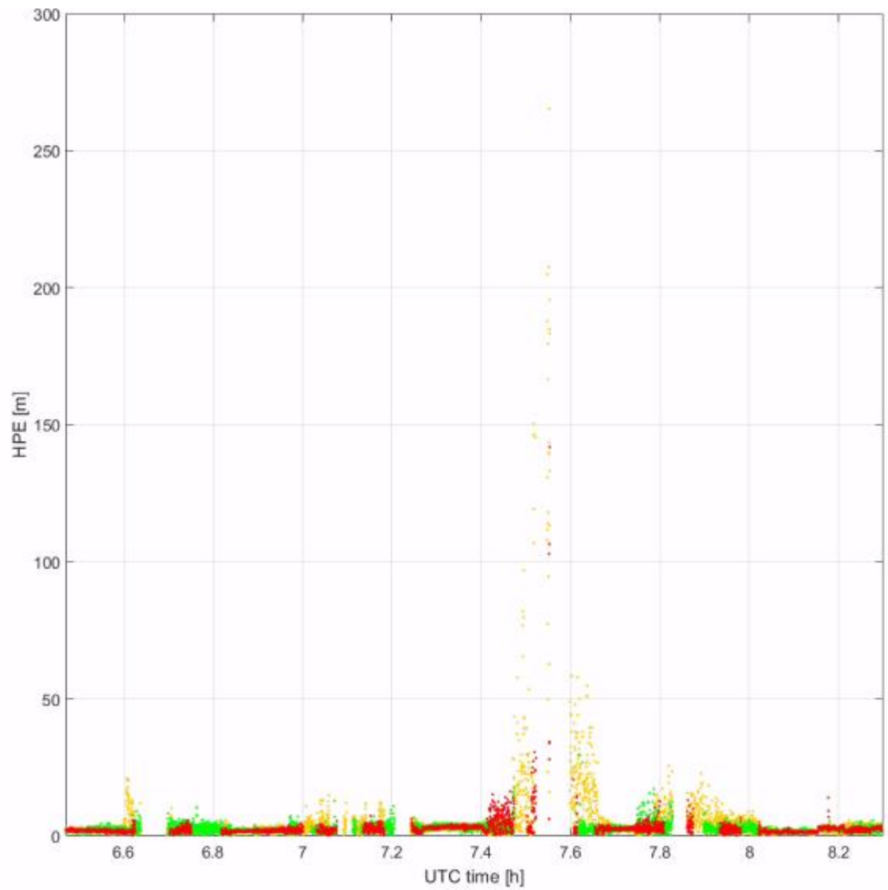

- Common way of jamming: sweeping with linear increasing frequency around center frequency of L1
- Here band with only 17 MHz
- Jamming Galileo E1 too
- GLONASS L1 not affected by jamming

=> Generation of reference trajectory possible

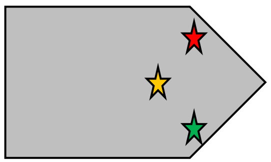


# GPS single point positioning results of the three antennas




## GNSS antennas



# 2. Theory

- Code and phase measurements [m] for different frequencies (Li):

$$R_i = \rho + c(\delta t_{rcv} - \delta t^{sat}) + Tr + I_i + \boldsymbol{M_i + \varepsilon_i}$$
$$\Phi_i = \rho + c(\delta t_{rcv} - \delta t^{sat}) + Tr - I_i + \lambda_i N_i + \lambda_i w + \boldsymbol{m_i + \epsilon_i}$$

- $R_i$, $\Phi_i$: Code and phase measurement of Li [m]
- $M_i$, $m_i$: Multipath error
- $\varepsilon_i$, $\epsilon_i$: Receiver noise

- Use linear combination of code and phase measurements to get noise:

$$\widetilde{\sigma_1} = R_1 - \Phi_1 - \frac{2}{\gamma - 1}(\Phi_1 - \Phi_2)$$

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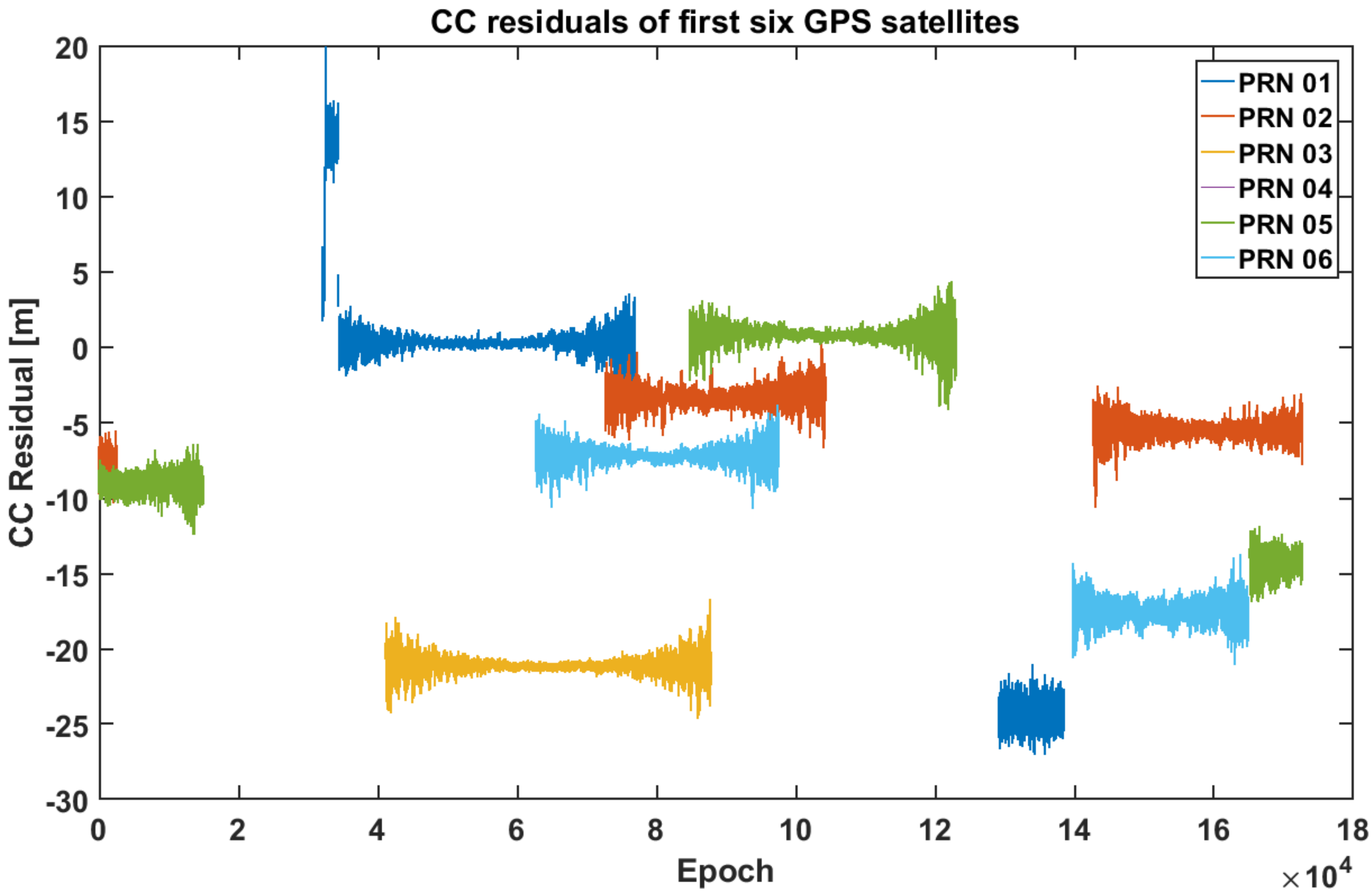
# Code-carrier residuals with bias and cycle slips

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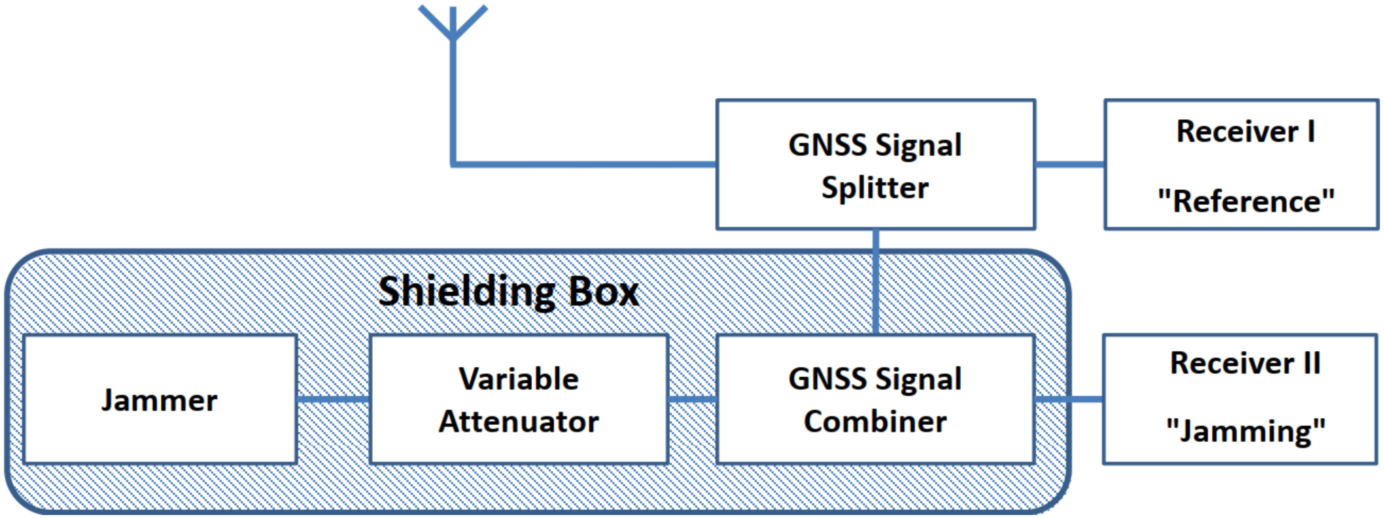
# 3. Experimental setup

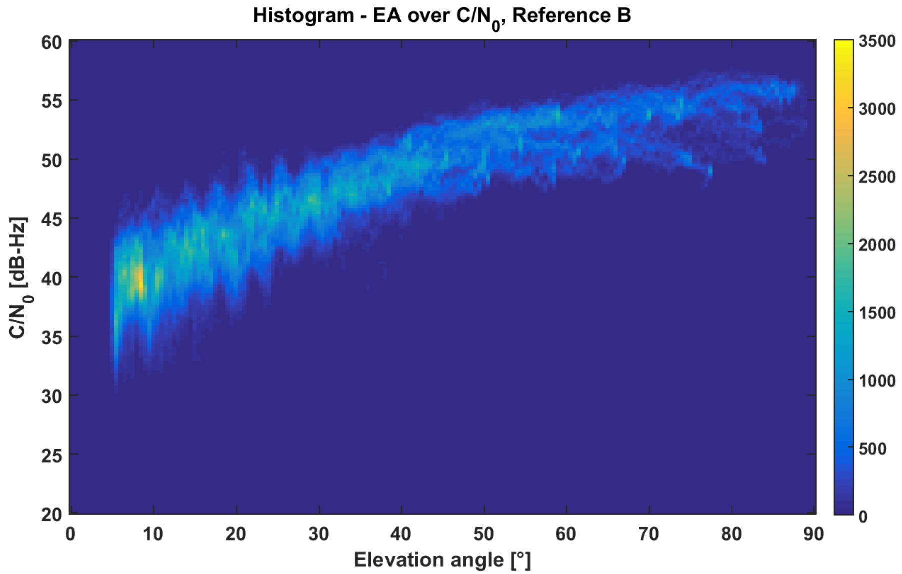


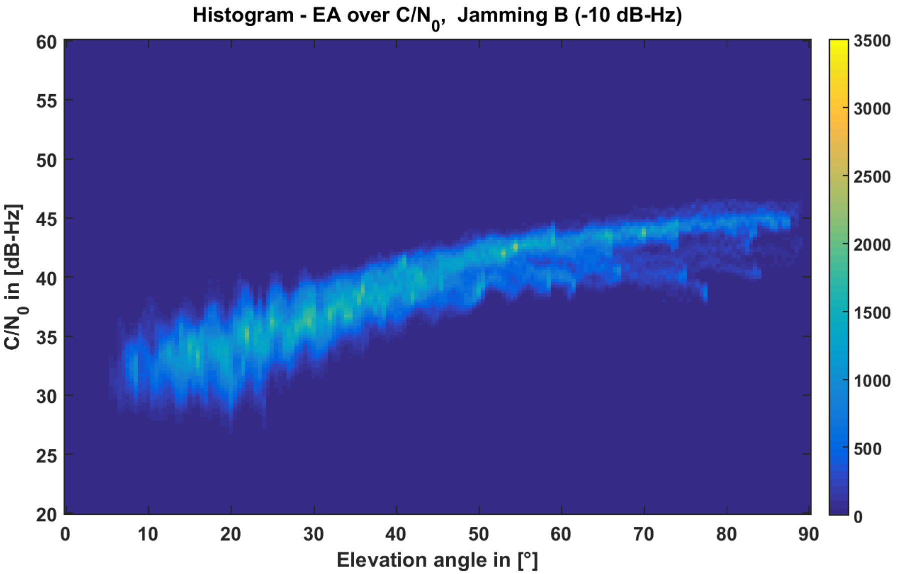

- One antenna on the roof of the Institute of Communications and Navigation in Neustrelitz, Germany, connected to two receivers (Javad Delta receiver, dual frequency)

- Strength of jamming adjusted using variable attenuator

# Measurement scenarios

- Two 48 hours 2 Hz measurements (A and B) with different jamming strength
- Decrease in $C/N_0$ compared to unjammed signal: 9.4 dB-Hz (A), 10 dB-Hz (B)

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# Noise models

- Elevation angle weighting:

$$\sigma_1^2 = \frac{a_1}{\sin^2 \alpha}$$

- **Additive noise model:**

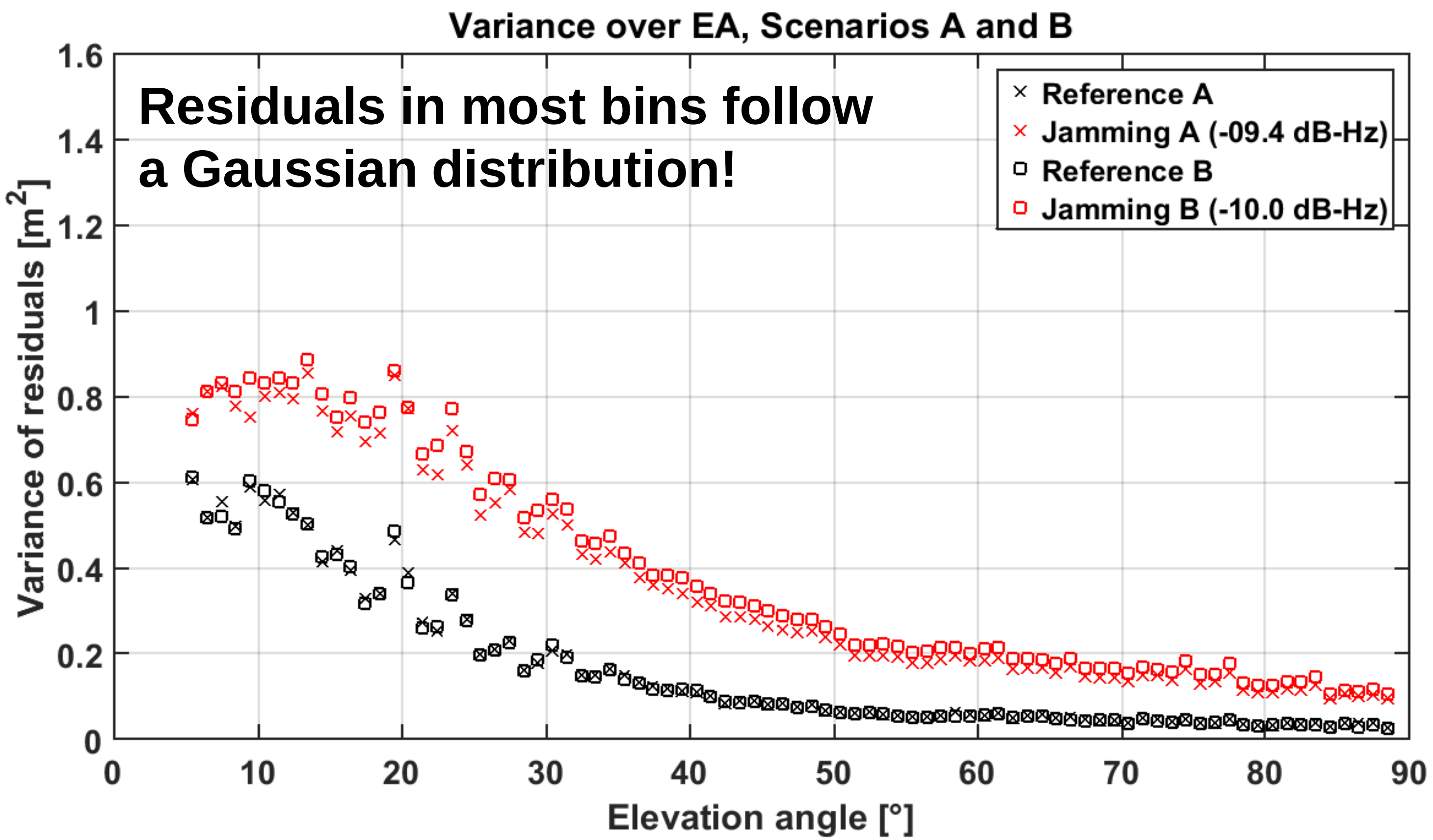
$$\boldsymbol{\sigma_2^2 = \frac{a_2}{sin\,\alpha} + 10^{-\frac{b_2 \cdot \mathrm{C/N_0}}{10} + c_2} + d_2(a_2, b_2, c_2)}$$

- Multiplicative noise model[3]:

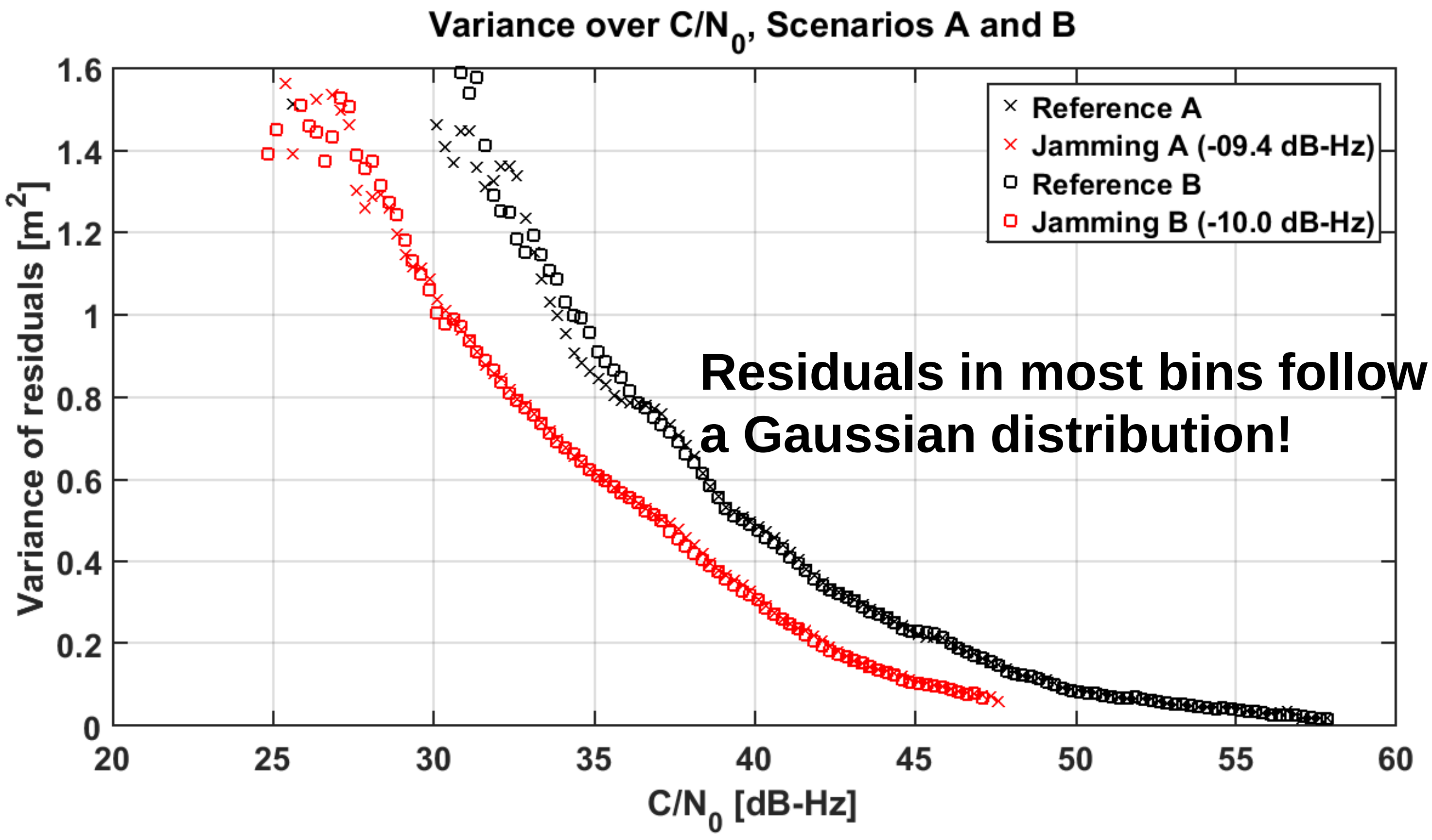
$$\sigma_3^2 = \frac{10^{-\frac{a_3 \cdot \mathrm{C/N_0}}{10} + b_3}}{sin^2\,\alpha} + c_3$$

[3] S. Tay and J. Marais “Weighting models for GPS Pseudorange observations for land transportation in urban canyons”, 6th European Workshop on GNSS Signals and Signal Processing, 2013

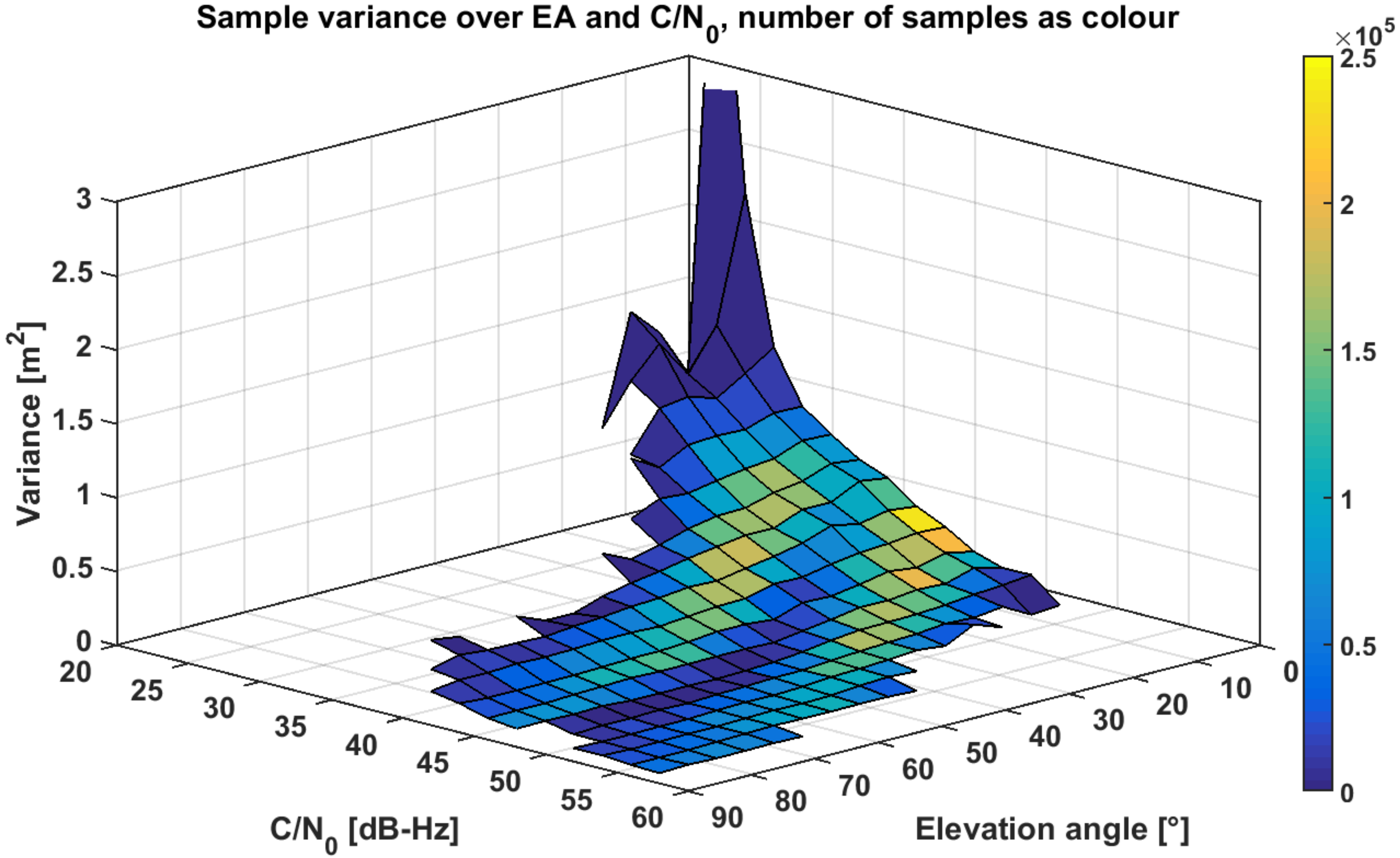
# 4. Results - Noise of GPS signals w.r.t. elevation



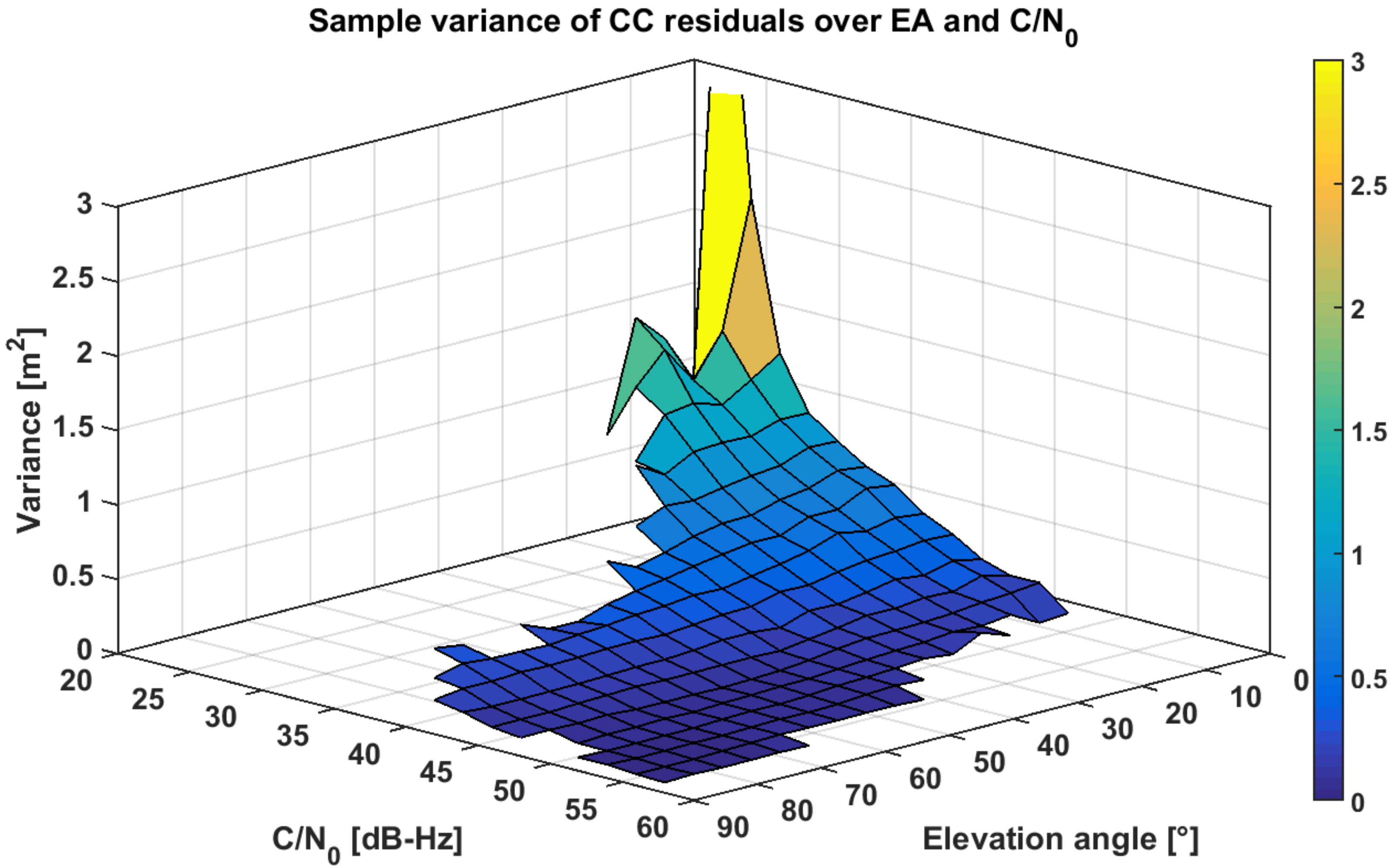
# Noise of GPS signals w.r.t. $C/N_0$



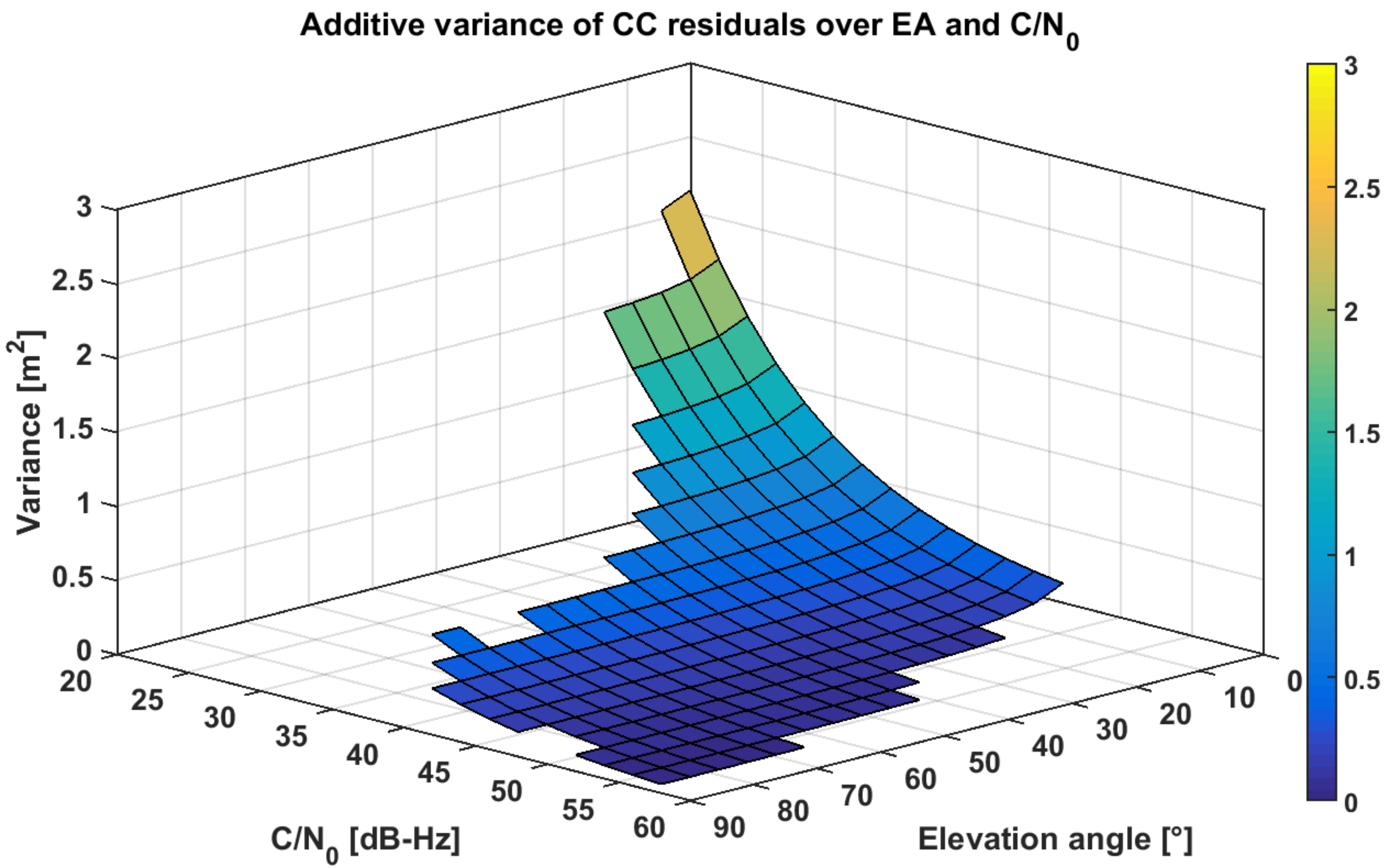
# Number of measurements (Reference & Jamming)



# Variance from measurement scenarios



# Additive Model



# Quality of fit

| Noise model | $L_1$ residual fit | $L_2$ residual fit |
|---|---|---|
| Elevation angle | $2.35 \cdot 10^{-1}$ | $1.08 \cdot 10^{-1}$ |
| **Additive** | $3.43 \cdot 10^{-2}$ | $4.59 \cdot 10^{-3}$ |
| Multiplicative | $1.65 \cdot 10^{-1}$ | $4.23 \cdot 10^{-2}$ |

- Additive model: Best fit
- Elevation model good for low elevation

# Reminder - Motivation II

- Measurement campaign in the Baltic Sea using allocated civilian maritime GNSS jamming testbed[2]
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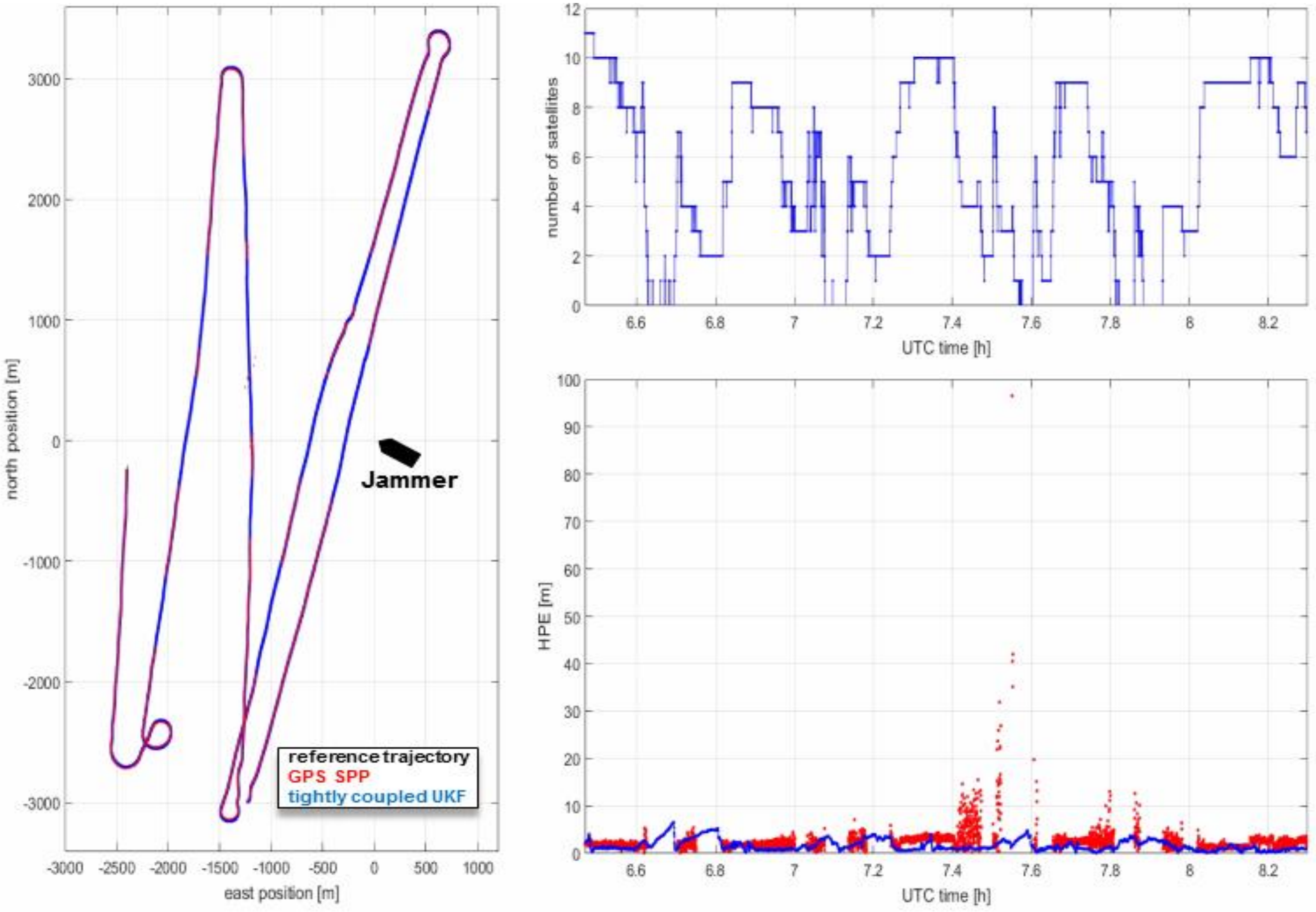
# Positioning results from campaign in Jamming testbed



# 5. Outlook

- Noise model for GNSS signals depending on $C/N_0$ and elevation angle that works with and without jamming $\Rightarrow$ Variance estimation in a Kalman filter
- Conduct more measurement scenarios
- Weighting scheme for least squares position solver
- Potential to be used as a Jamming detector

**Thank you for your attention!**

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# Common Jammers – Personal Privacy Devices (PPD)

- Low transmitting power: model K320
- Blocks single frequency (GPS L1)
- Range 2 – 10 m (producer)
- Measured disturbances: up to 50 m (loss of lock)


- High transmitting power: model K1001
- Blocks several frequencies (GPS L1, L2; GSM, Wi-Fi, …)
- Range 5 – 15 m (producer)
- Measured disturbances: up to 1500 m (loss of lock)