# Deformation Monitoring on Laacher See by GNSS

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## Introduction

The intracontinental volcanic systems west and north of the Alps, with the Massif Central and the Eifel as the two youngest volcanic regions, are characterized by large basaltic fields with hundreds of cinder cones and maars distributed over large areas, with episodic activity since about 60 Ma. The plumbing system beneath the Quaternary volcanic fields of the Eifel (EVF) is active and signs of incipient unrest have been recently detected. The transcrustal magmatic system has so far not been imaged with advanced geophysical techniques, although the Eifel region is ideally suited for applying and testing new models of magmatic systems and for inferring their implications for volcanic hazards and eruption scenarios.

In a recent paper by Hensch et al. (2019) it was discovered that the Laacher See Volcano (LSV), one of three explosive eruptive centers in the east Eifel with a VEI=VI eruption 13 ka ago, is affected by volcanic deep low frequency (DLF) earthquakes (Fig. 1), which are related to the unrest of magmatic fluids or magmas. The unrest activity started in 2013 and is ongoing today (latest located events in August 2021).

The East Eifel Volcanic Field (EEVF) region is unique areas characterized by clear uplift, a phenomenon driven by upper mantle upwelling with a diameter of ~200 km (Kreemer et al., 2020) and continuous magmatic processes. In our efforts to gain a deeper understanding of these geological dynamics, we focus on the Eifel region, where we aim to establish a dense GNSS network in collaboration with our partners since 2021 (Fig.2). This network is strategically positioned, particularly around the Laacher See Volcano (LSV). It includes 3 core stations (shown in red), which are collocated with seismic broadband sensors, tilt-meters, and corner reflectors. Simultaneously, 19 cost-efficient receivers (GFZ Tiny-Black).

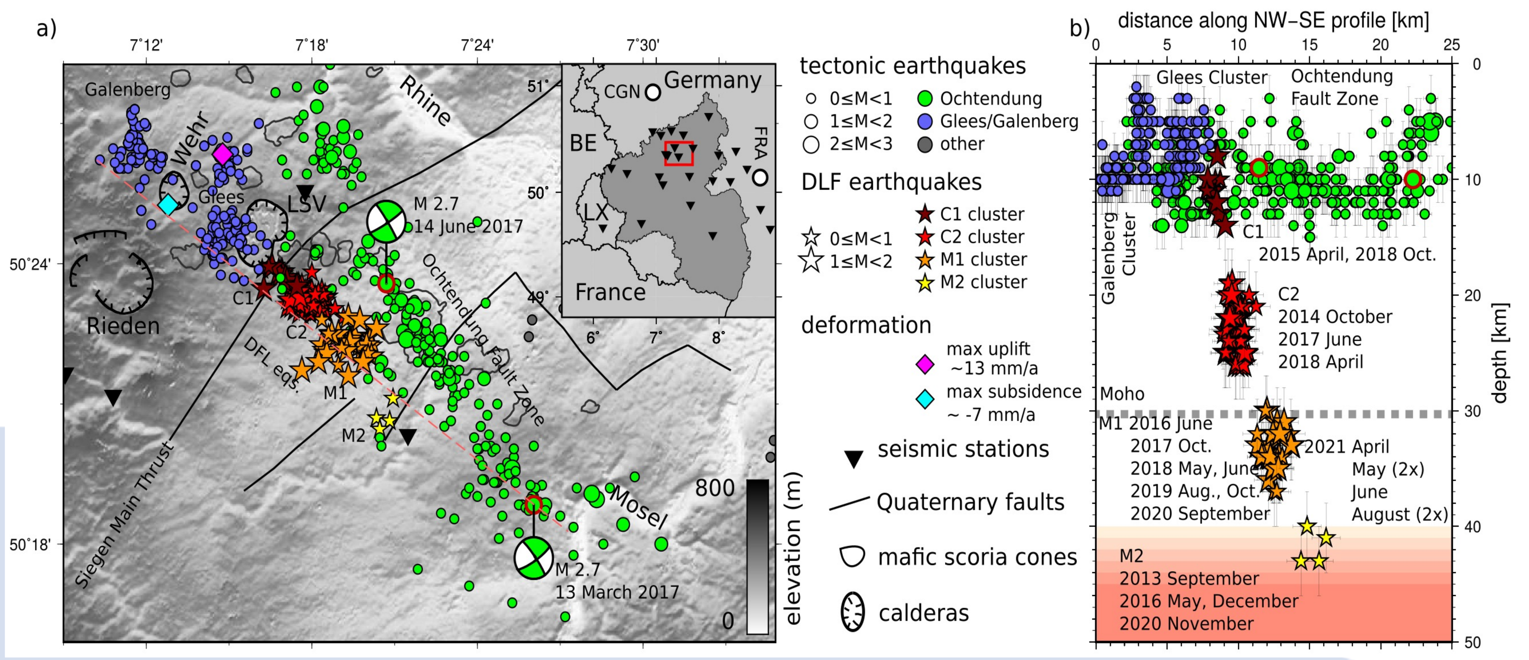



*Fig. 1: Topographic map of the East Eifel Volcanic Field (EEVF) including faults, calderas and scoria cones. Brittle earthquakes are marked as dots, DLF events as stars. Seismic stations are indicated as inverse triangles. Red circles mark the three largest tectonic earthquakes (ML > 2.3) in 2017. The small overview map outlines the target region as a red box, the state of Rhineland-Palatinate is highlighted in dark grey. A depth section of all earthquakes is given in the right-hand panel, seen in direction to N45°E (Hensch et al., 2019).*

## GNSS Data & Processing Strategy

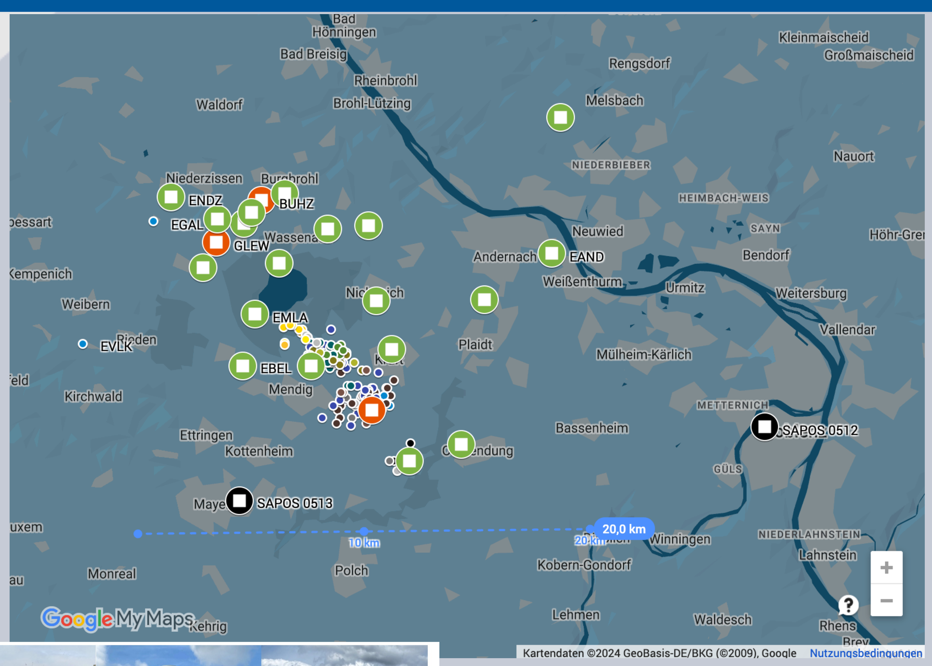


*Fig. 2: LSV GNSS network: 3 multi-parameter stations as core stations (red), 19 low-cost GNSS stations (green), 2 SAPOS stations (black); smaller dotes indicate DLF Earthquakes (the colour indicated depth).*

### GNSS Processing

The GNSS data processing is done in network mode. Currently total of 36 stations are analysed together. In the network processing all the stations are treated with the same weight. Since we do not fix any station in the network data processing, the coordinate solution is the same as a free network solution. The datum of the coordinate solution is defined by the satellite orbit & clock product (in ITRF2020) generated in GFZ. Routinely, we generate two solutions with varying resolution and delay:

**Daily Rapid static Solution**: 7-hours delay, achieves an accuracy of 2-5 mm.

**Hourly Ultra-Rapid kinematic Solution:** Generated with a 1-hour delay and employing a 24-hour sliding window, this solution attains an accuracy of better than 1 cm.

The same models and algorithms integral to our data processing as POD processing. A comprehensive list of these models and algorithms is given below:

**Observation data:**

24-hour data session, Ionosphere-free linear combination, un-differenced carrier phase and pseudo-range with sampling rate of 5 minutes, elevation cut-off angle 0°, elevation-dependent weighting: 1/2sin(e) for elevation e<30°

**Estimated parameters (Least Square Adj.):**

Station coordinates, ZTD per hour, gradients per 24 h and clocks of receivers per epoch

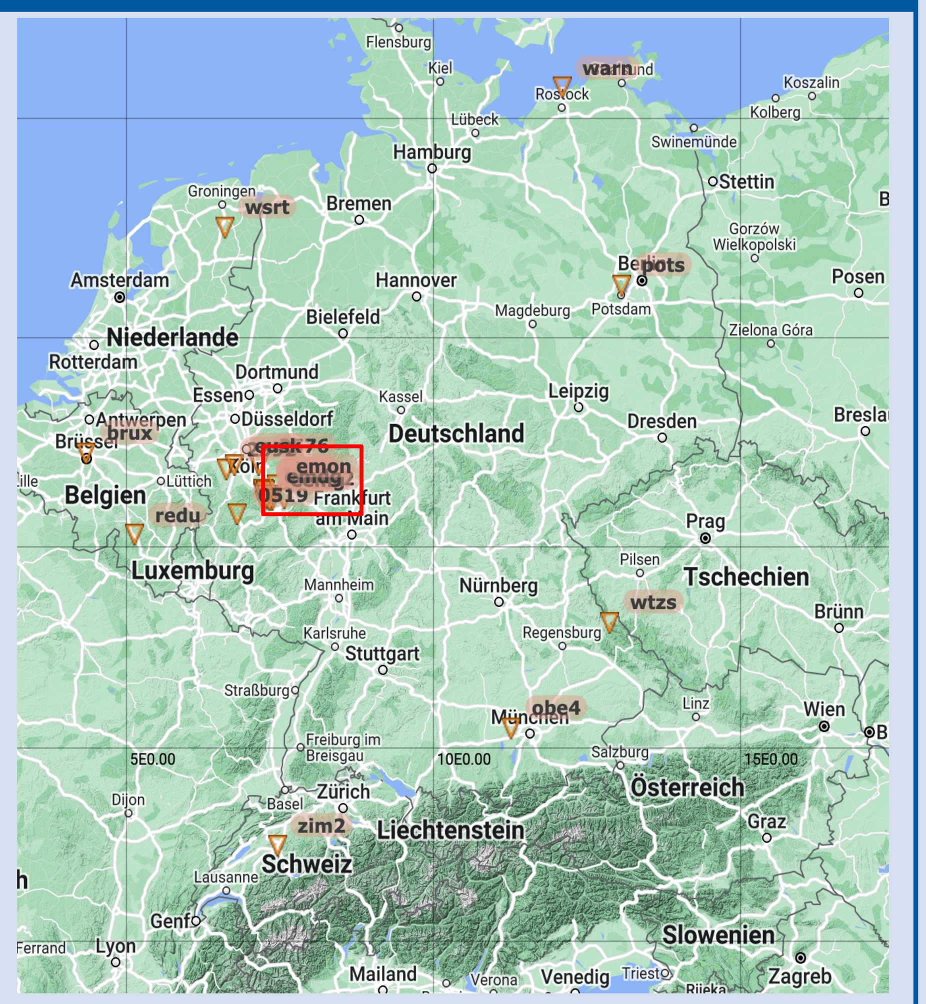
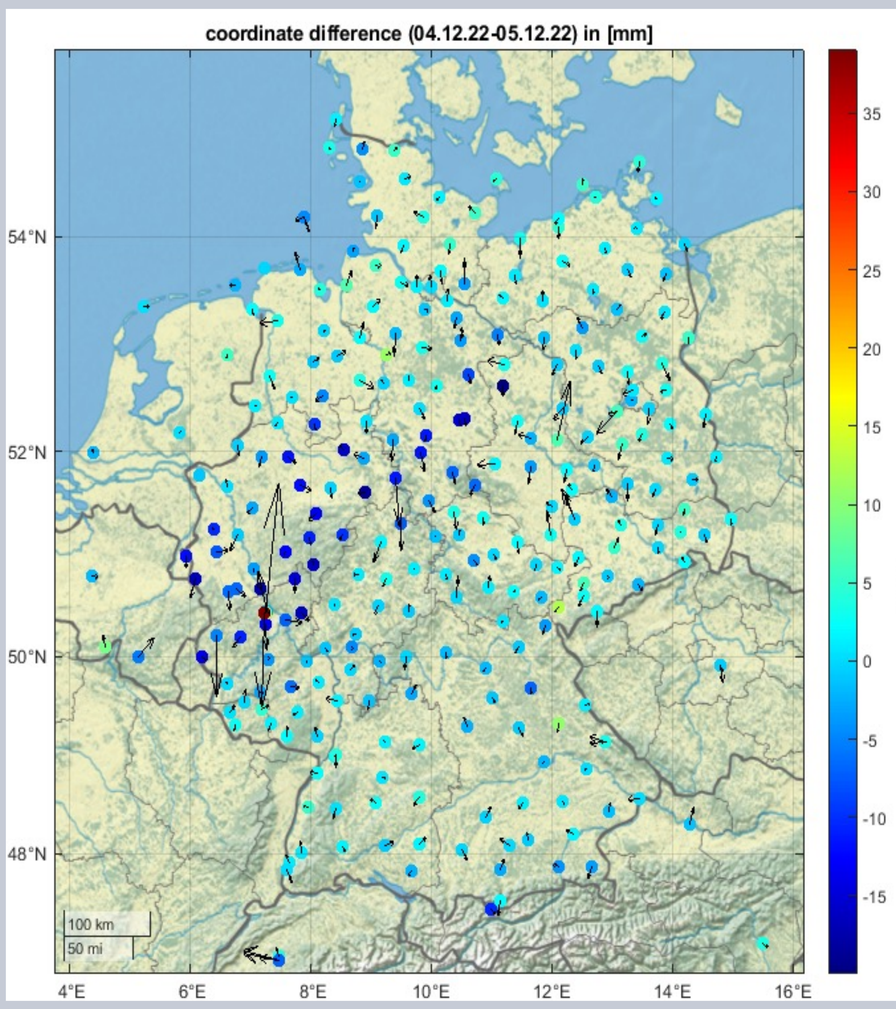
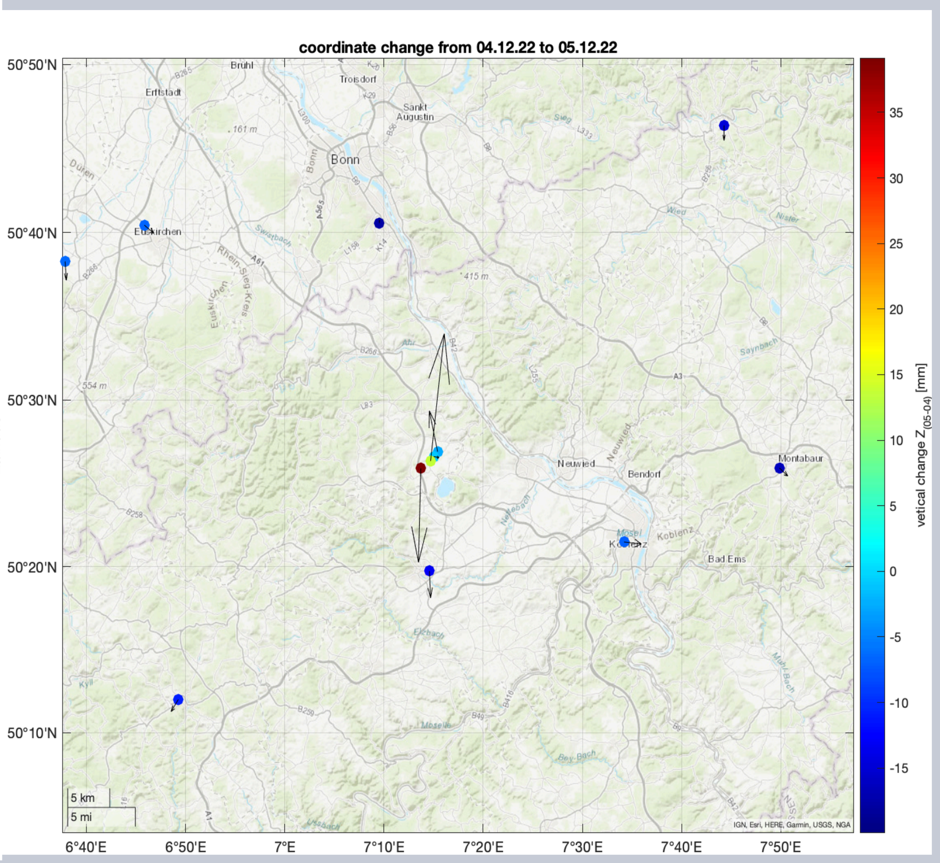


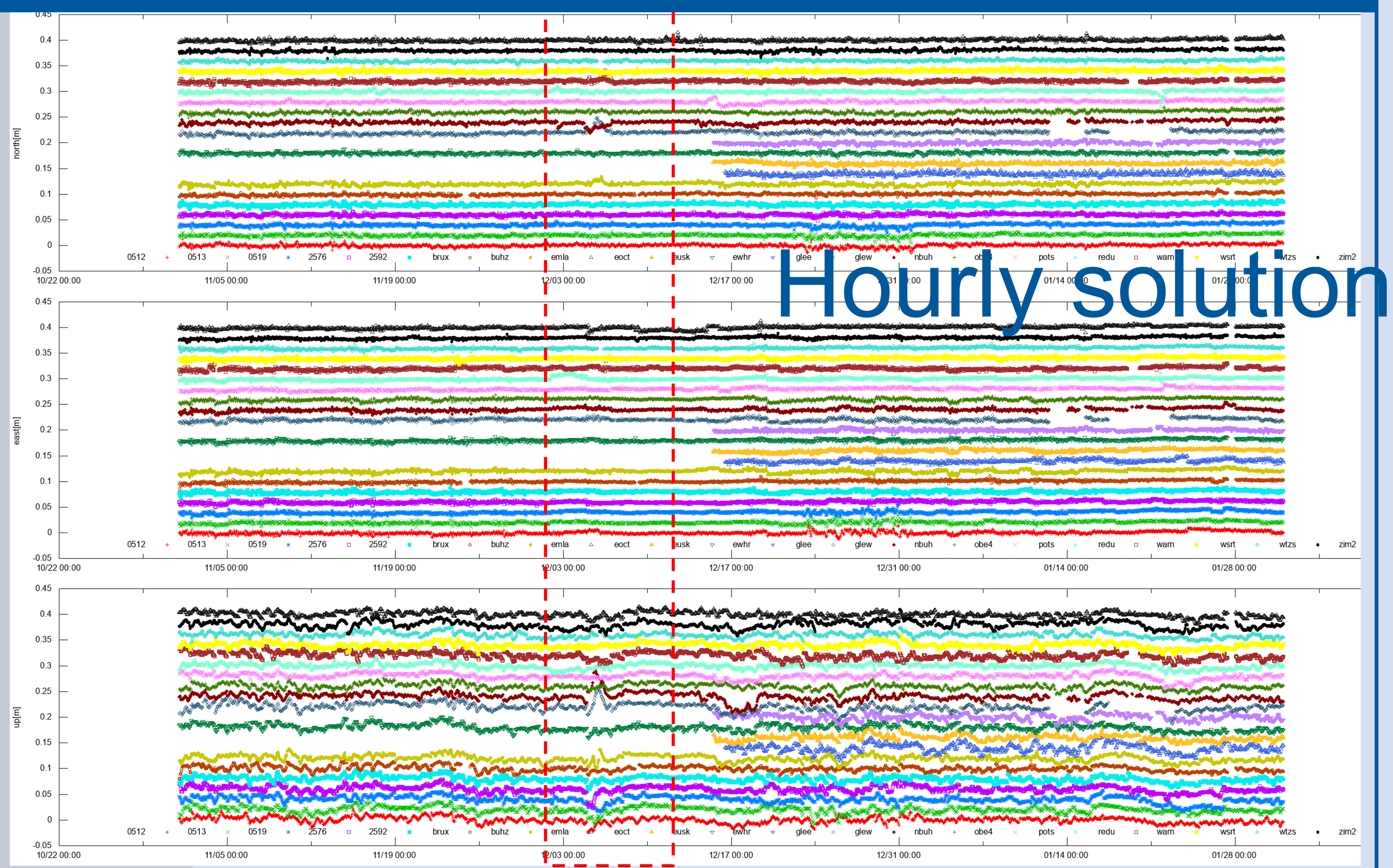

*Fig. 3: total of 36 stations are included in network processing: 8 IGS stations, 6 Germany SAPOS CORS stations close to Eifel, 22 LSV stations.*

## Short-term excursion in 2022 December




Excursion



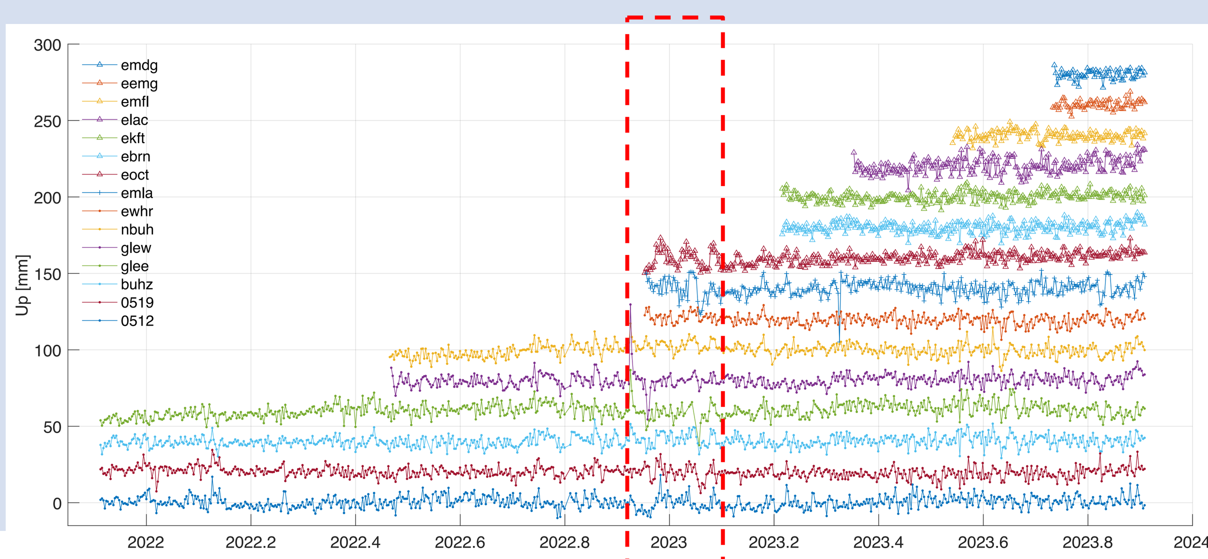



Hourly solution

On December 5, 2022, an unexpected short-term excursion was observed in both the daily and hourly GNSS solutions. Two stations located north of the Laacher See region exhibited an uplift of up to 39 mm compared to their positions on December 4. To investigate this excursion, we processed data from all German GNSS stations for the two days and examined coordinate changes using Helmert-Transformation.

The results indicated that surrounding SAPOS stations exhibited a subsidence of about 10 mm. In addition to vertical deformation, a horizontal coordinate change was also observed. Specifically, the station GLEW moved southward, while the two stations BUHZ and GLEE moved northward. This unexpected and localized deformation raises questions about the underlying geophysical processes, and further analysis and monitoring are essential to understand the nature and implications of these observed changes.

| STATION | Coordinate change (mm) from 04 Dec to 05 Dec 2022 | | |
|---|---|---|---|
| | UP | North | East |
| GLEW | 39.1 | -9.4 | -0.4 |
| GLEE | 13.7 | 12.7 | 2.3 |
| NBUH | -0.8 | -0.1 | 0.9 |
| BUHZ | -2.8 | 4.1 | -1.4 |
| EUSK | -6.7 | -0.8 | 1.6 |
| 2576 | -17.7 | 0.3 | 0 |
| 2592 | -6.4 | -1.9 | 0.2 |
| 0513 | -13.2 | -2.7 | 0.2 |
| 0512 | -7.1 | -0.2 | 2.9 |
| 0519 | -10.8 | -1.2 | -1.2 |




Daily solution