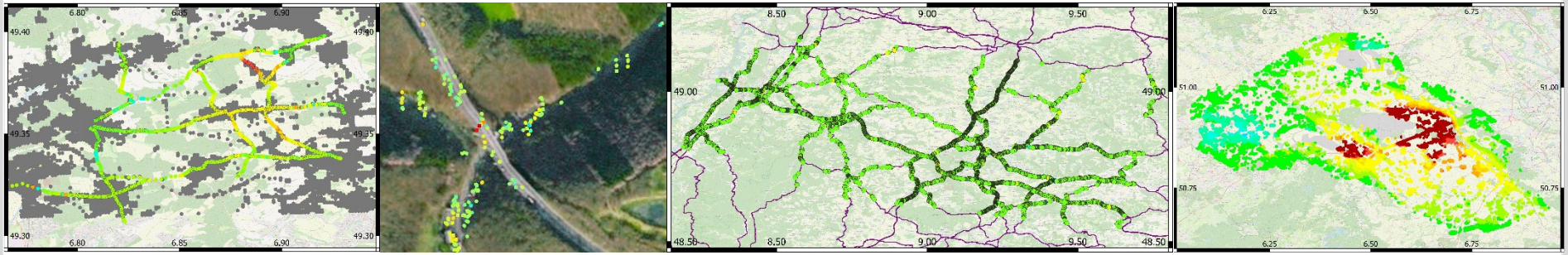
Karlsruher Institut für Technologie

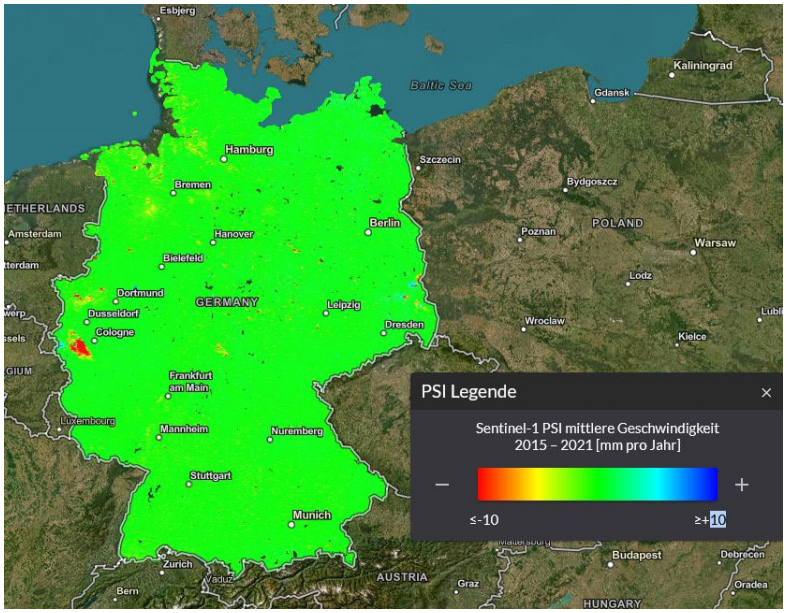
A COMPARISON OF THE GERMAN AND THE EUROPEAN GROUND MOTION SERVICE

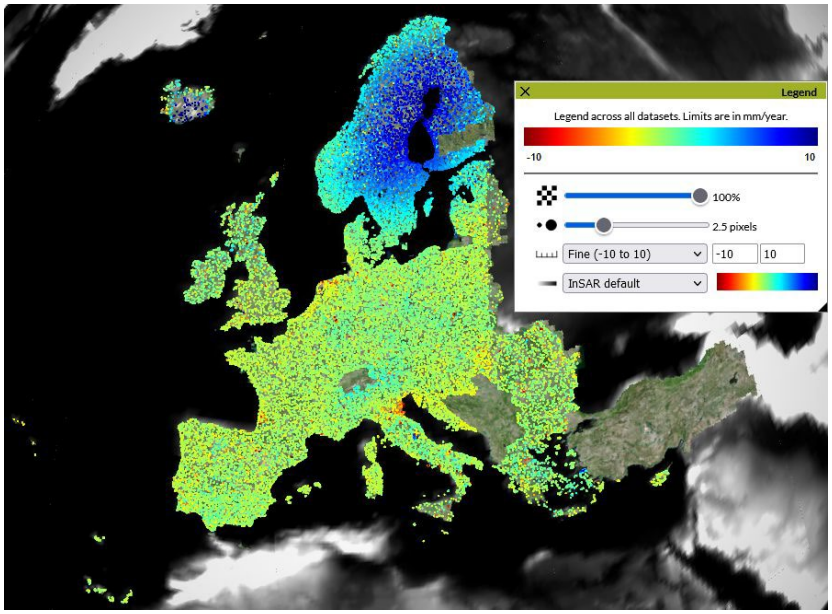
Markus Even, Malte Westerhaus, Hansjörg Kutterer

Karlsruhe Institute of Technology, Geodetic Institute Karlsruhe (GIK), Geodetic Earth System Sciences



German Ground Motion Service (BBD) and European Ground Motion Service (EGMS)





Bodenbewegungsdienst Deutschland (BBD):

- national service operated by Federal Institute for Geosciences and Natural Resources (BGR)
- currently 4th release

European Ground Motion Service (EGMS):

- part of the Copernicus Land Monitoring Service (EU)
- generated by the OpeRatIonal Ground motion INsar Alliance (ORIGINAL): e-GEOS, TRE Altamira, NORCE and GAF AG
- currently 2nd release

Both ground motion services are based on Sentinel-1 data.
For Germany, both are produced by GAF AG with the IWAP processor of DLR.

BBD and EGMS

	BBD	EGMS (Germany)	EGMS (other regions)
Calibration with	GREF, SAPOS	EPND, NGL	EPND, NGL
Grid	50 m x 50 m	100 m x 100 m	100 m x 100 m
Period	04.2015-12.2021	01.2016-12.2021	01.2016-12.2021
Scatterers	PS	PS	PS + DS
Point selection	coherence ≥ 0.75	RMS ≤ 5 mm	RMS ≤ 5 mm
Model	linear + sinusoid	linear + sinusoid	cubic + sinusoid

GREF+SAPOS provide denser network of GNSS stations in Germany than EPND+NGL

BBD and EGMS

	BBD	EGMS (Germany)	EGMS (other regions)
Calibration with	GREF, SAPOS	EPND, NGL	EPND, NGL
Grid	50 m x 50 m	100 m x 100 m	100 m x 100 m
Period	04.2015-12.2021	01.2016-12.2021	01.2016-12.2021
Scatterers	PS	PS	PS + DS
Point selection	coherence ≥ 0.75	RMS ≤ 5 mm	RMS ≤ 5 mm
Model	linear + sinusoid	linear + sinusoid	cubic + sinusoid

BBD data stacks start earlier

BBD and EGMS

	BBD	EGMS (Germany)	EGMS (other regions)
Calibration with	GREF, SAPOS	EPND, NGL	EPND, NGL
Grid	50 m x 50 m	100 m x 100 m	100 m x 100 m
Period	04.2015-12.2021	01.2016-12.2021	01.2016-12.2021
Scatterers	PS	PS	PS + DS
Point selection	coherence ≥ 0.75	RMS ≤ 5 mm	RMS ≤ 5 mm
Model	linear + sinusoid	linear + sinusoid	cubic + sinusoid

The criteria for point selection differ.

Agenda

1. Methods of comparisons
2. Baden-Württemberg
   a) Coverage of linear infrastructure with data of BBD or EGMS
   b) Comparison of BBD and EGMS versus GNSS data
   c) Comparison BBD versus EGMS
3. Saarland: Comparison of BBD and EGMS versus levelling data
4. Western North Rhine-Westfalia (post-mining and lignite mining): Comparison of BBD and EGMS versus levelling data
5. North Rhine-Westfalia (cavern field Epe): Comparison of BBD and EGMS versus levelling data

Methods of comparisons

Time series from InSAR, GNSS and levelling of adjacent points are compared based on

1. differences of linear displacement rates
2. standard deviations σ_P between the signals

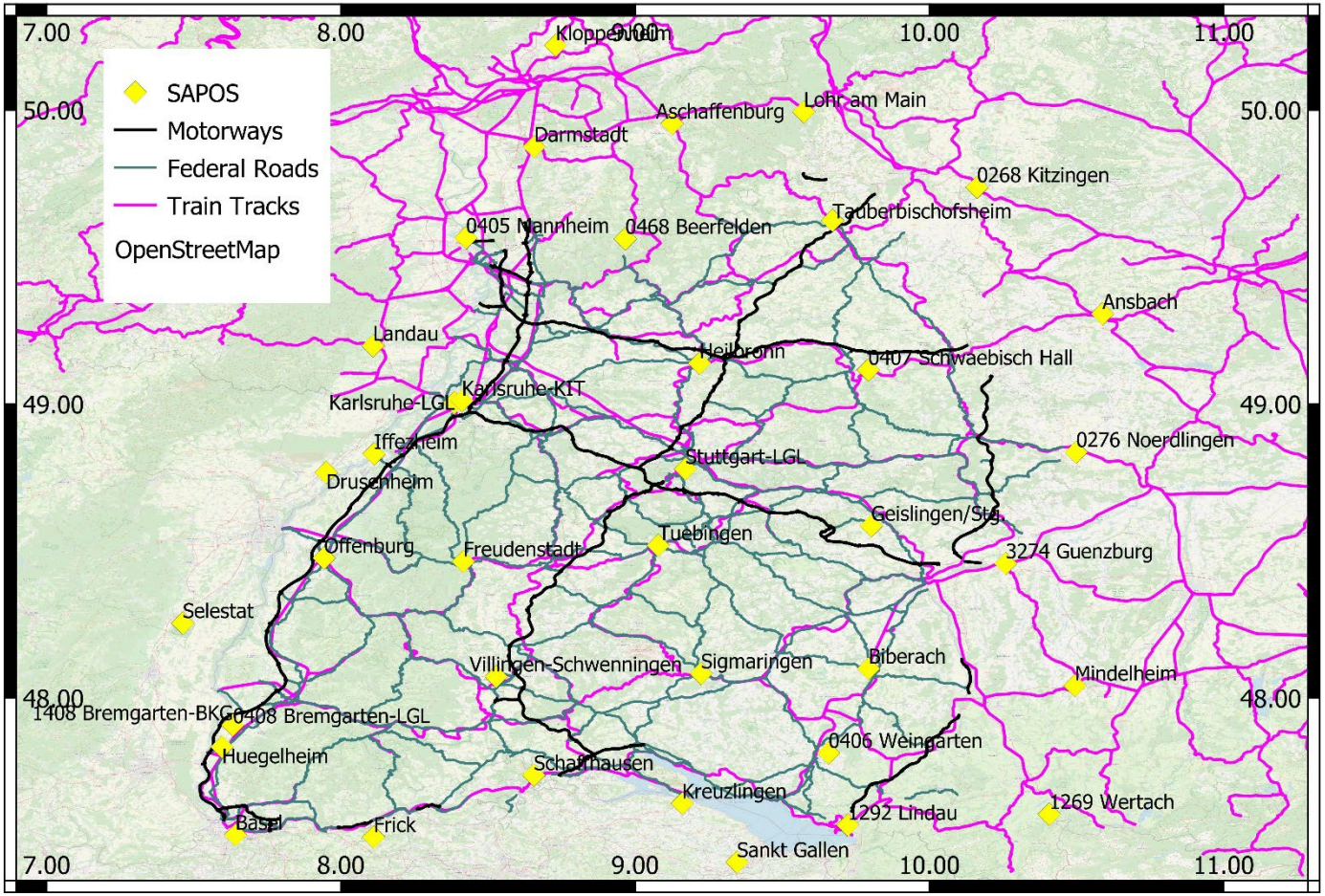
These are calculated from data prepared as follows:

- For InSAR and GNSS the comparison is prepared by **smoothing** the time series with robust quadratic regression (RLOESS) over a window of 7 data points length.
- Only measurement times in the **temporal overlap of BBD and EGMS** are considered.
- Data have to be **interpolated**:
  - on the union of the sets of temporal sampling points for the comparison BBD versus EGMS
  - on the measurement times of levelling for comparisons with BBD or EGMS
  - GNSS data are interpolated to sampling times of BBD or EGMS

Finally, an overall standard deviation is calculated according to the formula

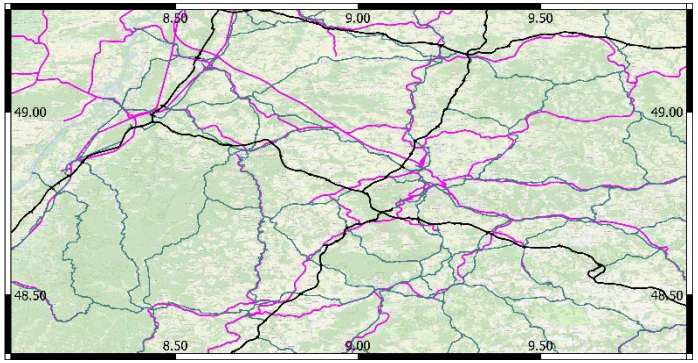
$$\sigma = \sqrt{\frac{1}{N-1}\sum_{P}(N_P - 1)\cdot {\sigma_P}^2}$$

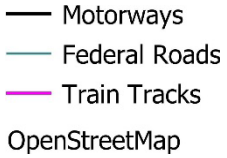
Data Baden-Württemberg

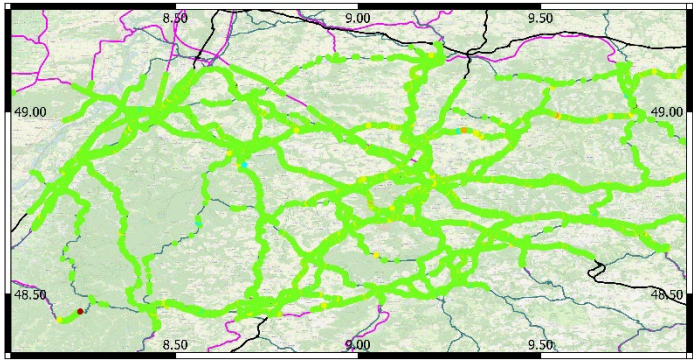


1. Coverage of linear infrastructure with data of BBD or EGMS
2. Comparison of BBD and EGMS versus GNSS data
3. Comparison BBD versus EGMS

Coverage of linear infrastructure with data of BBD or EGMS in Northern Baden-Württemberg



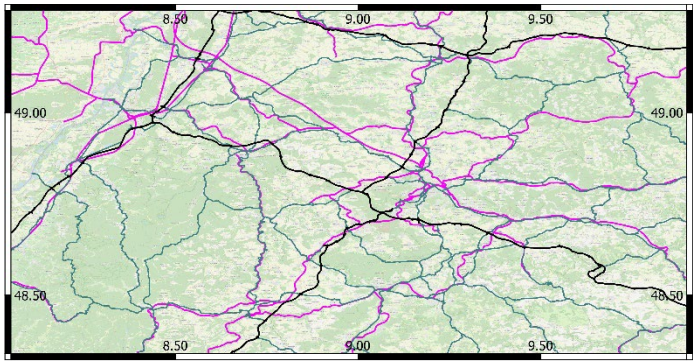


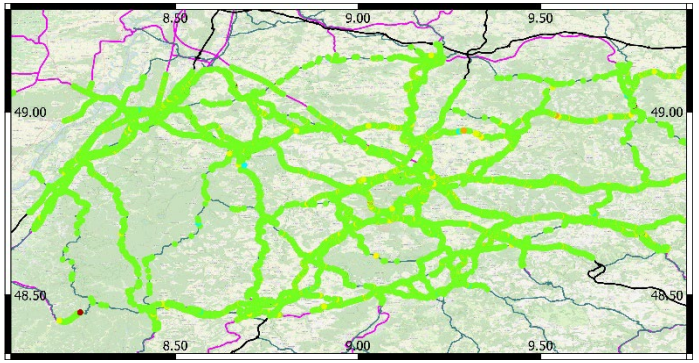


EGMS, ascending, path 015

- Use of shapefiles for
  - motorways and federal roads in Baden-Württemberg (provided by LGL)
  - train tracks of Deutsche Bahn
- The shapes were subdivided in segments of different lengths (25 m, 50 m, 100 m).
- To assess the coverage of the different InSAR products, we determined the **percentages of segments that contain at least one PS** in a perpendicular distance of less than 10m from each segment.
- The total length of the investigated train tracks is about 1450 km, the one of motorways about 1500 km and the one of federal roads about 2800 km.

Coverage of linear infrastructure with data of BBD or EGMS in Northern Baden-Württemberg





Percentages of segments, which contain at least one PS

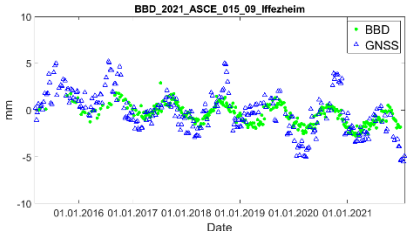
	Length of segments (m)	BBD, vertical	BBD, asc., path 015	BBD, desc., path 066	BBD, asc. +desc.	EGMS, vertical	EGMS, asc., path 015	EGMS, desc., path 066	EGMS, asc. +desc.
German Railways	25	5.4	25.4	28.2	42.0	3.7	58.9	57.68	70.8
	50	10.5	38.2	41.6	55.8	7.2	70.7	69.0	79.4
	100	16.3	46.4	50.2	63.0	11.8	75.6	74.1	83.0
Motorways	25	2.9	12.8	14.3	22.3	3.6	32.5	40.0	48.0
	50	5.0	18.6	21.2	30.7	6.4	41.4	51.0	57.5
	100	7.7	23.9	27.5	38.0	10.3	48.2	59.2	64.2
Federal roads	25	3.1	8.9	9.2	16.0	2.9	28.0	27.4	39.6
	50	5.1	12.8	13.2	21.6	4.9	35.0	34.4	46.6
	100	7.0	15.9	16.3	25.7	3.7	39.3	38.7	50.4

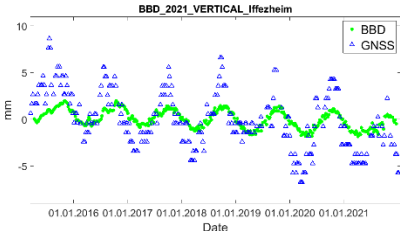
- Coverage in LoS is much better than in vertical direction
- EGMS shows a distinctly better coverage than BBD

Good agreement between GNSS and BBD or EGMS

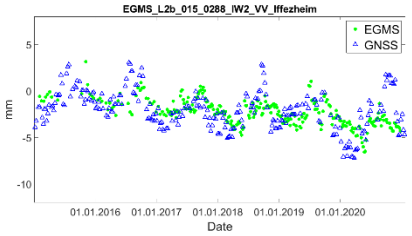
SAPOS station at lockage Iffezheim

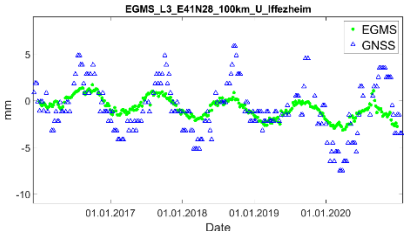
BBD





EGMS

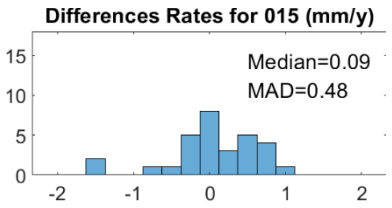


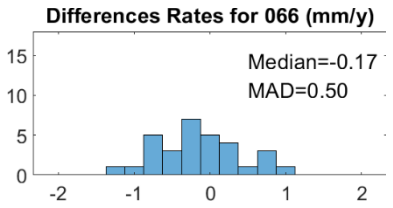


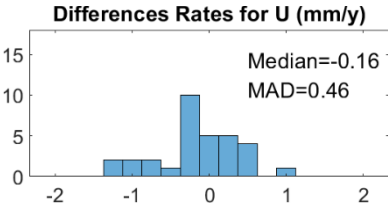
Time series of GNSS stations of the SAPOS network in Baden-Württemberg and in bordering regions were provided by LGL.

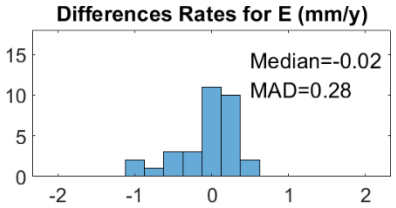
32 stations were nearby points of BBD and 36 (32 plus 4 French or Swiss stations) nearby points of EGMS.

BBD

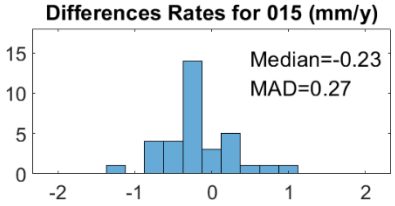


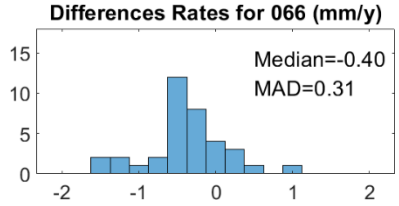


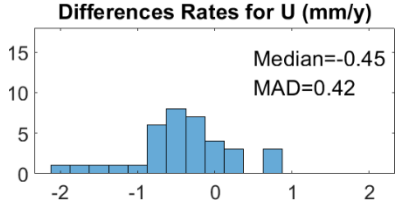


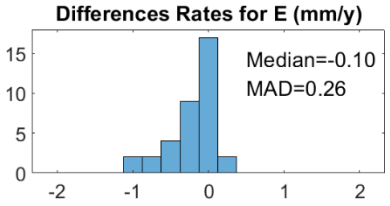


EGMS



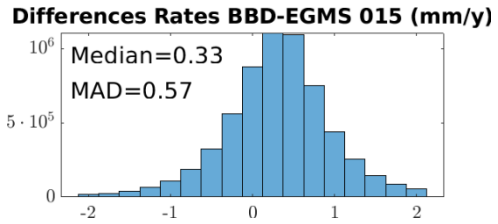


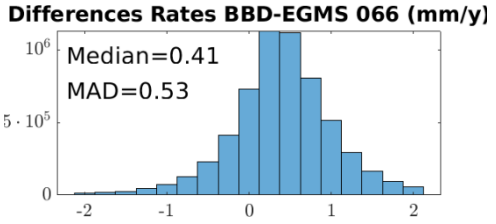


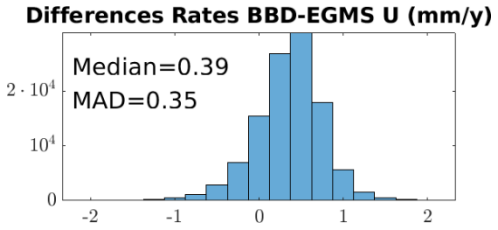


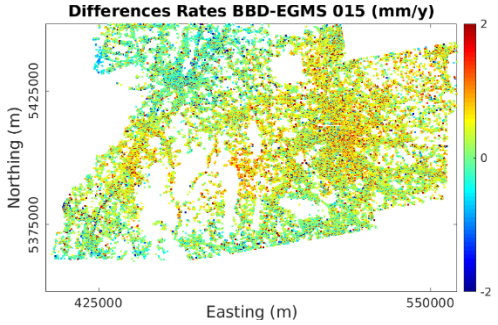
- BBD is slightly less biased than EGMS.
- Typical error characteristics of GNSS are visible.

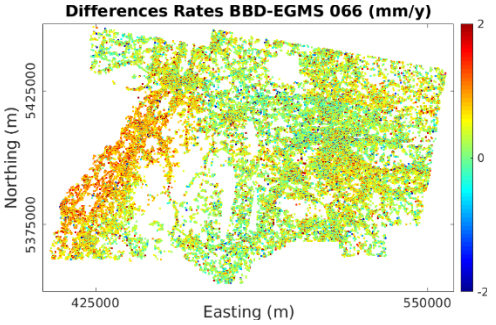
Baden-Württemberg: BBD versus EGMS

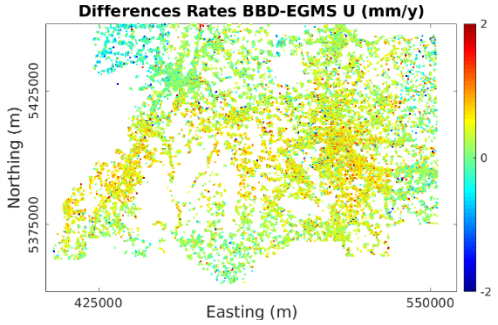


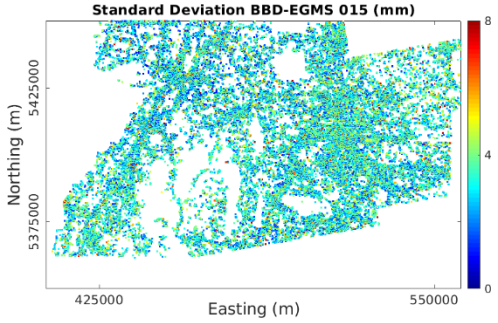


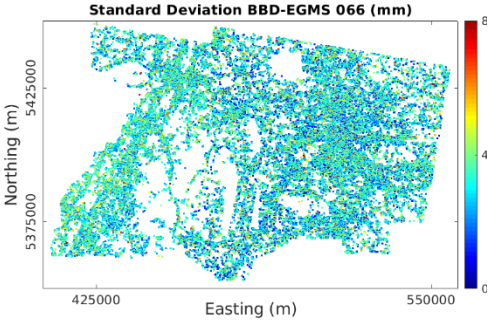


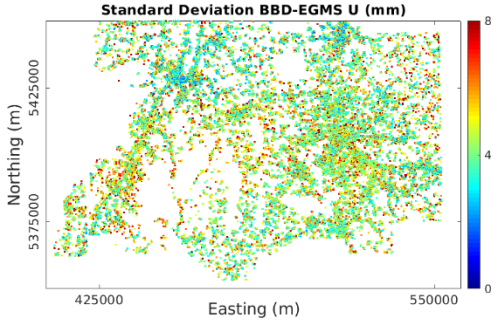


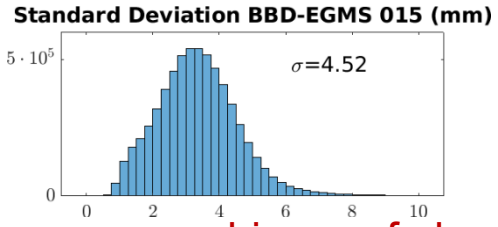


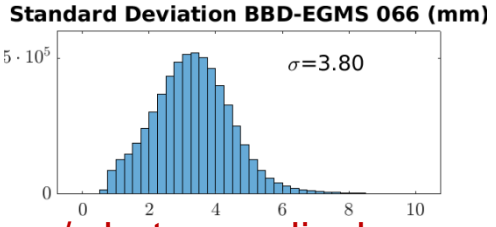


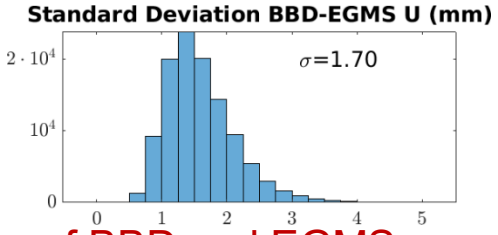






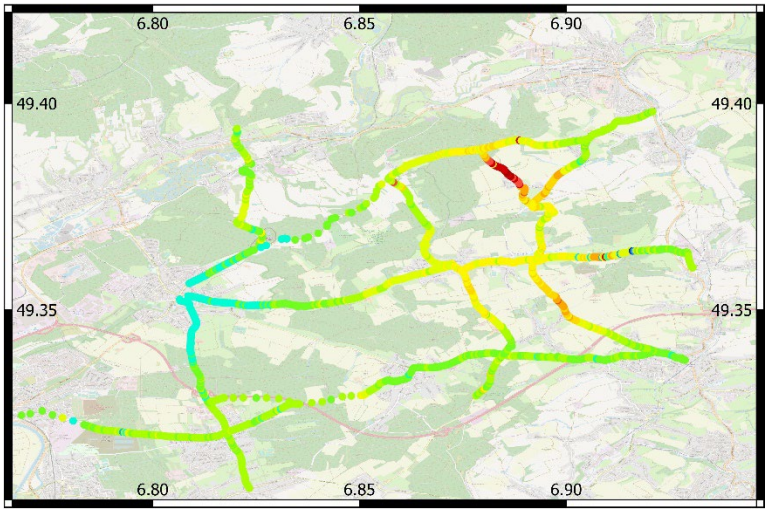






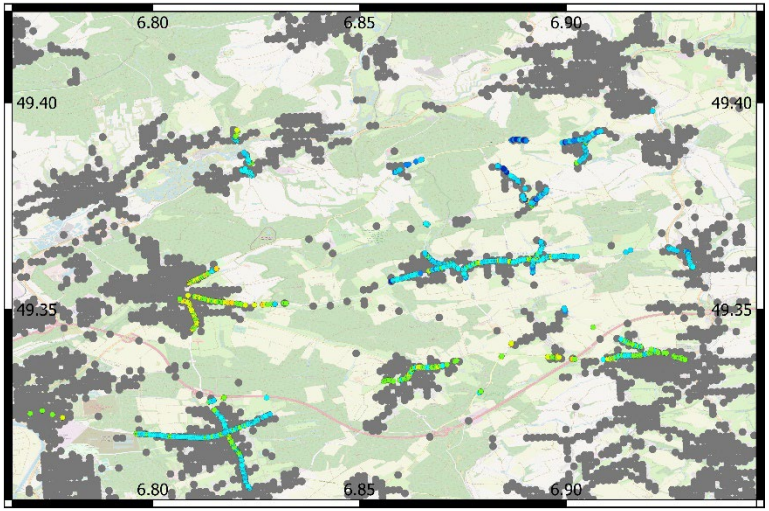
- biases of about 0.4 mm/y between displacement rates of BBD and EGMS
- overall standard deviations for LoS of about 4 mm

Saarland:Comparison of vertical displacements of BBD and EGMS versus levelling data

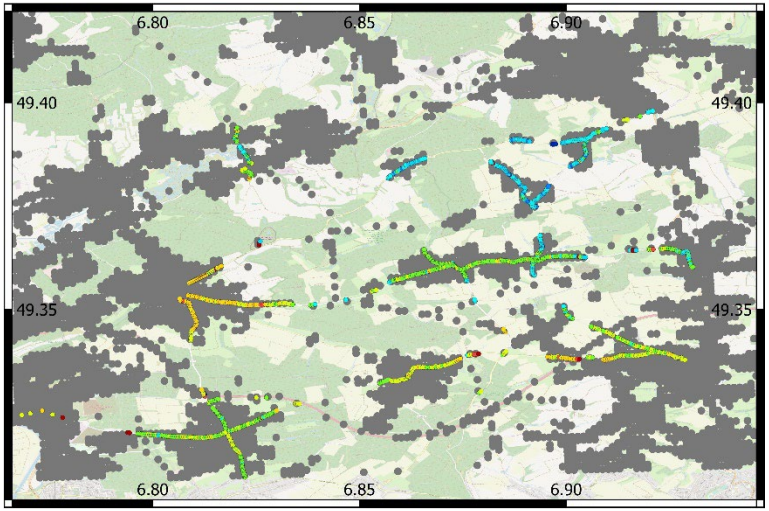


Displacement Rates
Levelling (mm/y)
-10.2 - -9.0
-9.0 - -7.8
-7.8 - -6.6
-6.6 - -5.4
-5.4 - -4.2
-4.2 - -3.0
-3.0 - -1.8
-1.8 - -0.6
-0.6 - 0.6
0.6 - 1.8
1.8 - 3.0
3.0 - 4.2
4.2 - 5.4
5.4 - 6.6
6.6 - 7.8
7.8 - 9.0
9.0 - 10.2
OpenStreetMap

During the period April 2016 to April 2021, where both data from BBD and EGMS are available, RAG performed **ten approximately half-annual measurement campaigns** at Primsmulde (**2436 levelling points**), a former hard coal mining area.



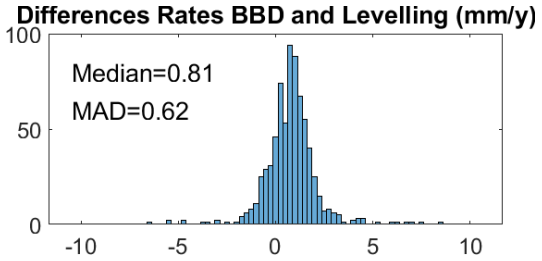
Differences
Displacement Rates
(mm/y)
-3.6 - -2.8
-2.8 - -2.0
-2.0 - -1.2
-1.2 - -0.4
-0.4 - 0.4
0.4 - 1.2
1.2 - 2.0
2.0 - 2.8
2.8 - 3.6
BBD Points
OpenStreetMap

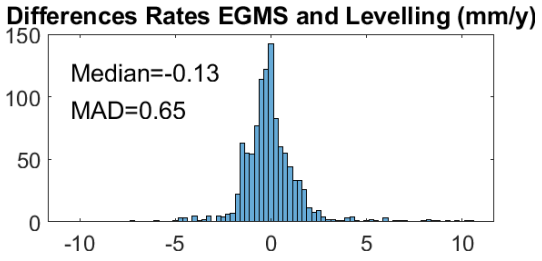


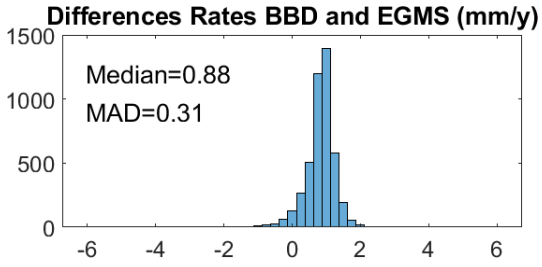
BBD, 727 PS

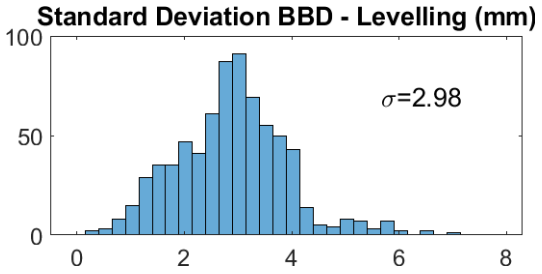
EGMS, 1024 PS

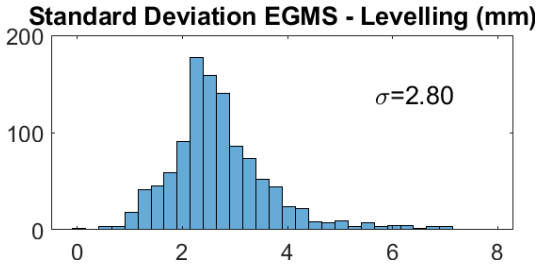
Saarland: Comparison of BBD and EGMS versus levelling data

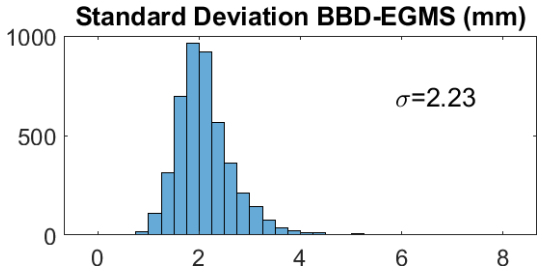






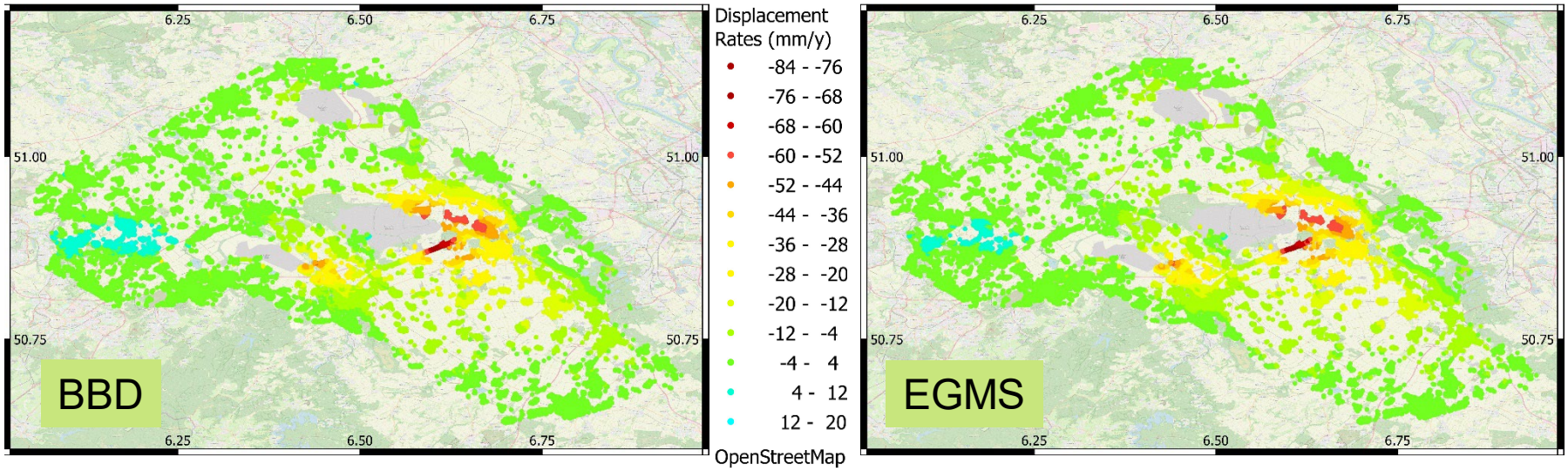


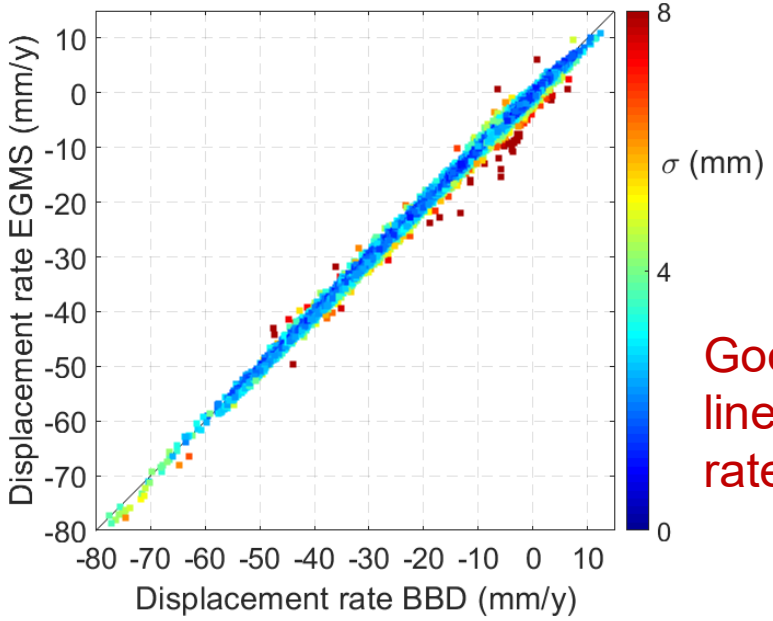




- larger bias between BBD and levelling than between EGMS and levelling
- overall standard deviations for all three comparisons are moderate
- good general agreement

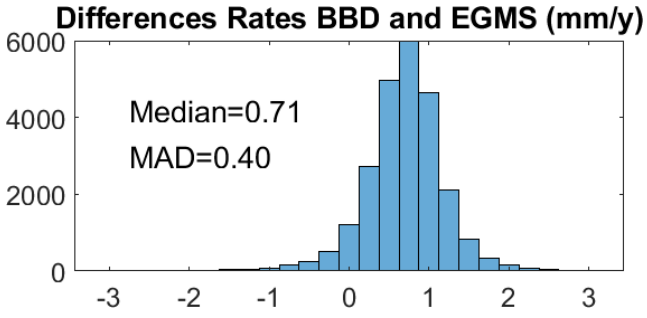
Western NRW: BBD versus EGMS



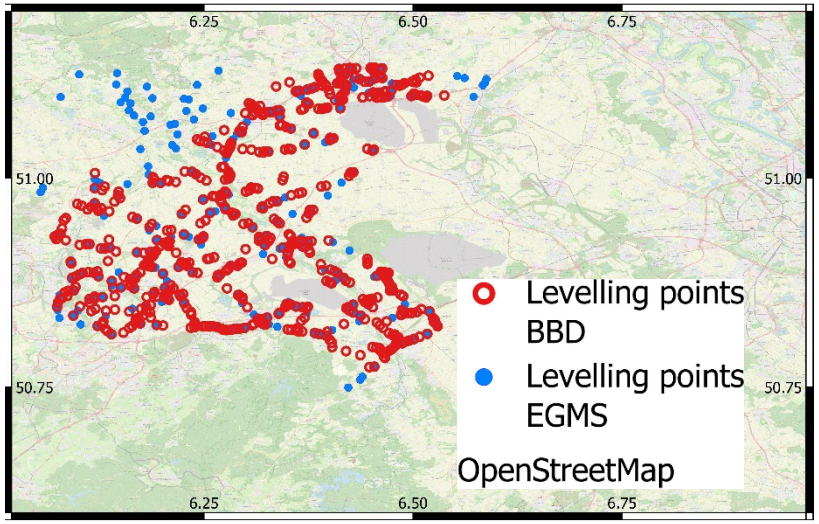


- linear subsidence caused by lowering the ground water table in the surroundings of lignite surface mines
- uplift as a consequence of the flooding of former hard coal mines (Aachen mining district)

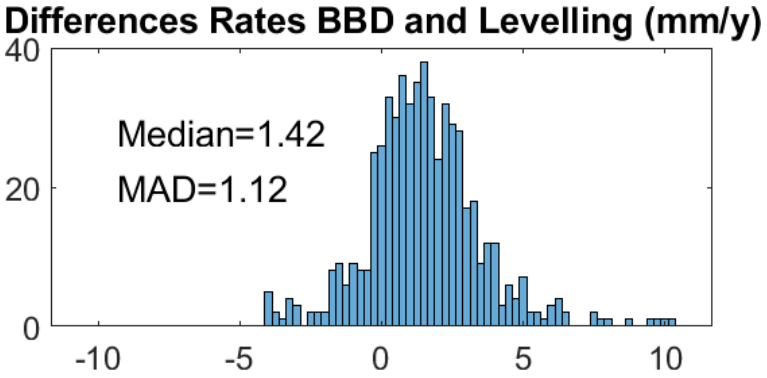
Good agreement of linear displacement rates (24376 points)!

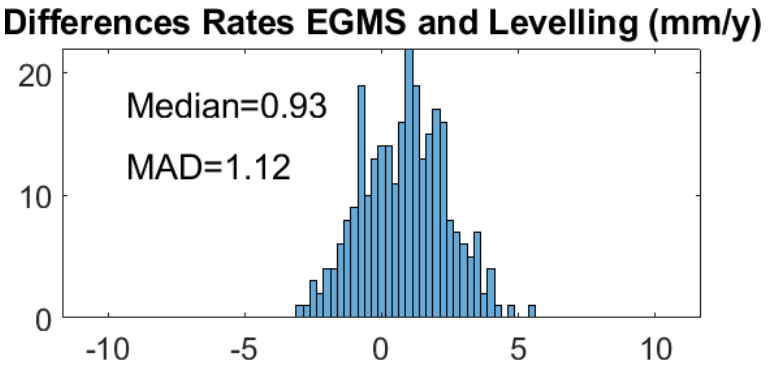


Western NRW: Comparison of BBD and EGMS versus levelling data



- Levelling campaigns in 2017 and 2019 were used for the comparison (611 points BBD and 278 points EGMS) of displacement rates.
- Observation: Moderate biases

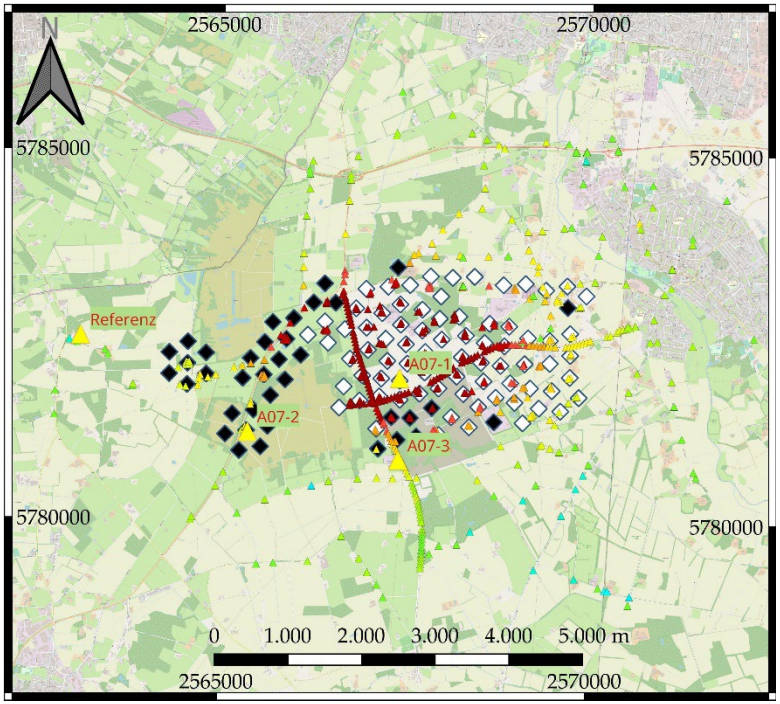




Cavern storage field Epe: Unwrapping error caused by strong gradients of the displacement field

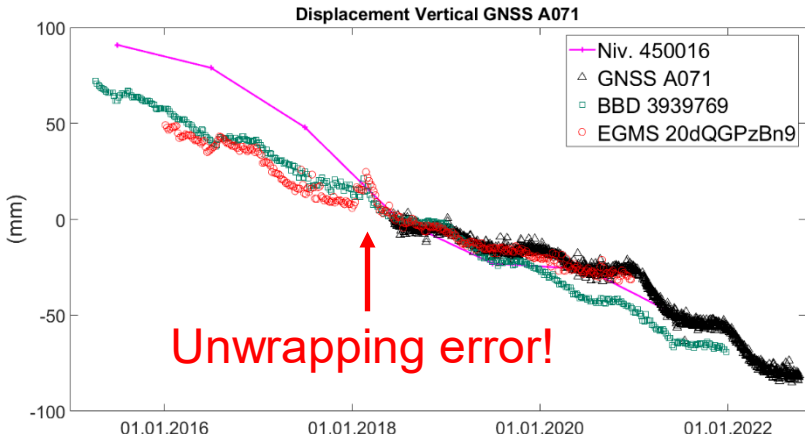
Three phenomena contribute to displacements at Epe :

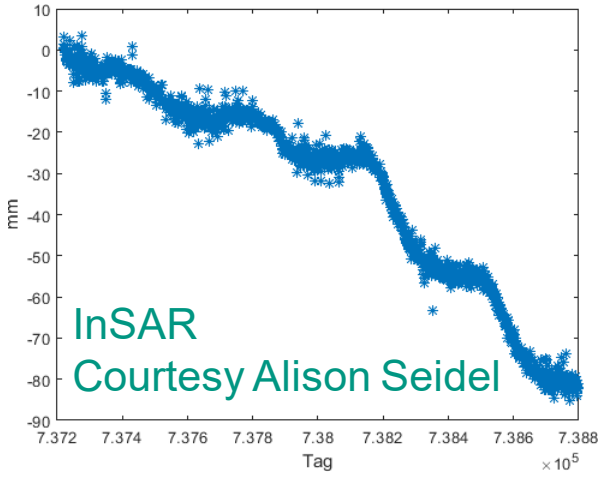
1. Shrinkage of caverns due to flow of the surrounding salt
2. Movements in response to pressure changes in the gas filled caverns
3. Seasonal movements with changing groundwater levels of the Hündfelder Moor



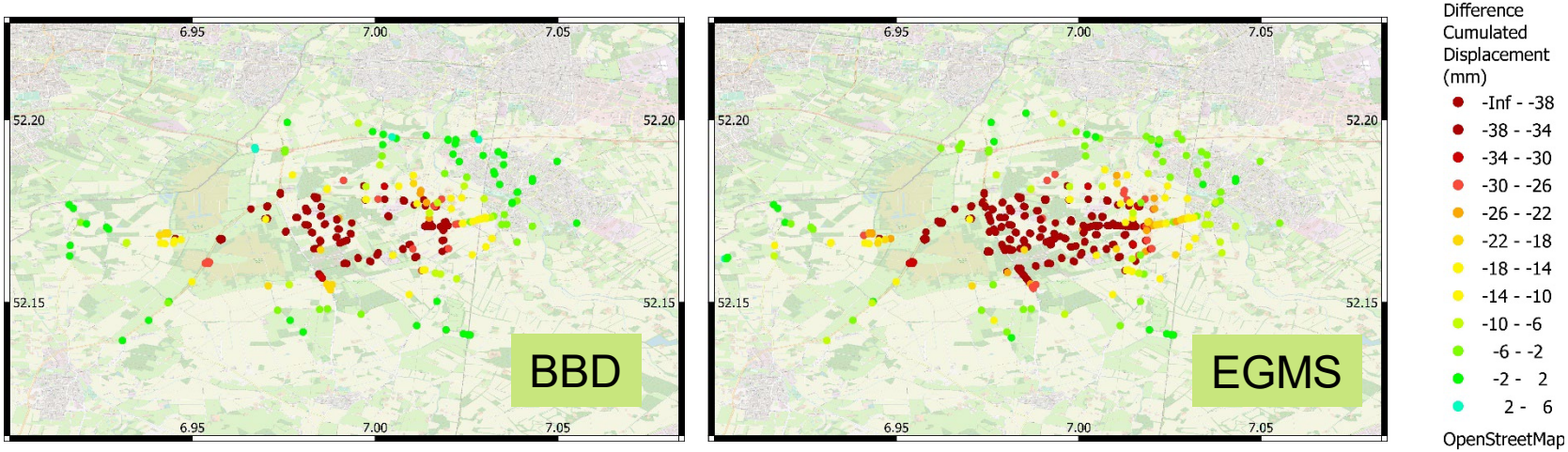
The levelling data were collected by the owner SGW during **annual campaigns** from 2015 to 2021 at **615 measurement points**. In order to achieve comparability, the **campaigns from 2016 to 2021 were used**, when data from both BBD and EGMS are available. We used 303 levelling points close to points of BBD and 447 levelling points close to points of EGMS.

Cavern field Epe: Unwrapping error caused by strong gradients of the displacement field





Differences between cumulated displacements of InSAR and levelling for the period 2016 to 2021



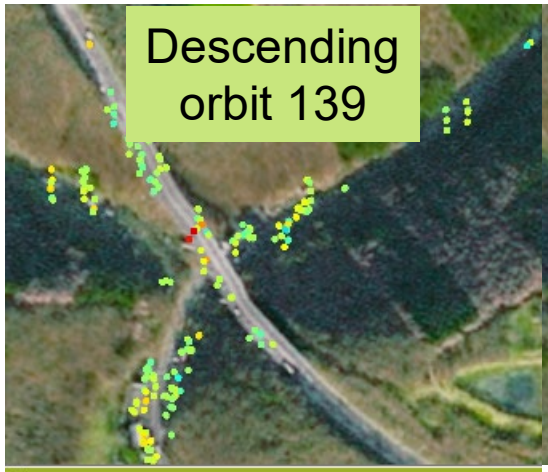
- displacement model linear + sinusoidal cannot describe the displacements adequately
- differences of ~40 mm of cumulated displacement between levelling and BBD or EGMS

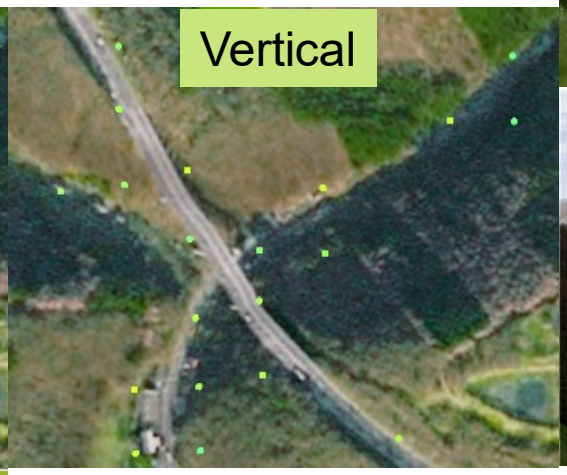
Summary Comparisons

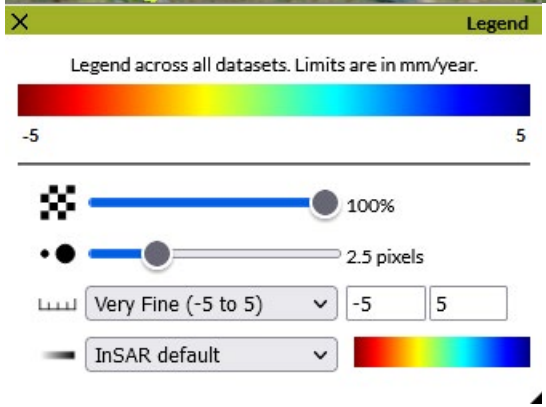
- Generally, both services show good performance and good agreement.
- An exemption is the cavern field Epe, where strong gradients of the displacement field and a temporal displacement pattern that cannot be described by the linear + sinusoidal model lead to large deviations from the displacements according to levelling.
- The calibration of BBD is somewhat better than that of EGMS for SAPOS in Baden-Württemberg.
- The coverage on train tracks, motorways and federal roads is better for EGMS.
- Because of the distinctly better coverage should InSAR based monitoring use LoS products.

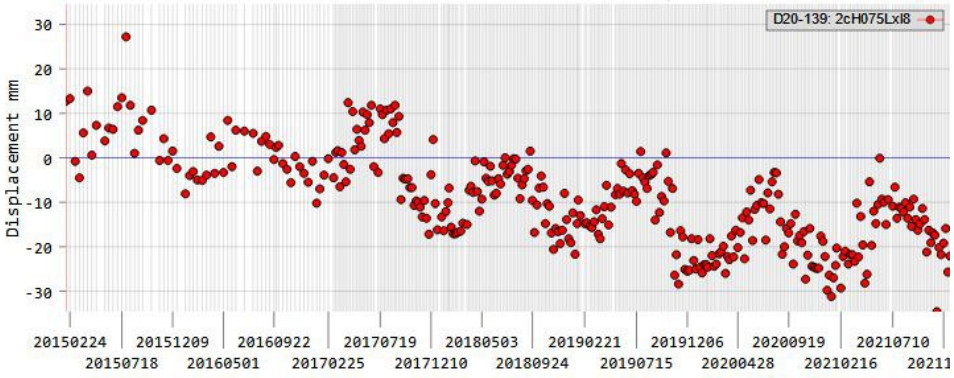
Detection of anomalies for the example of the viaduct of motorway A45 near Rahmede (EGMS)

In December 2021 heavy damage to the bridge had been discovered in the course of surveying works that caused immediate closure. On 7th Mai 2023 it has been blasted.









Considerations for the future

- In Germany, several states are currently introducing InSAR monitoring based on Sentinel-1 data (Saarland, NRW, Lower Saxony). Baden-Württemberg as well is in the initial stage of implementing such a monitoring system.
- A possible product could be anomaly detection along train tracks, motorways and federal roads. Although higher resolved data are superior regarding coverage and positioning, BBD/EGMS data could help to provide additional information on an ageing infrastructure on a large scale.

- @EGMS: Use of PS + DS for better coverage is desirable.
- @EGMS: Use of temporary PS + DS is desirable.
- @EGMS: Better point positioning would be helpful.

Thank you for your attention!

Markus Even, Malte Westerhaus, Hansjörg Kutterer
German and European Ground Motion Service: A Comparison
Submitted to PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science

We are grateful to Jenny Uskow and Hans-Georg Dick of LGL for providing geodetic data of Baden-Württemberg. Furthermore, we want to thank RAG, namely Michael Drobniewski, Ute Kristin Weißenborn, Andreas Thoß and Steffen Bechert, for providing the levelling data of Saarland. For the levelling and GNSS data of Epe we want to thank SGW, in particular Stefan Mayer. Last but not least, we are grateful to André Kalia of BGR for providing information on the processing of data for BBD and EGMS.