



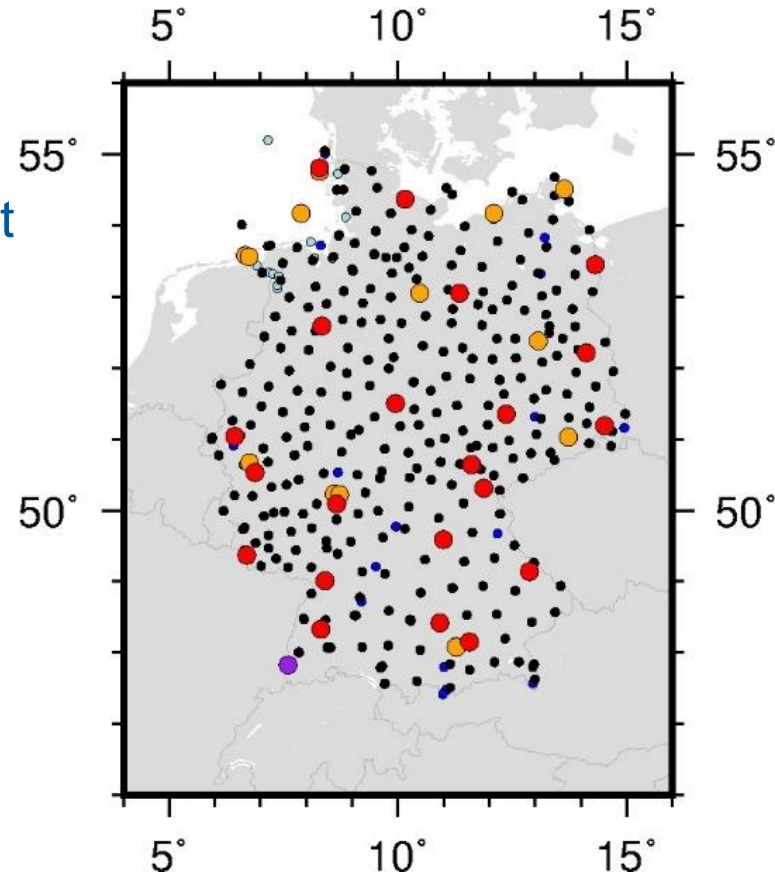
# INVESTIGATING GNSS-BASED SURFACE DEFORMATION IN GERMANY: PRELIMINARY RESULTS BASED ON PPP

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# GNSS Stations in Germany

- GNSS data from approx. 450 stations with observation periods of up to 25 years
- Initial PPP solution to derive (preliminary) surface deformation results as starting point for further investigations

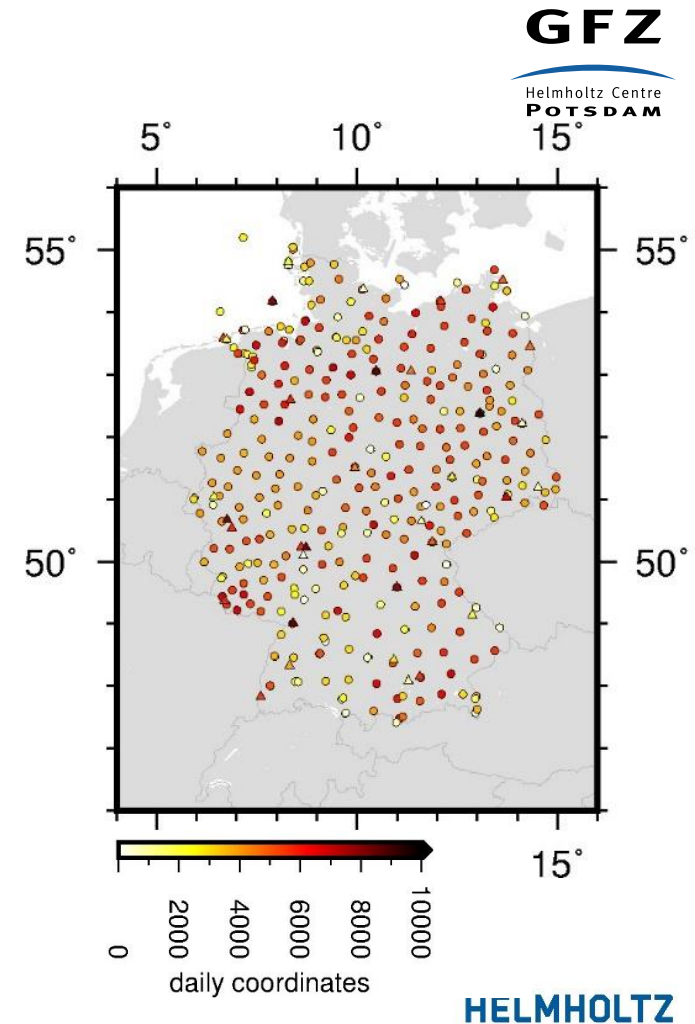
Network	#	Remarks
SAPOS	340	<a href="https://sapos.de/">https://sapos.de/</a>
REF	27	Bundesamt für Kartographie u. Geodäsie
EPN	29	
IGS	1	(if not also EPN)
GFZ	25	(if not also EPN)
Tide Gauges	16	Federal Institute of Hydrology
others	9	



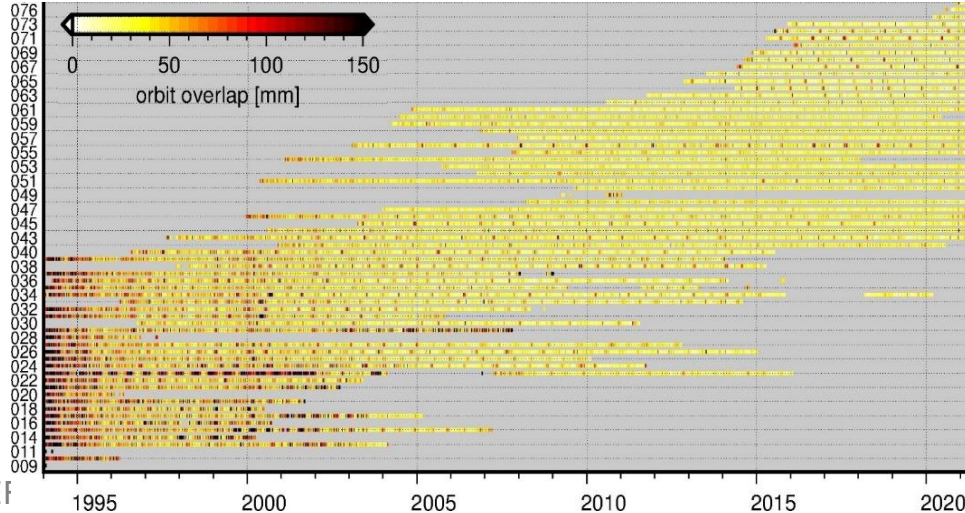
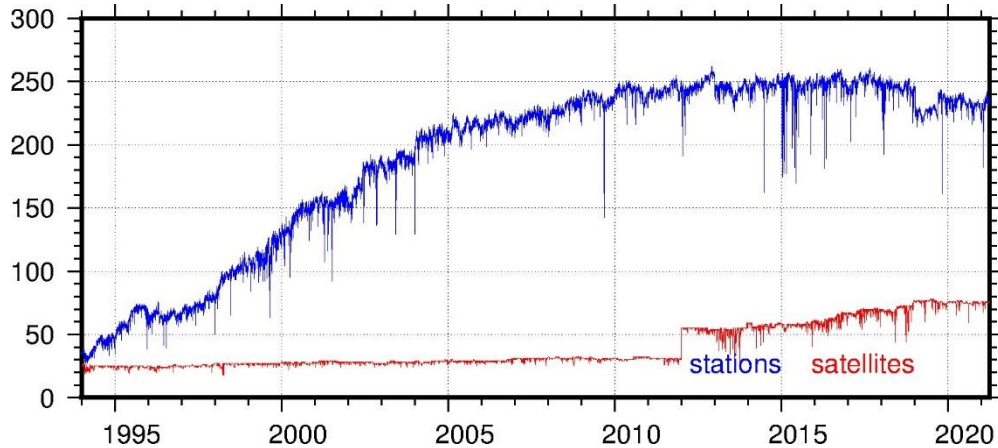
# GNSS Processing

- GNSS PPP processing based on GFZ's repro3 solution

PPP Setup	
observations	GNSS zero-difference phase observations, ionosphere-free linear combination
coordinates	estimated w.r.t. IGSR3 (introduced via orbit products)
troposphere	GMF, ZTDs 1 h intervals, gradients with 24 h intervals
clocks are pre-eliminated every epoch, phase ambiguities are pre-eliminated	



# IGS Repro3: GFZ Products



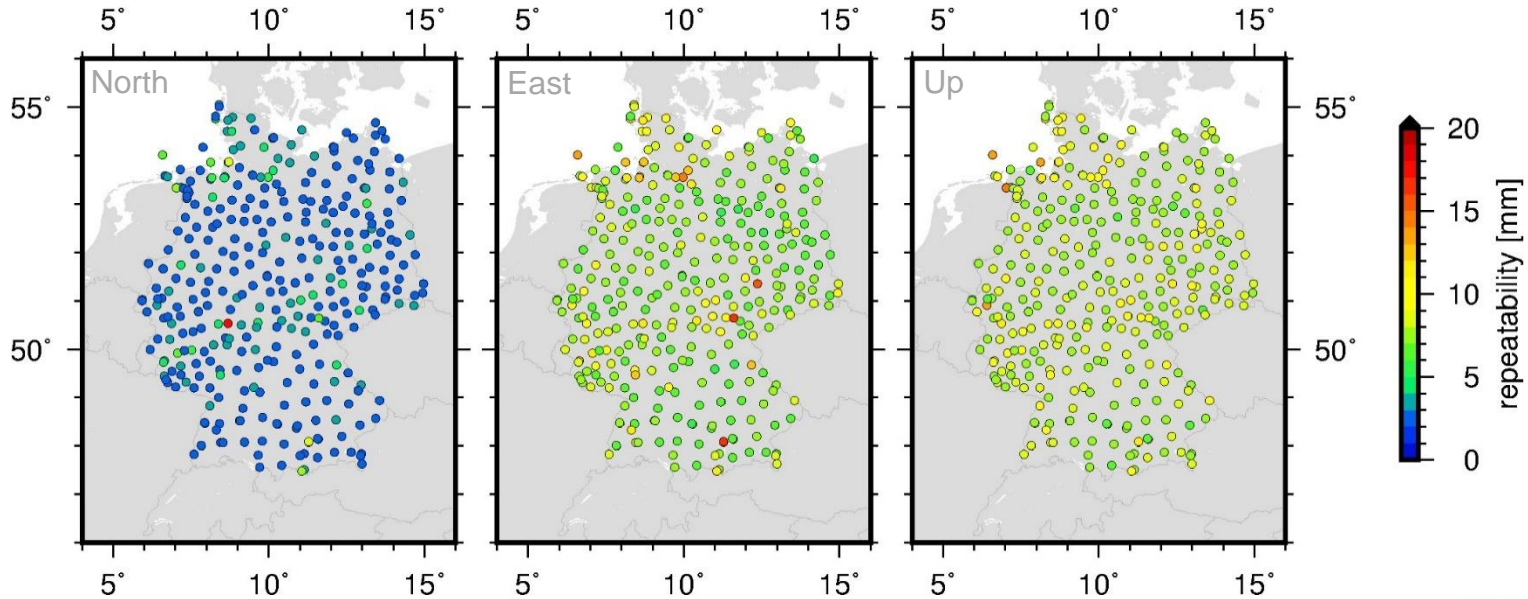
## Key facts

Number of stations	322
Number of satellites	132 (G:67, R:39, E:26)
Systems	GPS, GLONASS (>2012), Galileo (>2014)
GNSS phase center	Dedicated multi-GNSS ANTEX
Models	IERS2010 Conventions + GOCO6s, FES2014b, Desai-Sibois model, linear mean pole
Parameters	Coordinates, Orbits, ERP, ZTD, Gradients, (PCO), ISBs

Männel et al. (2021): GFZ repro3 product series for the International GNSS Service (IGS). GFZ Data Services. <https://doi.org/10.5880/GFZ.1.1.2021.001>

# Coordinate Repeatabilities

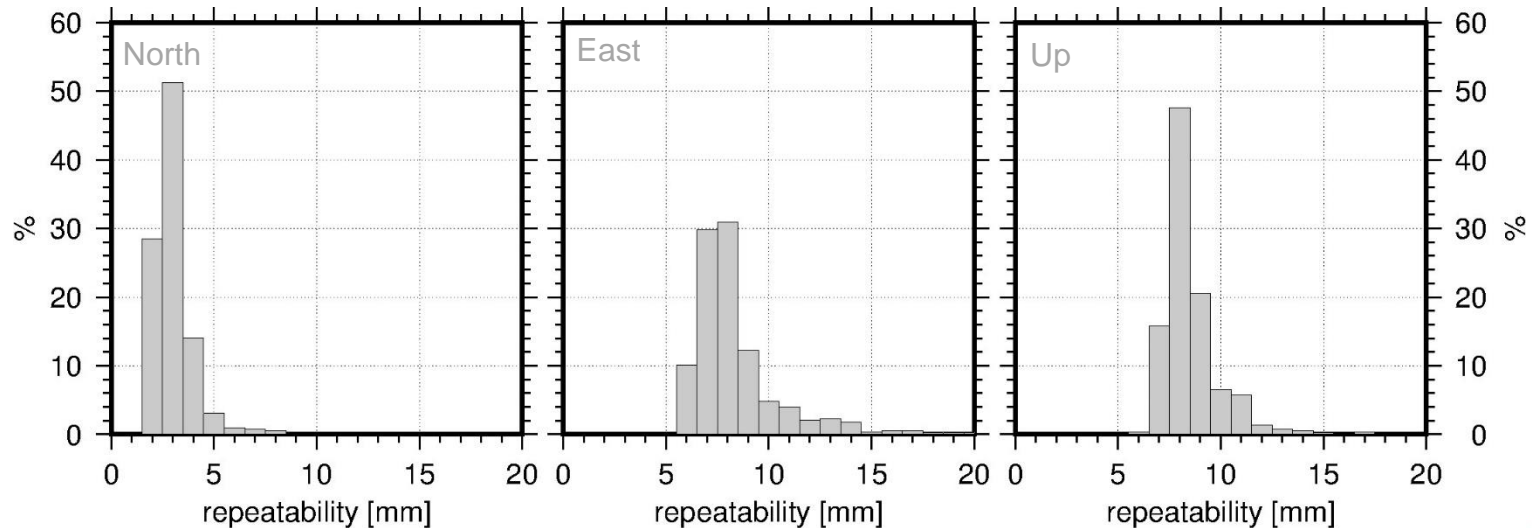
- Simply station coordinate trajectory model (linear velocity, offsets to account for station displacements, annual signal as sine function)
- Repeatability, e.g. differences between daily and final solution





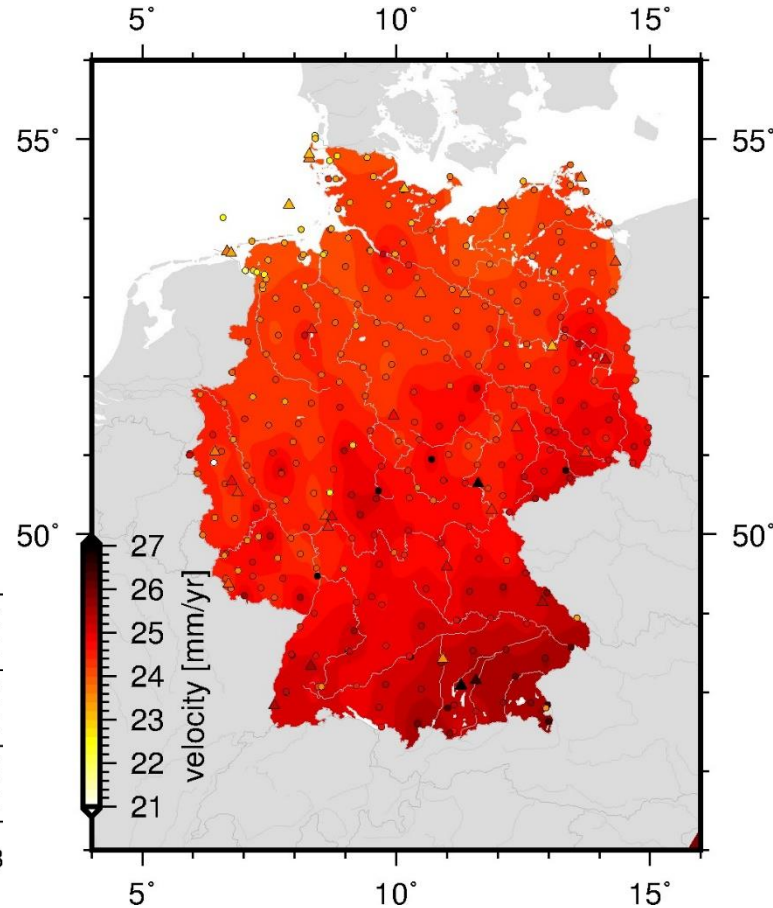
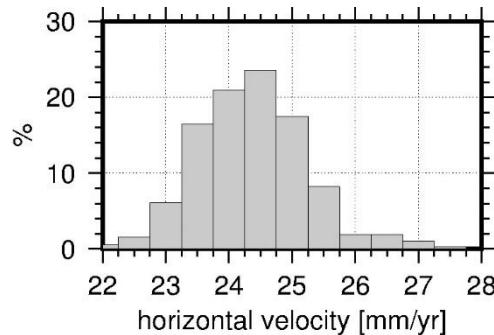
# Coordinate Repeatabilities

- Only stations / intervals of >900 solutions and >1500 days are considered
- Repeatability, e.g. differences between daily and final solution
- Statistics [unit mm]:  $N = 2.1 \pm 0.1$  (rms 1.1),  $E = 5.9 \pm 0.2$  (rms 2.9),  $U = 6.1 \pm 0.2$  (rms 3.1)



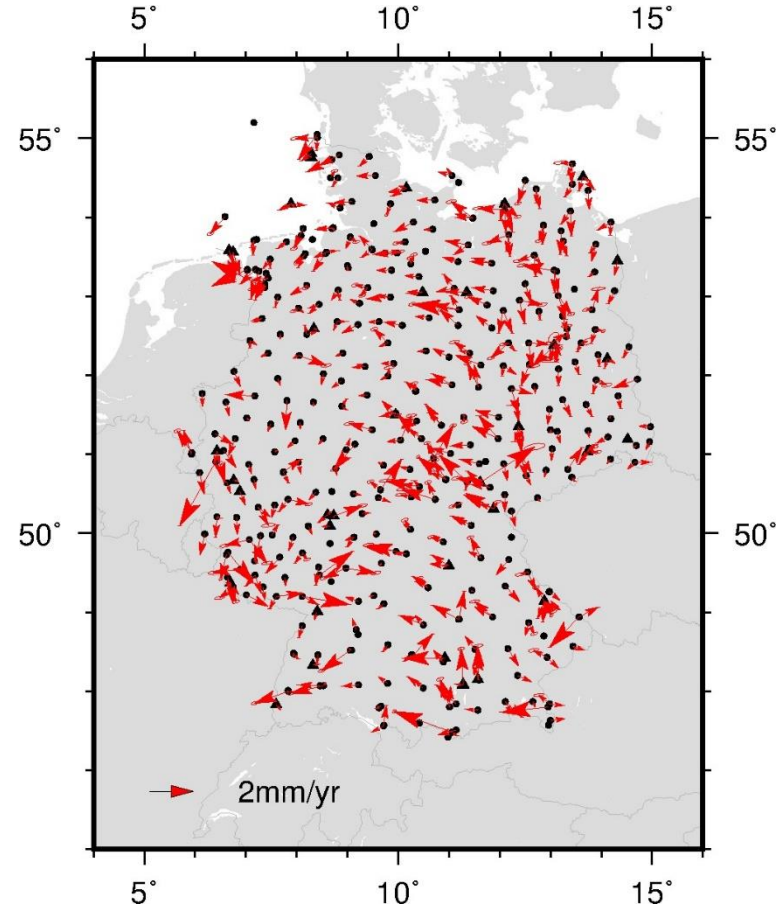
# Horizontal Velocities

- Reference frame: IGSR3 reference frame
- Velocity in North-East direction between 23 and 26 mm/yr
- Larger velocities in Southern Germany
- GREF, EPN, and IGS stations are indicated by triangles, others by circles



# Horizontal Velocities

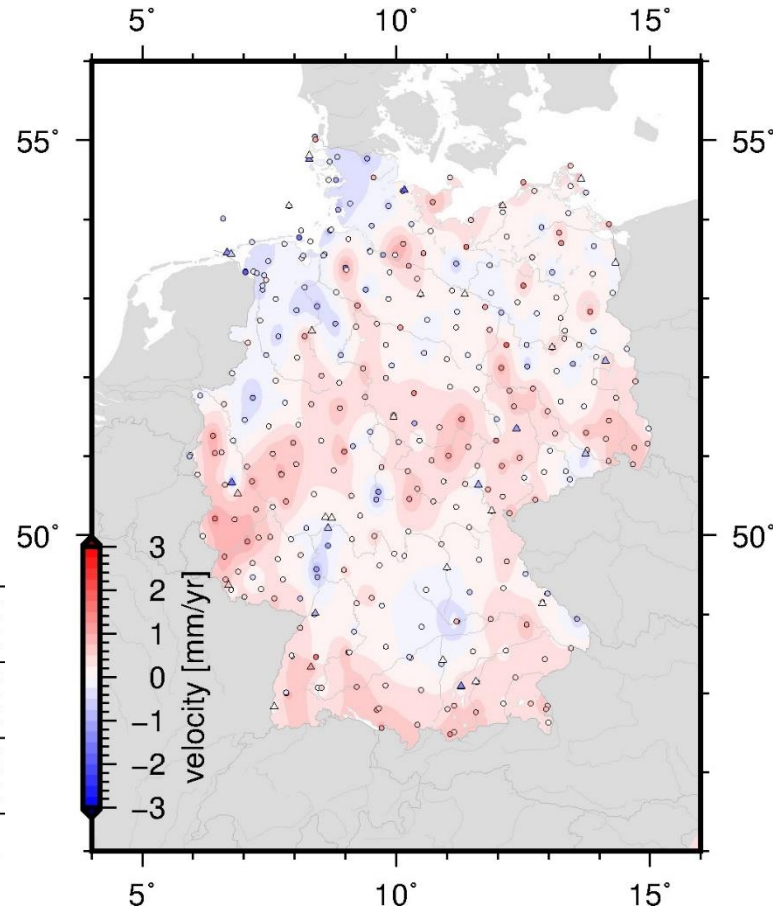
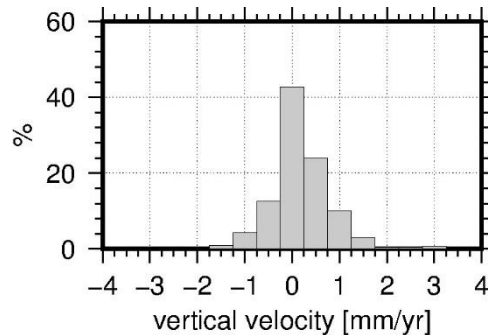
- For each station the plate motion is subtracted (UNAVCO plate motion calculator, ITRF2014 model)
- Remaining velocity (= residual) are potentially
  - artefacts,
  - reference frame issues or
  - intra-plate velocities





# Vertical Velocities

- Mostly close to zero
- Results overall noisy (PPP solution)
- Uplift in the Eifel region (Eifel volcanic fields) and potentially in Central Germany
- Subsidence at the North Sea coastline (Frisia)
- To be verified by network solutions



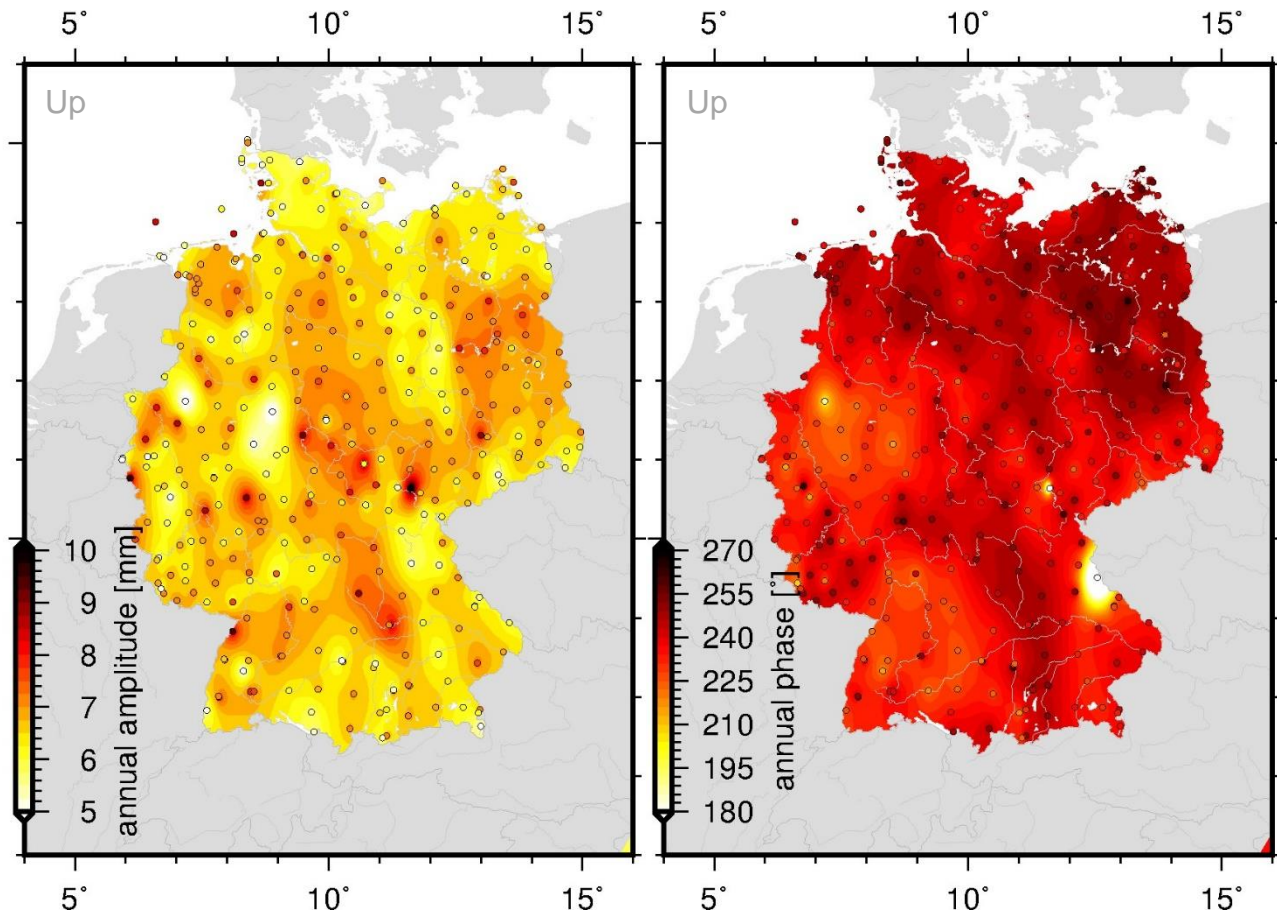
# Seasonal Signals

- Amplitudes

[mm]	Mean	RMS
N	$2.1 \pm 0.1$	2.4
E	$3.1 \pm 0.1$	2.1
U	$5.7 \pm 0.1$	1.2

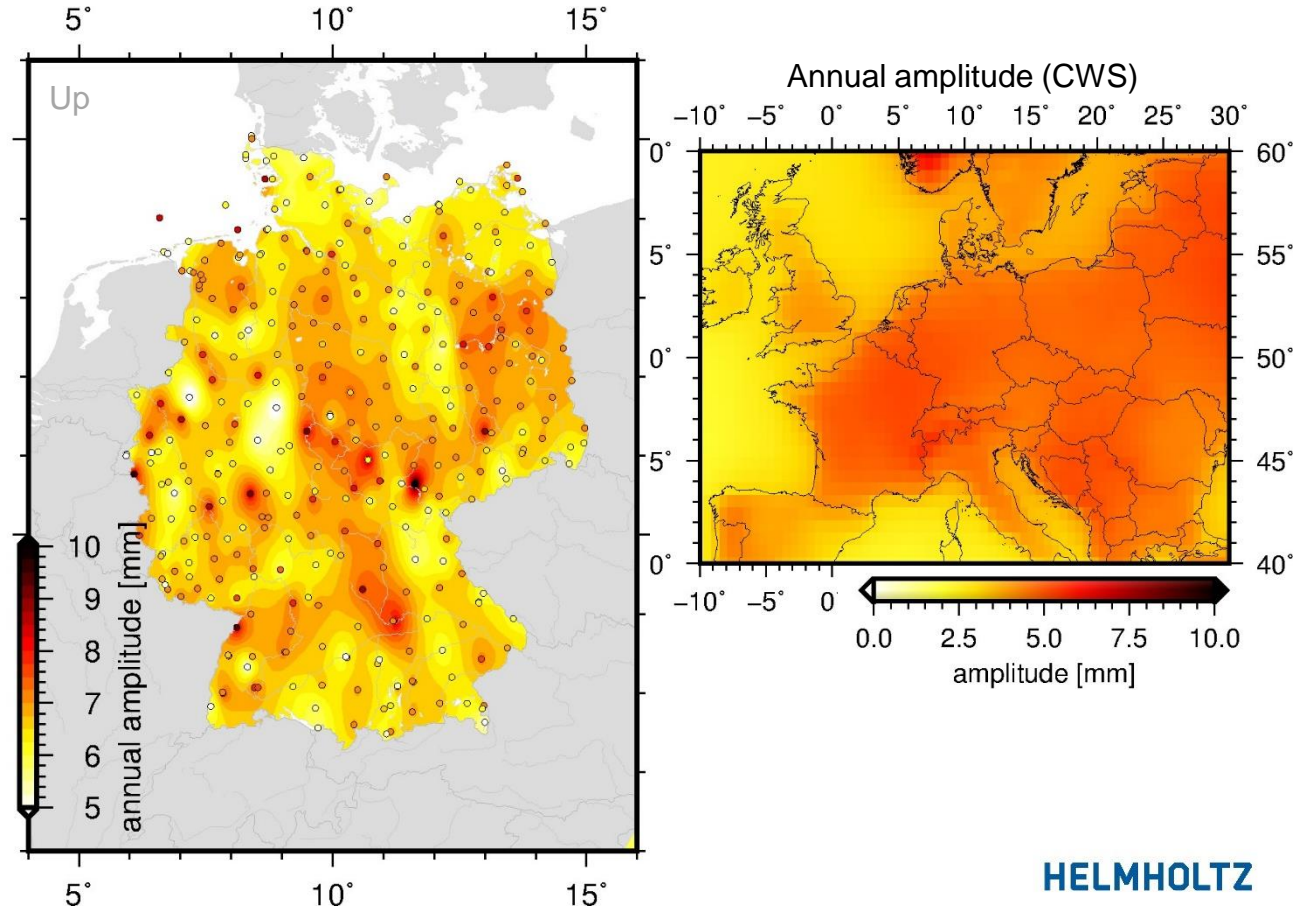
- Phase offset

[°]	Mean	RMS
N	$223 \pm 2$	45
E	$172 \pm 3$	61
U	$240 \pm 1$	11



# Seasonal Signals

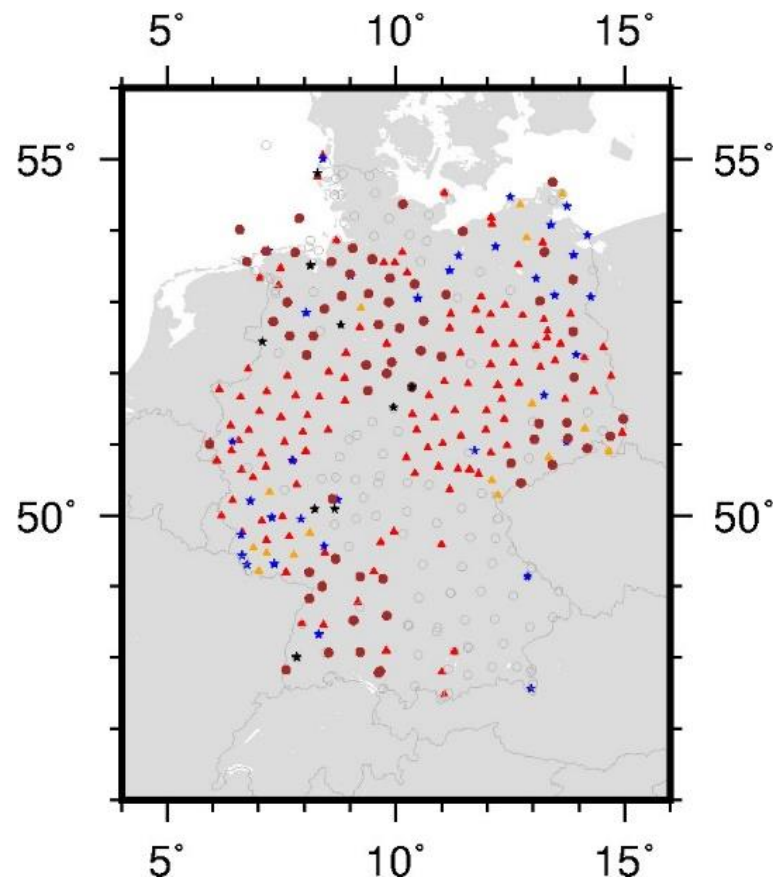
- Non-tidal loading corrections were not applied
- ESMGFZ models for continental water storage (amplitude 3-4 mm, phase offset  $\sim 210^\circ$ )



# Monuments

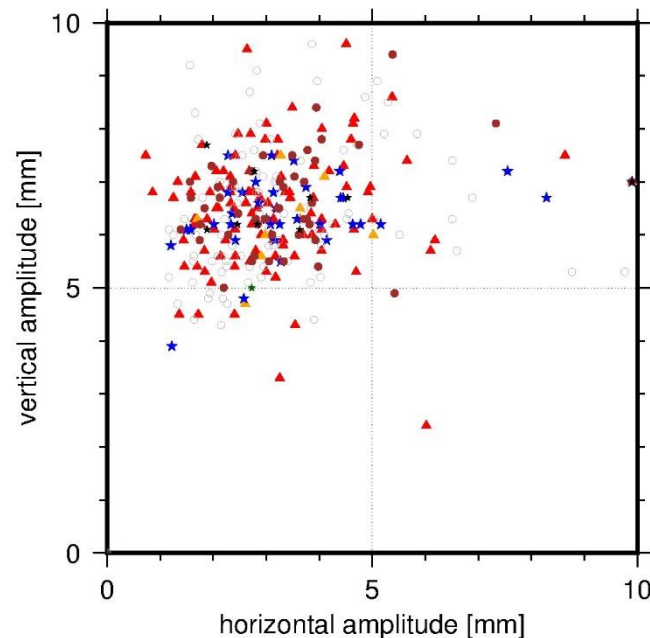
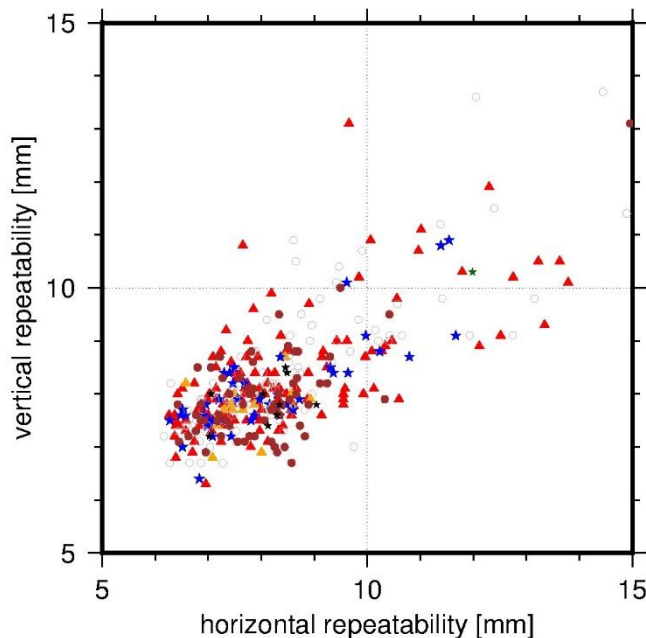
- Majority of stations was not deployed for geodynamic investigations → various monument types
- Based on the (inhomogeneous) site log information we tried an initial classification

Monument	Number	Symbol
Roof top	146	(triangle)
Wall	70	(circle)
Concrete pillar	55	(asterisk)
Chimney	16	(triangle)
Mast / Rack	11	(asterisk)
Not specified	149	Entry was empty or wrongly used



# Assessment of Monuments

- Main question: Are there systematics related to the monuments?
- Larger repeatabilities for some “roof-top” and “concrete” type stations, larger amplitudes for some stations → detailed study needed



## Monument

Roof top

Wall

Concrete

Chimney

Mast / Rack

Not specified



# Summary

- GNSS data from approx. 450 stations in Germany are processed
- Currently PPP solution based on GFZ repro3 products
- Preliminary results show:
  - Typical repeatability values for PPP (N: 2 ... 4mm, E & U: 5 ... 10mm)
  - The expected homogeneous horizontal velocity pattern (23 ... 26 mm/yr)
  - In some regions small uplift (Eifel) or subsidence (Frisia) rates (-1 ... 1 mm/yr)
  - Homogeneous pattern of annual amplitudes (U: ~6 mm) and phases (U: ~240°)
- Next steps:
  - Network adjustment
  - Detailed investigation in monument stability

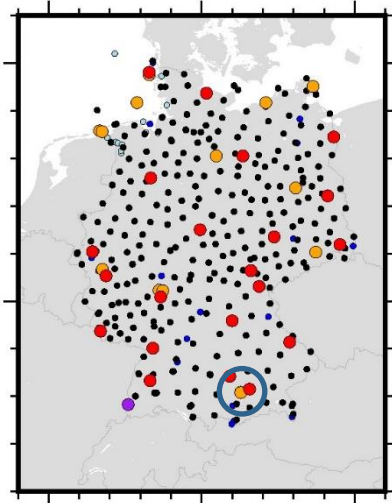
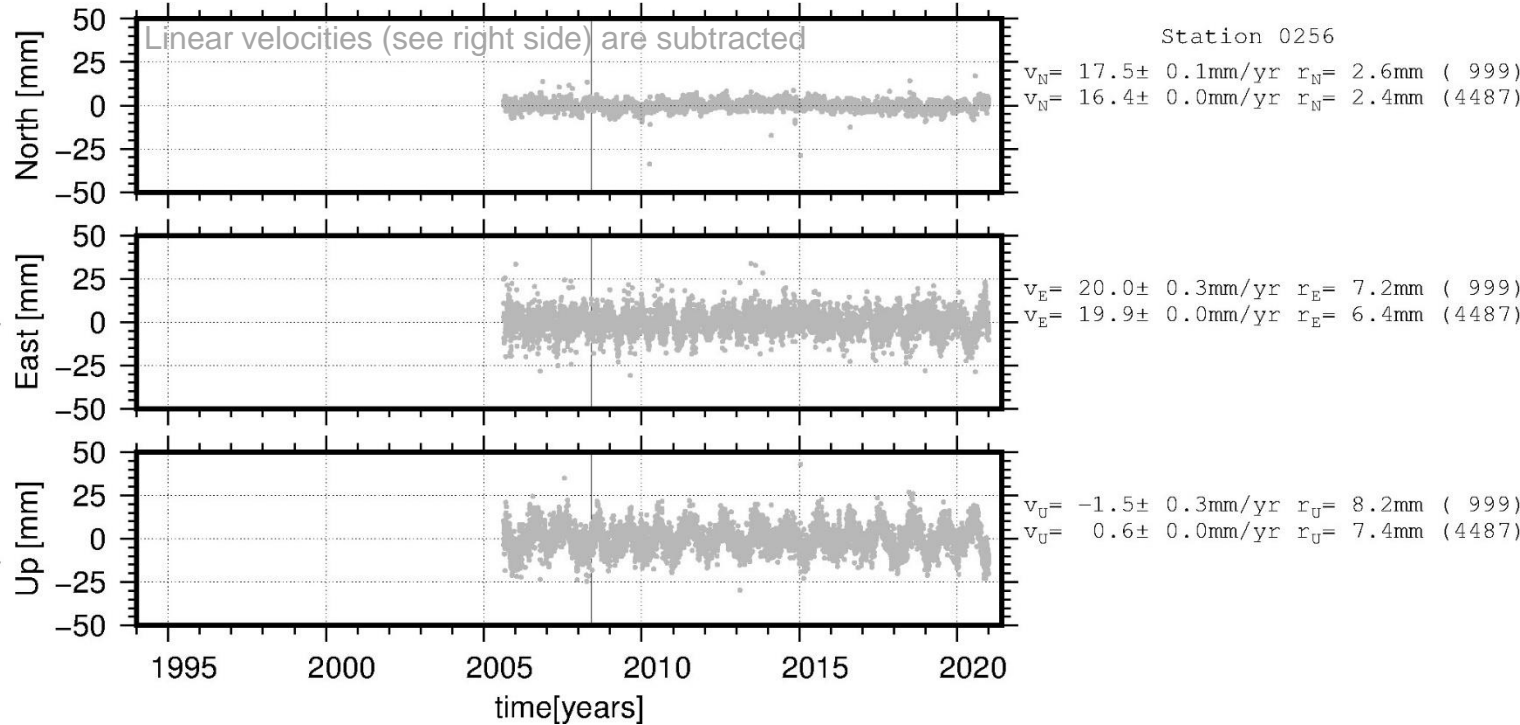
# Thank you

Contact: [benjamin.maennel@gfz-potsdam.de](mailto:benjamin.maennel@gfz-potsdam.de)

> [gnss.gfz-potsdam.de](http://gnss.gfz-potsdam.de) <

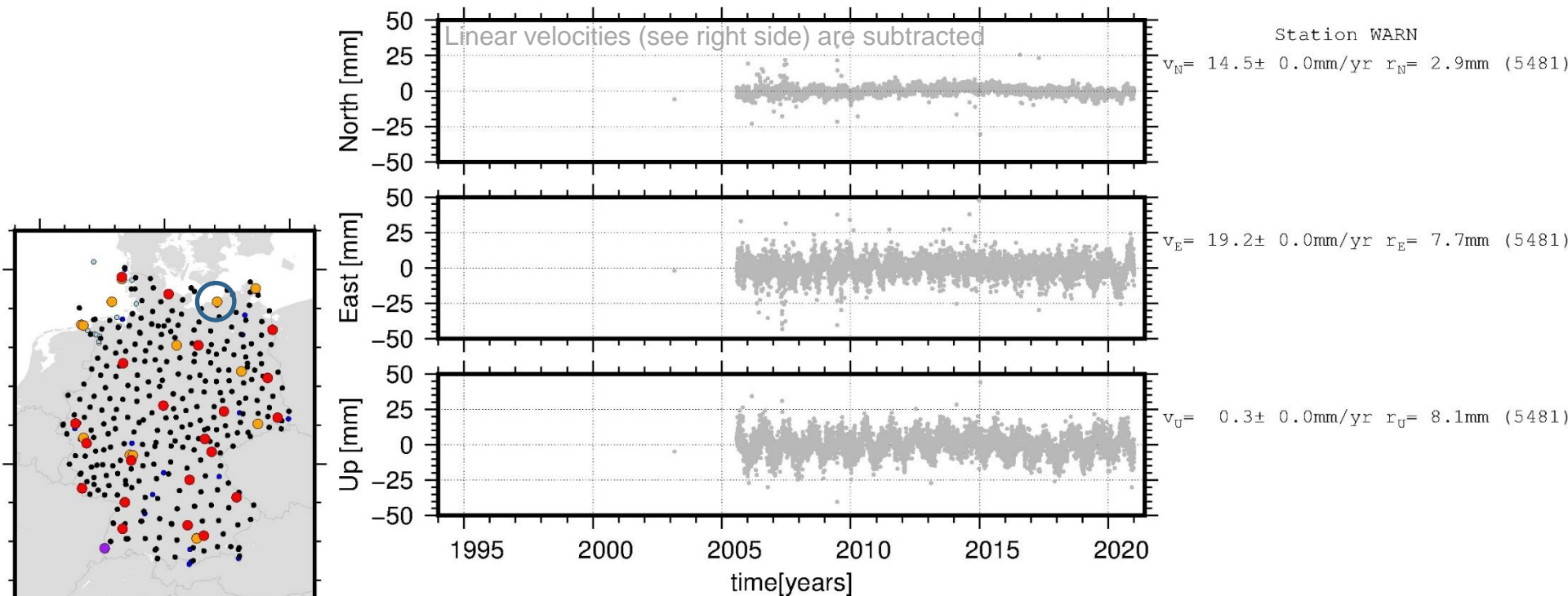
# Time Series

## ➤ SAPOS station 0256 (Munich)



# Time Series

## ➤ Station WARN (Warnemünde-Rostock)



# Horizontal Velocities

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- Remaining signal (= residual) are potentially
  - artefacts,
  - intra-plate velocities or
  - coordinate frame issues
- Only GREF, EPN, and IGS stations are plotted

