A quality model of open-source Sentinel-1 SAR data by temporal and spatial modelling

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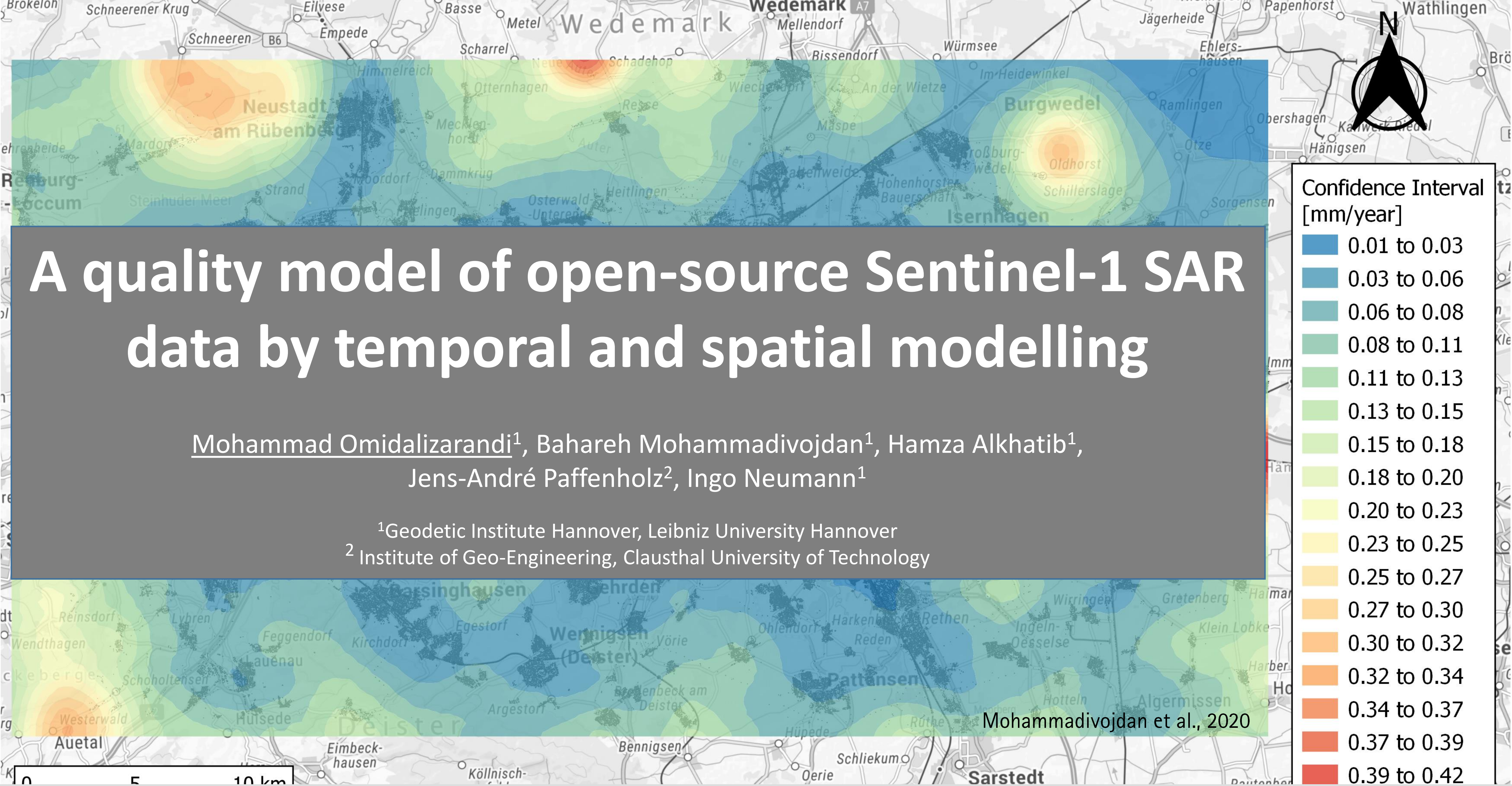
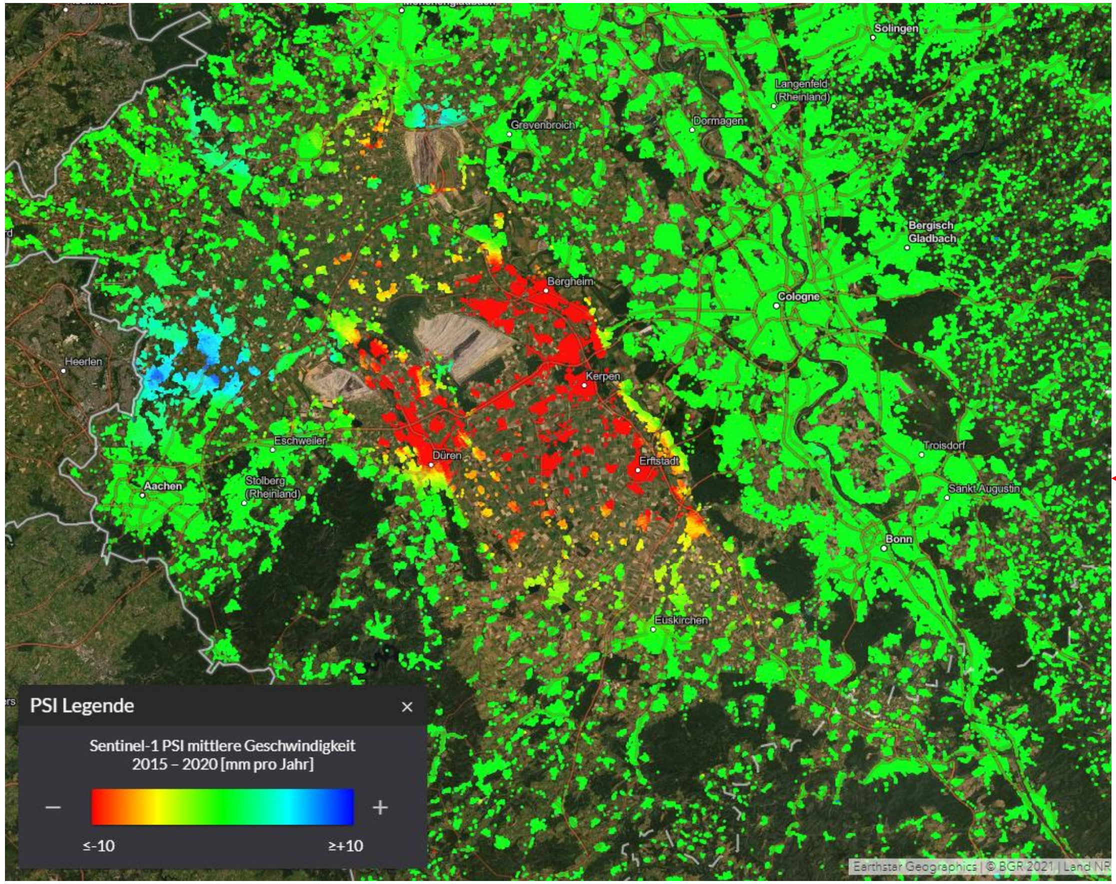


Mohammadivojdan et al., 2020

Motivation



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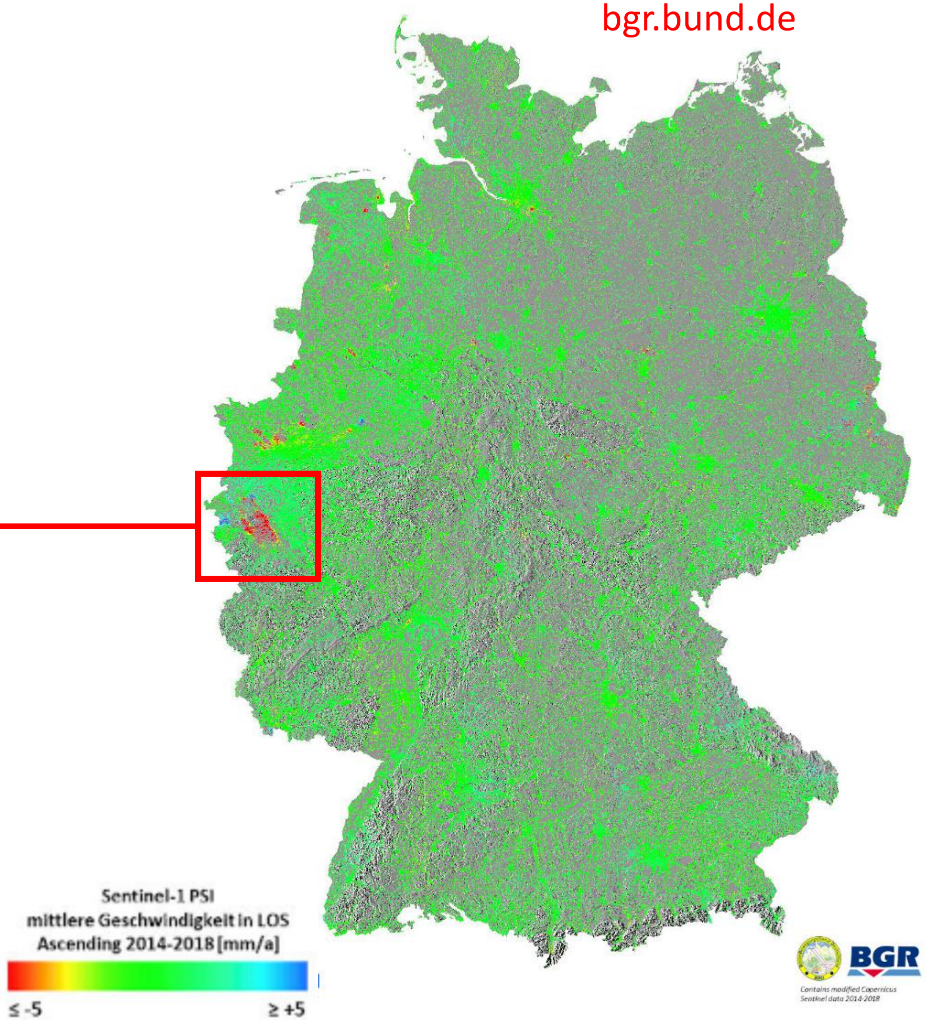
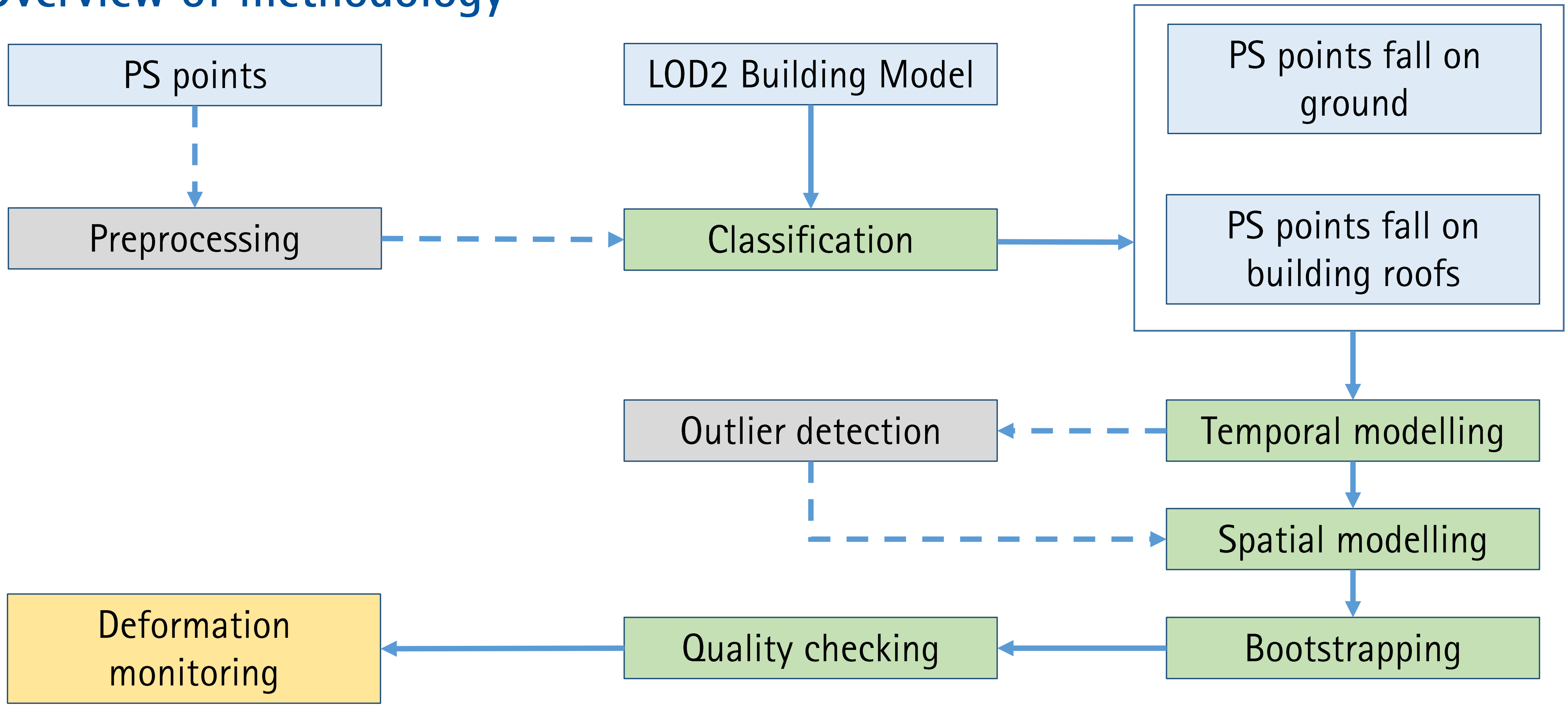


Motivation

- **Why using Persistent Scatterer Interferometry (PSI) data in deformation monitoring?**
  - Large-scale monitoring with a millimetre (mm) level accuracy
  - Wide area coverage
  - Relatively low-cost
  - Observing trend of damaged structures or natural objects over a long-term
  - High-density data mostly in urban areas
  - Acquiring data mainly independent of weather conditions

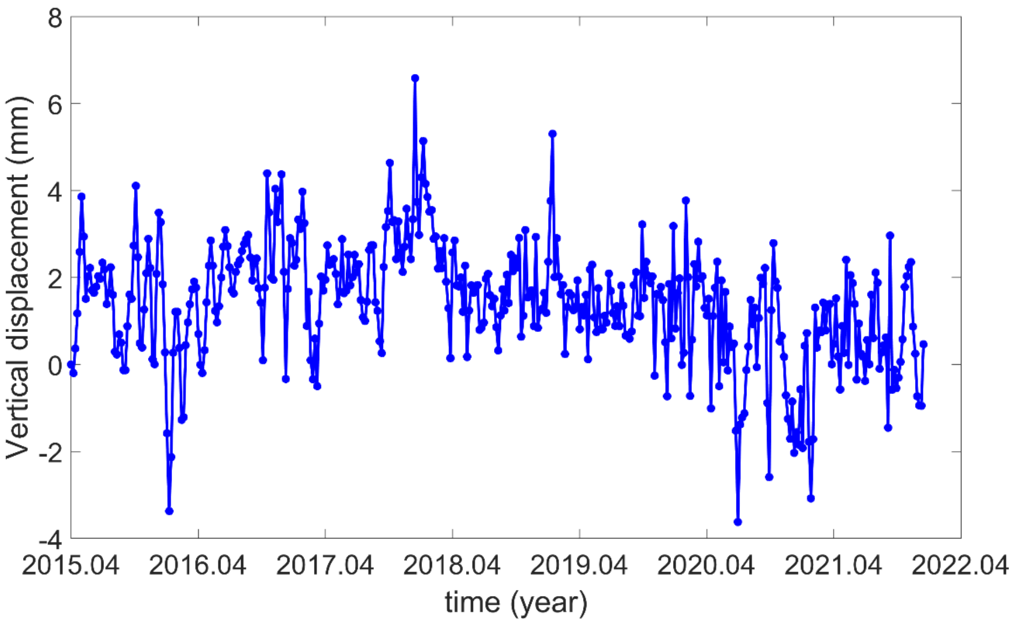
- **Problem statement:**
  - Spatio-temporal quality model of the PSI data obtained from any open source Sentinel-1 SAR data
  - Handling outliers and data gaps
  - Predict the deformation rate (mm/year) and its uncertainty at any arbitrary point
  - Judge the significance of deformations

Overview of methodology

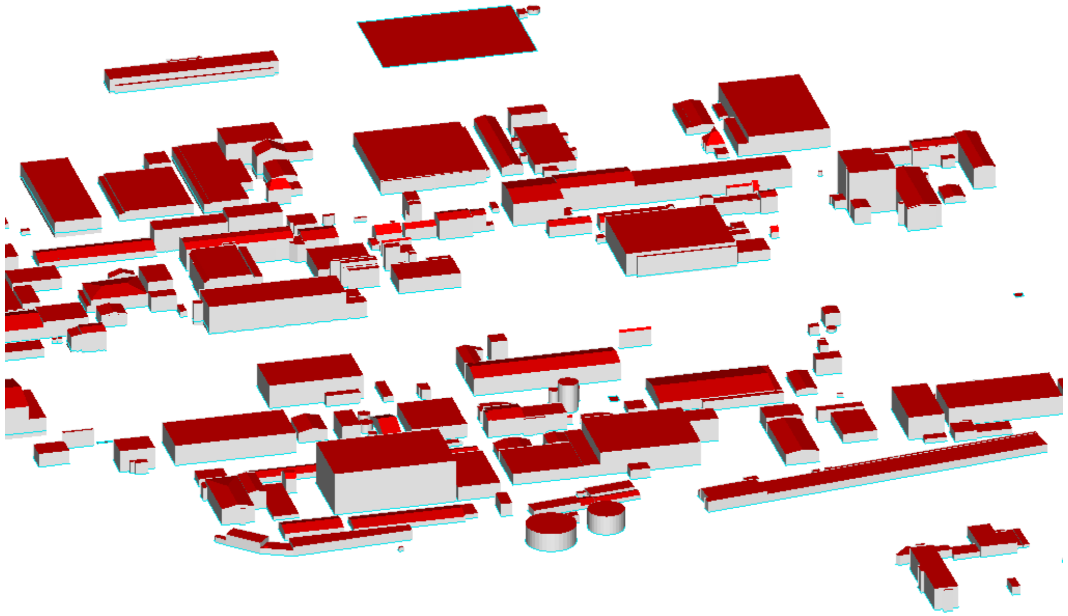


PSI data specification and preprocessing

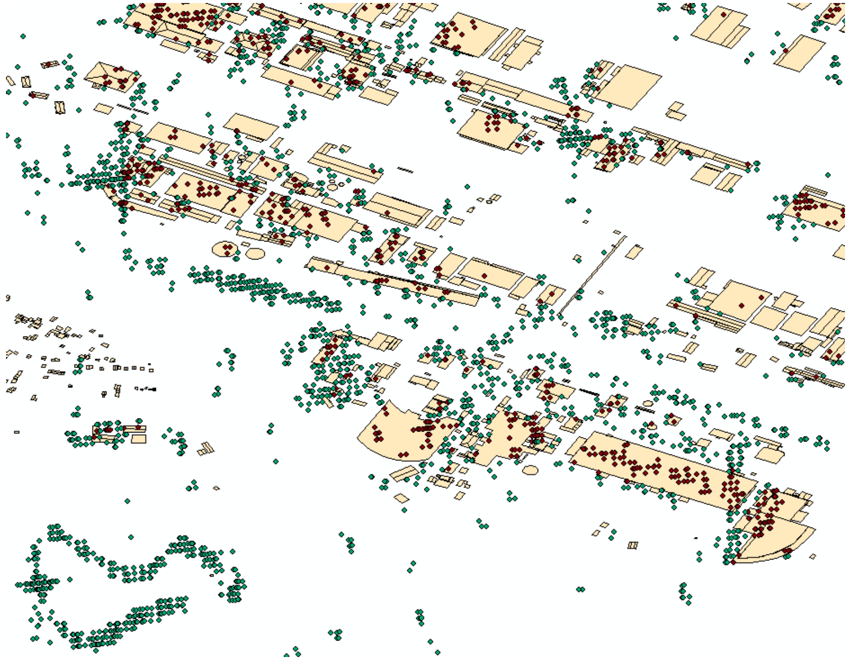
- PSI data obtained from satellite Sentinel-1 with an area coverage, approx. 45,000 km^2 and swath of 240 km for a single image
- Sampling time of 12 days by using only Sentinel-1A, and 6 days using both Sentinel-1A and -1B
- Sampling frequency of 61 PS points per year including data gaps
- PS points covering a period of April 1st, 2015 to December 31th, 2021



PSI data classification



Exemplary representation of the LOD2 building model for parts of the city of Hamburg



PS points on the ground (green dot), and on the building roofs (red dot)

Omidalizarandi et al. (2023)

Temporal modelling (Pointwise based)

1. Functional model (Harmonic oscillation model)

Velocity (mm/year) Fourier series coefficients Given time instances (year) Coloured noise

$$h_t(\boldsymbol{\beta}) = c_0 + c_1 x_t + \sum_{j=1}^{M} a_j \cos(2\pi f_j x_t) + b_j \sin(2\pi f_j x_t) + e_t$$

Offset (mm) Frequencies

2. Correlation model (autoregressive (AR) model) (Kargoll et al. 2018)

$$e_t = \sum_{j=1}^{p} \alpha_j e_{t-j} + u_t$$

3. Stochastic model with Student process (Kargoll et al. 2018) $u_t \sim t_\nu(0, \sigma^2)$
   - Fused in joint log-likelihood function, and jointly adjusted by means of the generalized expectation maximization (GEM) algorithm (Alkhatib et al., 2017)

Spatial modelling (Area based)

- Multilevel B-Splines approximation

Cubic basis functions

$$f(x,y) = \sum_{k=0}^{3}\sum_{l=0}^{3} B_k(s)B_l(t)\phi_{(i+k)(j+l)}$$

Unknown control points in Φ

Location parameters

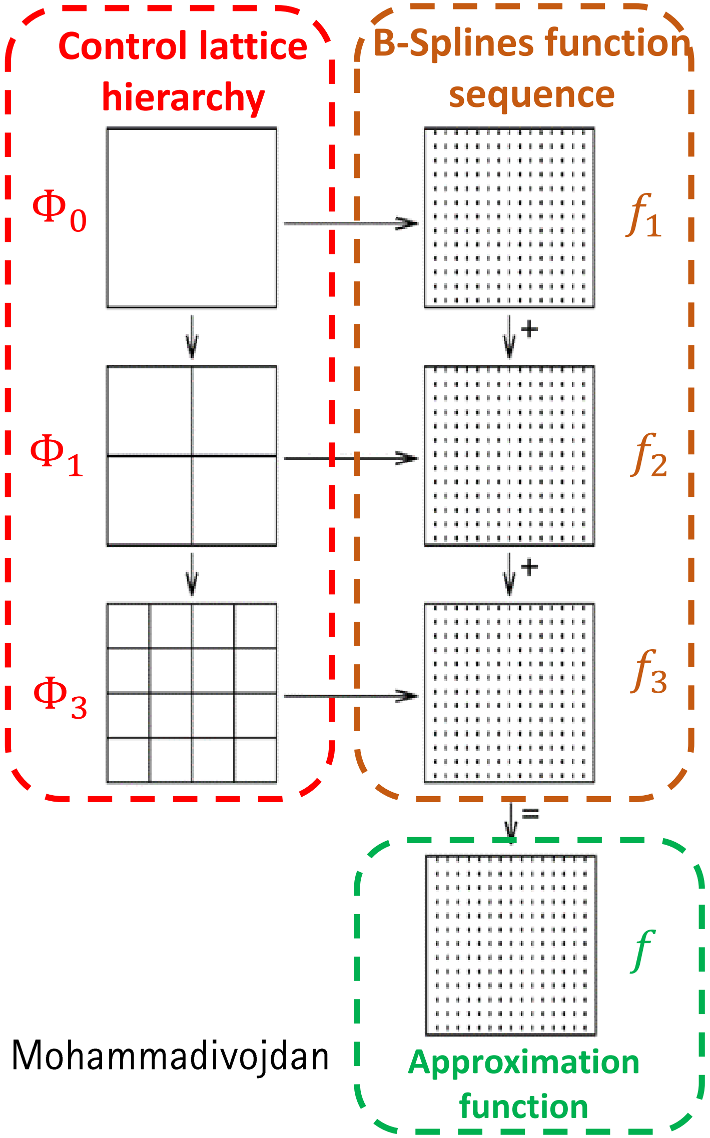
  - Defining control lattices $\Phi_0, \Phi_1, \dots, \Phi_h$
  - Calculation of function f_k successively

$$P_k = \{(x_c, y_c, \Delta^k z_c)\}$$

$$\Delta^k z_c = z_c - \sum_{i=0}^{k-1} f_i(x_c, y_c) = \Delta^{k-1} z_c - f_{k-1}(x_c, y_c)$$

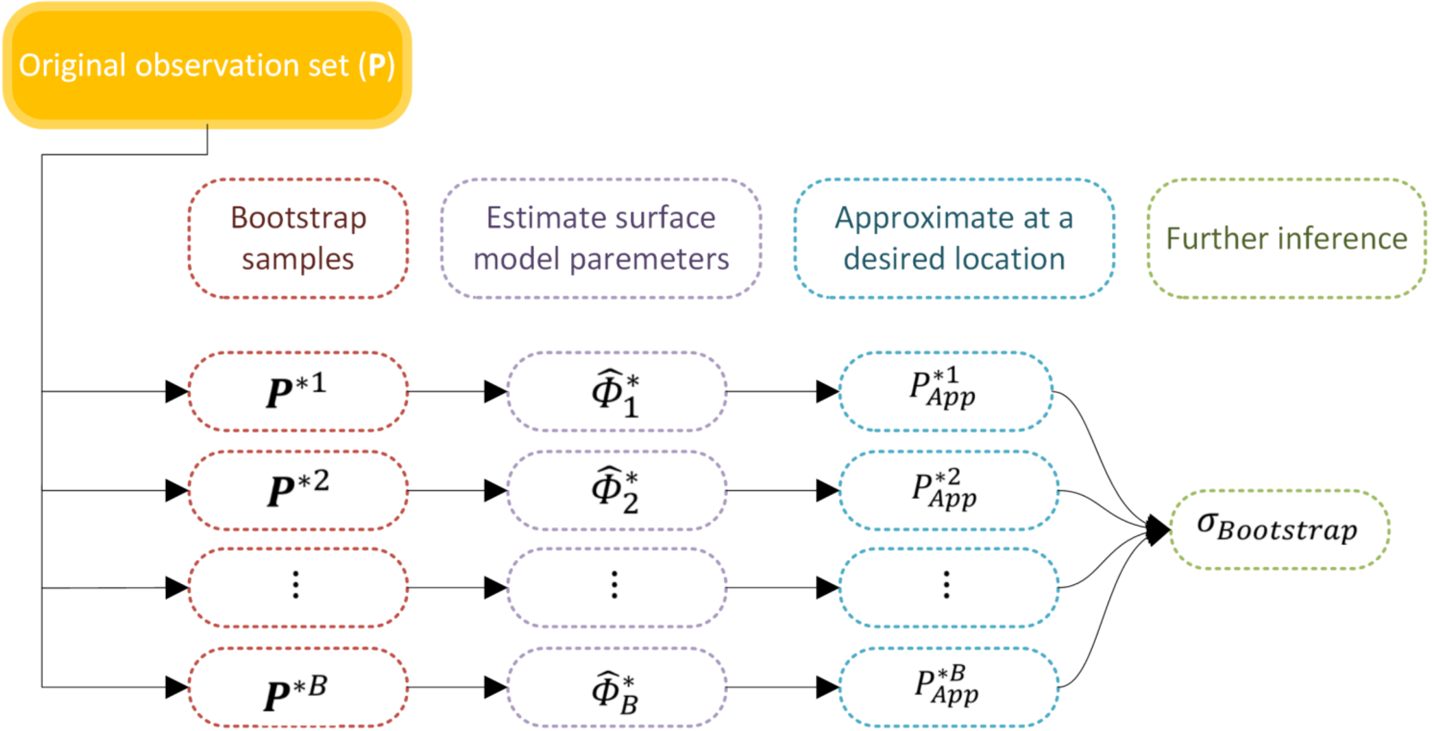
  - Final approximation, sum of all layers

$$f = \sum_{k=0}^{h} f_k$$



(Lee et al., 1997; Mohammadivojdan et al., 2020)

Bootstrapping



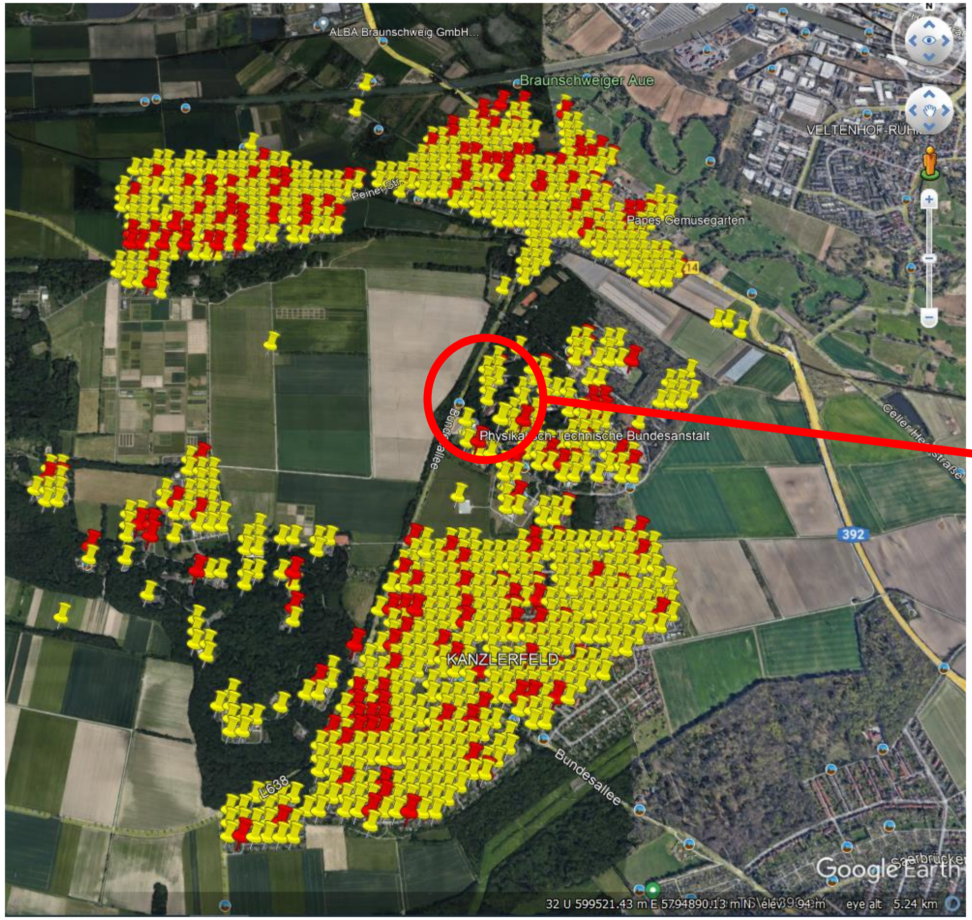
$$\sigma_{Bootstrap} = \sqrt{\frac{\sum_{i=1}^{B}\left(\boldsymbol{P}_{App}^{*i} - \boldsymbol{P}_{App}^{*}\right)^2}{(B-1)}},$$

$$with \quad \boldsymbol{P}_{App}^{*} = \sum_{i=1}^{B} \frac{\boldsymbol{P}_{App}^{*i}}{B}$$

B : The number of realizations

- Performing bootstrapping to provide uncertainty of the MBA with 95% confidence interval
  - Intensive resampling from an existing sample and generating new samples to derive bootstrap samples
  - Calculate the standard deviation and confidence interval of the predicted surface at a desired location

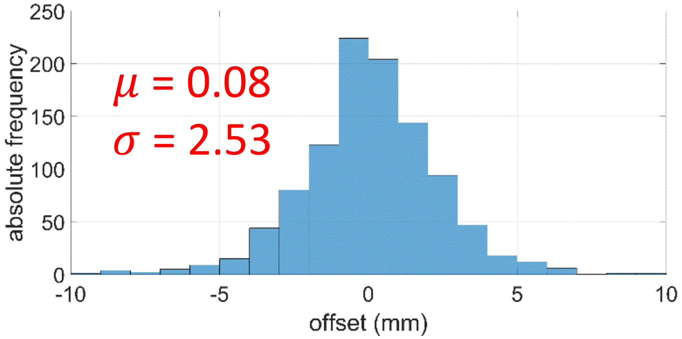
Case study: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig

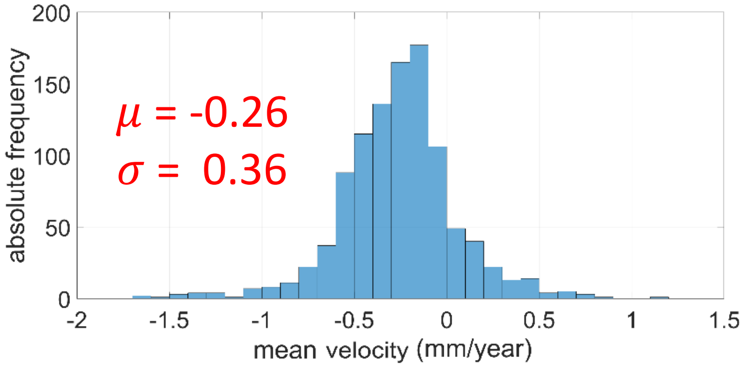


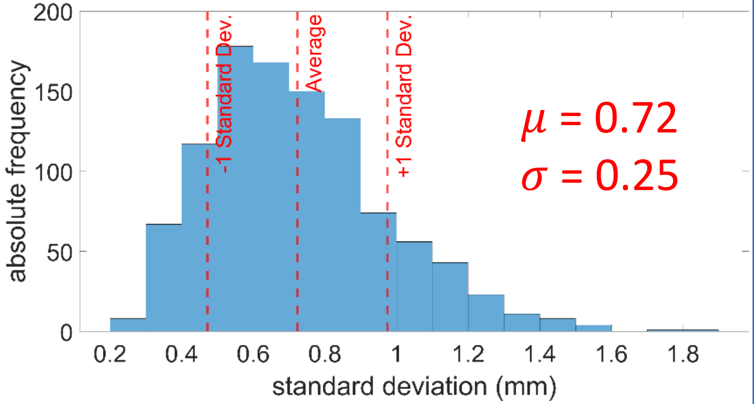
The classified PS points fall on the roof (red symbol) and on the ground (yellow symbol), located in the vicinity of the PTB, Braunschweig, Germany, shown in google earth

Case study: Analyses of temporal modelling for PSI data fall on the ground compared with the analyses from BGR

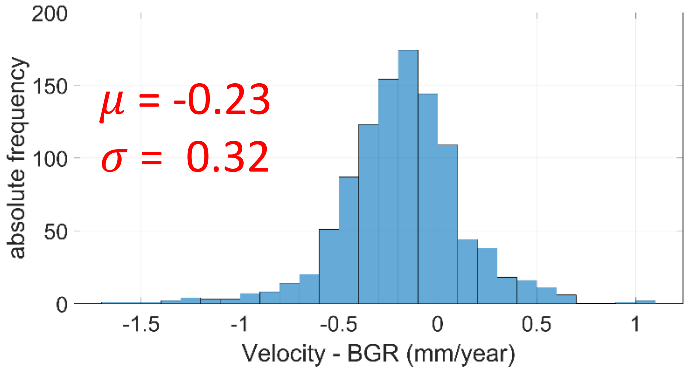
Our Temporal analyses

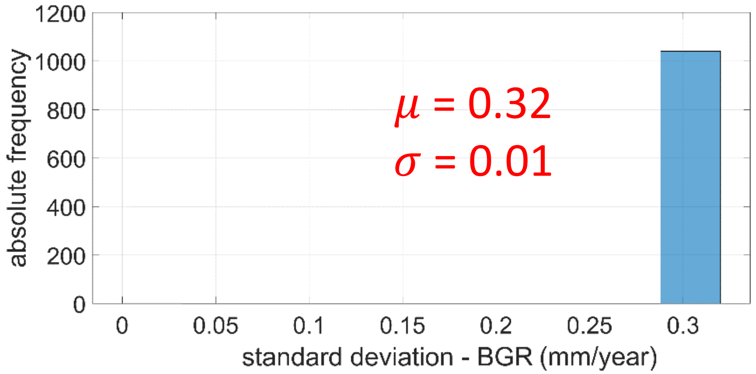




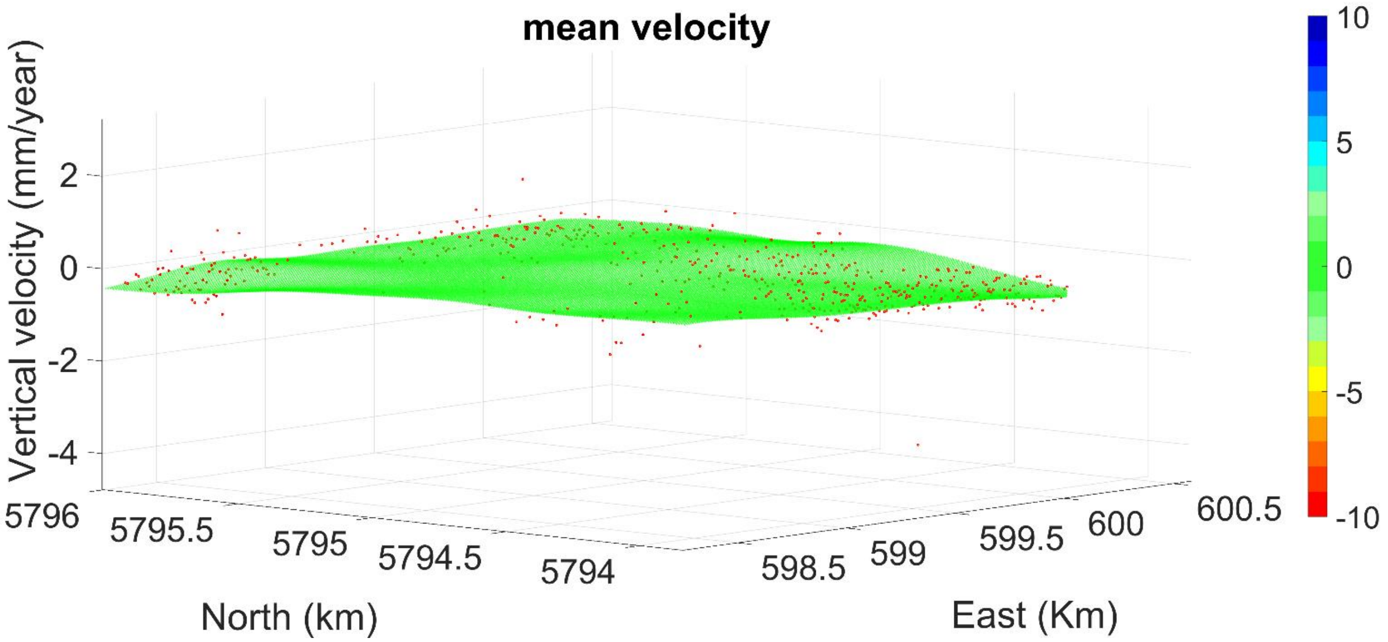


BGR

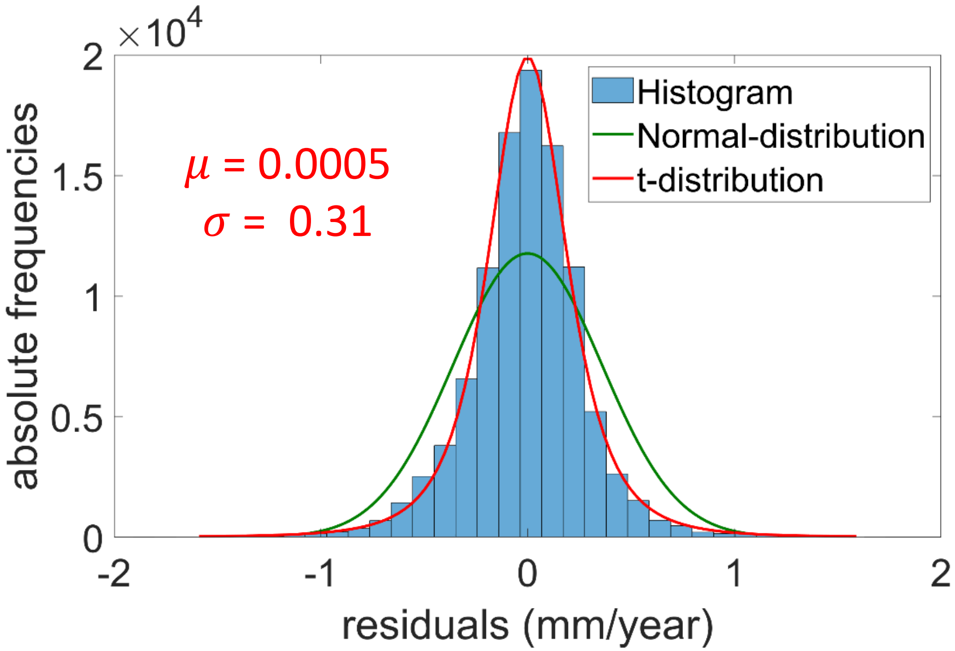




Case study: Analyses of spatial-temporal modelling for PSI data fall on the ground

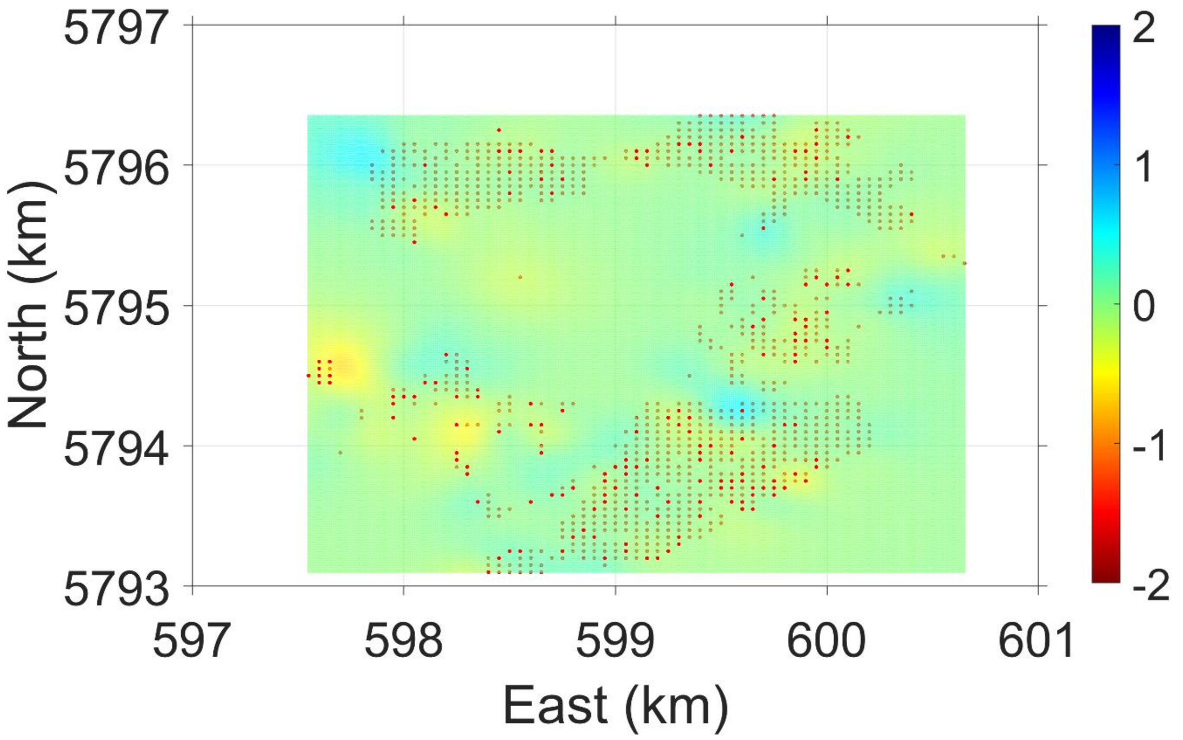


Spatial-temporal modelling of the mean velocity (mm/year) for PS points fall on the ground

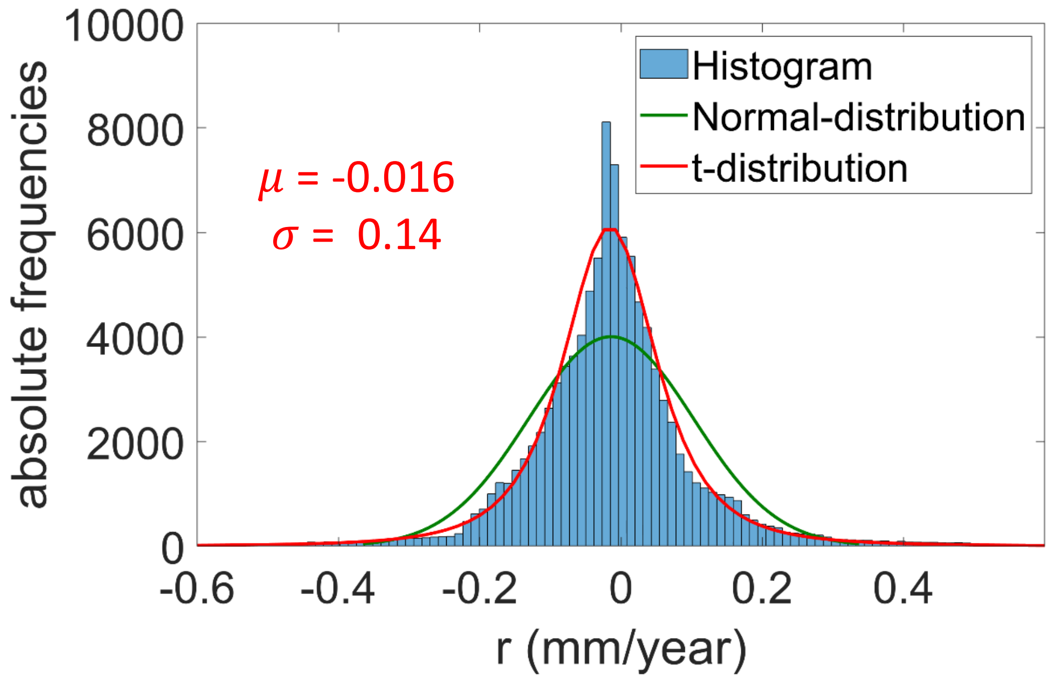


Histogram of residuals obtained from bootstrapping of spatial-temporal model

Case study: Comparison of spatial-temporal models of our results and BGR for PSI data fall on the ground



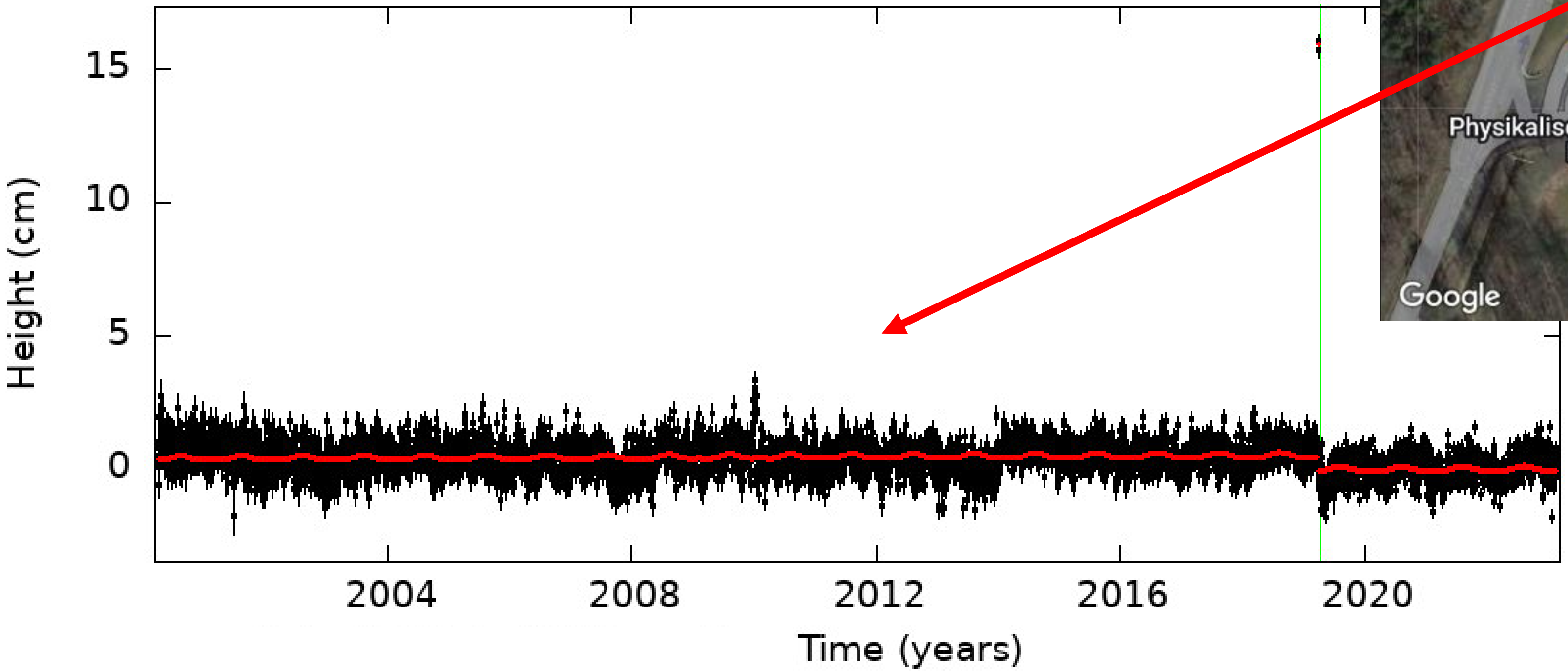
Differences of spatial-temporal models of our results and BGR based on the mean velocity (mm/year) of PS points fall on the ground

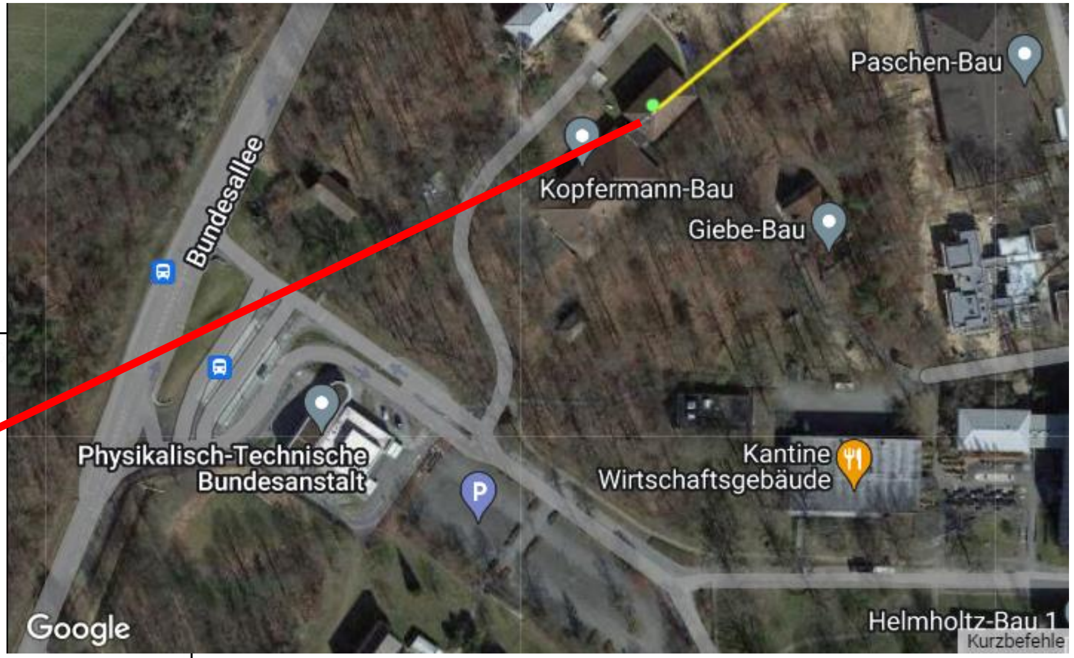


Histogram of differences of spatial-temporal models of our results and BGR

Case study: GPS station in PTB and its vertical time series

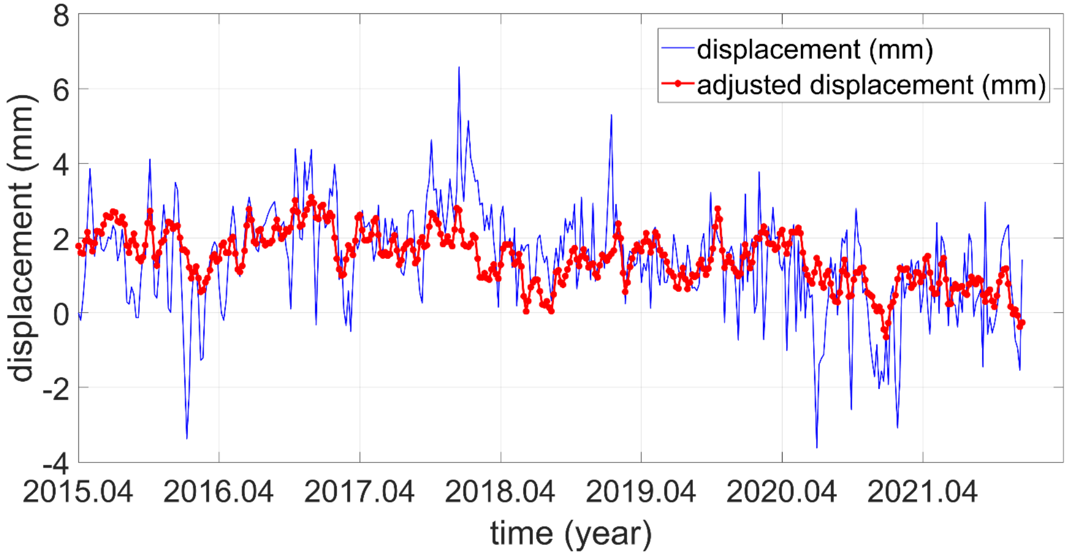
GPS Time Series - vertical direction (nasa.gov)





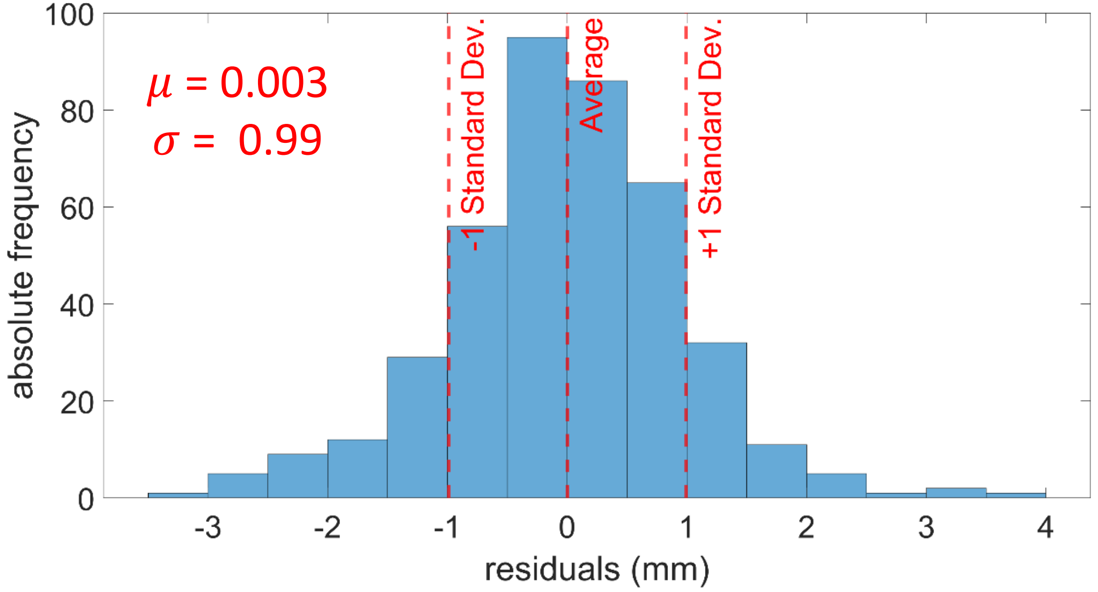
GPS location (nasa.gov)

Case study: Our analysis for the PS point close to GPS station in PTB

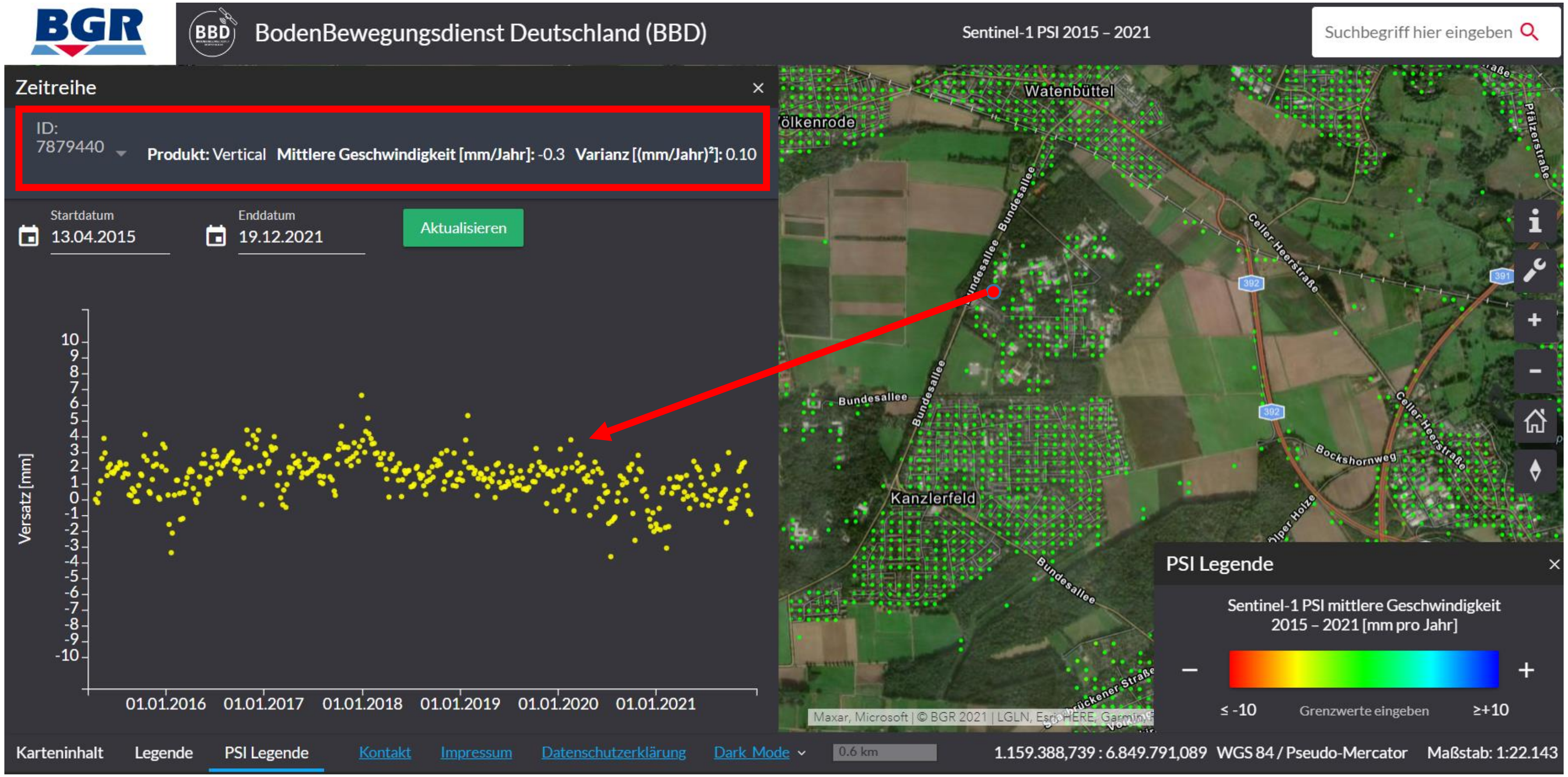


Displacement and adjusted displacement time series of PS data point close to PTB, Braunschweig

Histogram of white noise residuals obtained from temporal analysis



Case study: PSI data analyses in the vicinity of PTB obtained from BGR



Analyses of the PS data points obtained from BGR in the vicinity of the PTB, Braunschweig

Case study: Results of temporal and spatial–temporal modelling for a PS point compared with the BGR analyses and GPS time series

Quality check and deformation results for the PS point close to GPS station in PTB

Case study	PS point	Temporal modelling				Bootstrapping of spatial-temporal model		BGR		GPS			
		Mean velocity (mm/year)		White noise displ. residuals (mm)		Mean velocity (mm/year)		Mean velocity (mm/year)		Mean velocity (mm/year)		White noise displ. residuals (mm)	
		v	σ	μ	σ	v	σ	v	σ	v	σ	μ	σ
1	PTB	-0.23	0.001	0.003	0.99	-0.22	0.06	-0.3	0.32	-0.14	0.02	0.002	4.12

- No significant deformation

Conclusion and outlook

- Estimation of an offset and a deformation rate for each individual PS point based on temporal modelling
- Confidence interval of overall standard deviations of the PS data points, considering 1σ, at the level of approximately 1 mm
- Bootstrapping of spatial-temporal model to derive a quality of the model at the level of 0.3 mm/year
- A better judgement about significance of deformations with the spatial-temporal quality model
- Nearly the same results in both approaches (ours and BGR) despite of different processing strategies for the PSI time series
- Higher uncertainty of the GPS time series at the level of 4 mm

- Outlook
  - The comprehensive quality assessment including reliability analysis as well as statistical tests

Thank you very much to your attention!

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