On the use of randomly occurring radar reflectors for the establishment of local ties between InSAR and GNSS

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Introduction

InSAR is an important and well-established remote sensing technique used for mapping of small-scale deformation phenomena on the Earth's surface. InSAR deformation maps are usually calibrated with GNSS in order to refer the inherently relative InSAR measurements to the "absolute" geodetic reference frame of GNSS as well as to introduce into the deformation maps large-scale deformation phenomena not detectable by InSAR.

The calibration of InSAR using GNSS requires a tie between InSAR and GNSS, which can be established using either purpose-build artificial radar reflectors or randomly occurring radar reflectors nearby the GNSS-stations. As the installation of artificial reflectors has only begun in the recent years, using randomly occurring radar reflectors is the best short-term option. Furthermore, randomly occurring radar reflectors might even be relevant in the long-term as an additional means for monitoring the stability of artificial reflectors.

The purpose of this study is to evaluate different criteria and approaches for the establishment of InSAR-GNSS ties using randomly occurring radar reflectors nearby GNSS-stations.

Methods

The establishment of InSAR-GNSS ties using randomly occurring radar reflectors presupposes the calculation of an Average Time Series (ATS), i.e. an average InSAR velocity based on InSAR measurement points (MPs) nearby each GNSS station. The calculation of the ATS implies a choice of criteria regarding the selection/weighting of InSAR MPs and the purpose of this study is to evaluate the following criteria regarding selection/weighting:

- Distance to GNSS station: 150 m – 2000 m
- Weighting: No weighting (ATS), Inverse variance weighting (IVW ATS), Inverse distance weighting (IDW ATS), Coherence weighting (CW ATS)
- Outlier rejection based on modified z-score

For combinations of the above criteria different planar calibration models are estimated, i.e. one model for each specific combination of criteria:

$$\Delta v = ax + by + z\,,$$

where $\Delta v = \mathrm{ATS} - \mathrm{GNSS}$ is the difference between the ATS calculated for a specific combination of criteria and the GNSS velocity computed by a linear fit of daily GNSS positions. The fitted value $\widehat{\Delta v}$ describes the correction to be applied in order to calibrate the uncalibrated InSAR deformation map. x and y are Easting and Nothing in UTM32.

Finally, each planar calibration model is evaluated and compared by the standard deviation of the residuals of the planar calibration model:

$$\hat{\sigma}_{res} = \sqrt{\frac{\sum_{i=1}^{N}\left(\Delta v_i - \widehat{\Delta v}_i\right)^2}{\mathrm{N-3}}},$$

and the RMSE calculated by leave-one-out cross-validation applied on the planar calibration model:

$$\mathrm{LOO\ RMSE} = \sqrt{\frac{\sum_{i=1}^{N}\left(\Delta v_i - \widehat{\Delta v}_i\right)^2}{\mathrm{N}}}.$$

Data

Data used in this study includes:

- Nationwide Sentinel-1 InSAR uncalibrated deformation maps processed by TRE Altamira (Giannico et. al, 2020)
- Time series of SDFIs GNSS stations processed in IGS14 by DTU Space (Khan et al, 2020)

The nationwide Sentinel-1 InSAR deformation maps of Denmark consist of 2D (vertical and east component) and line of sight (LOS) maps. Figure 1 shows examples of the InSAR deformation maps together with the GNSS stations used in this study.

2D velocities

Figure 2 and 3 show $\hat{\sigma}_{res}$ and the LOO RMSE as a function of InSAR MP search radius for different weighting approaches with or without outlier rejection. Figure 2 and 3 show the results of the 2D vertical and the 2D east component resp.

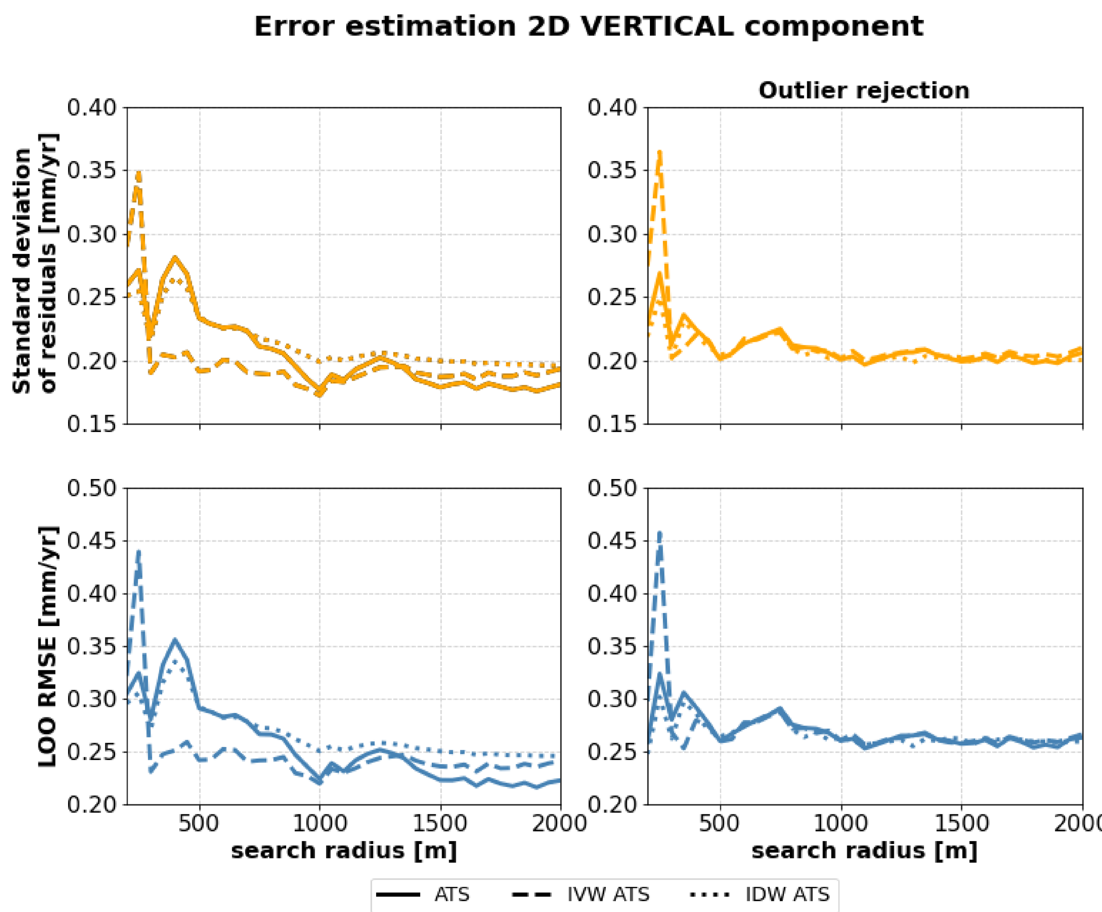

Figure 2: Error estimation of the planar calibration models for 2D vertical component. Plots to the left are without outlier rejection and plots to the right are with outlier rejection.

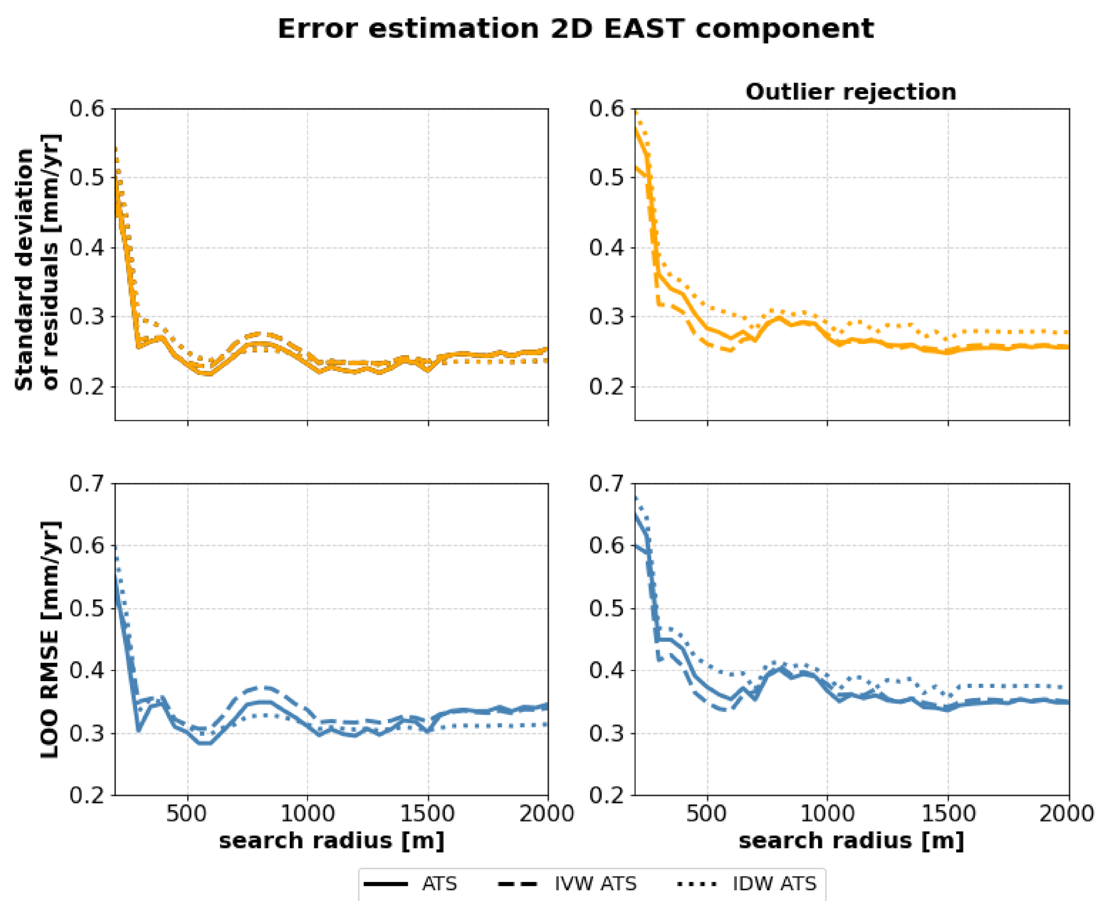

Figure 3: Error estimation of the planar calibration models for 2D east component. Plots to the left are without outlier rejection and plots to the right are with outlier rejection.

As can be seen from the figures outlier rejection does not give a better result, neither for vertical nor for east component. Further, it can be seen that increasing the search radius, i.e including more InSAR MPs, results in a decrease in the error of the planar calibration model. For the east component at smaller search radii, the IDW yields the best results, but as the search radius increases the different approaches yield similar results. Based on figure 2 and 3, the optimal search radius is around 1000 m. Increasing the search radius to more than 1000 m does not improve the InSAR-GNSS-ties.

LOS velocities

Figure 4 shows $\hat{\sigma}_{res}$ and the LOO RMSE for tracks with at least 6 GNSS stations using no weighting and no outlier rejection. Based on figure 4, the optimal search radius is approx. 500 - 800 m. Increasing the search radius to more than 800 m does not improve the result.

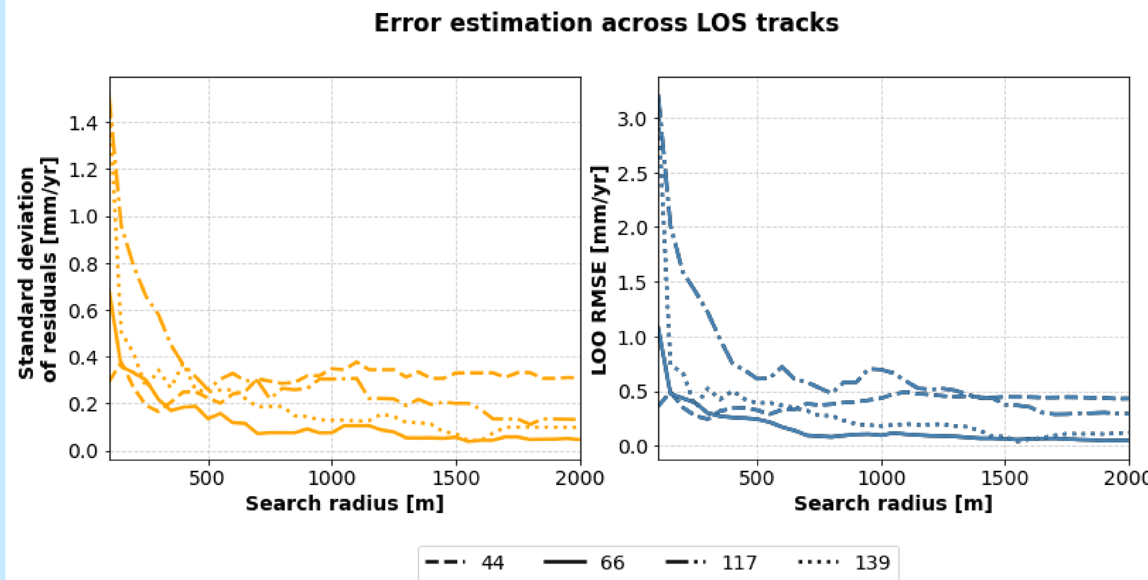

Figure 4: Error estimation of the planar calibration models for tracks that overlap with at least 6 GNSS stations. The ATS used for estimating the planar calibration models is calculated using no weights and no outlier rejection. Similar results are obtained if ATS is calculated using weights and/or outlier rejection, cf. figure 5.

Figure 5 shows $\hat{\sigma}_{res}$ and the LOO RMSE for track 66 as a function of search radius for different weighting criteria with and without outlier rejection. In general the various criteria only result in small differences, however the largest improvement occurs when increasing the search radius.

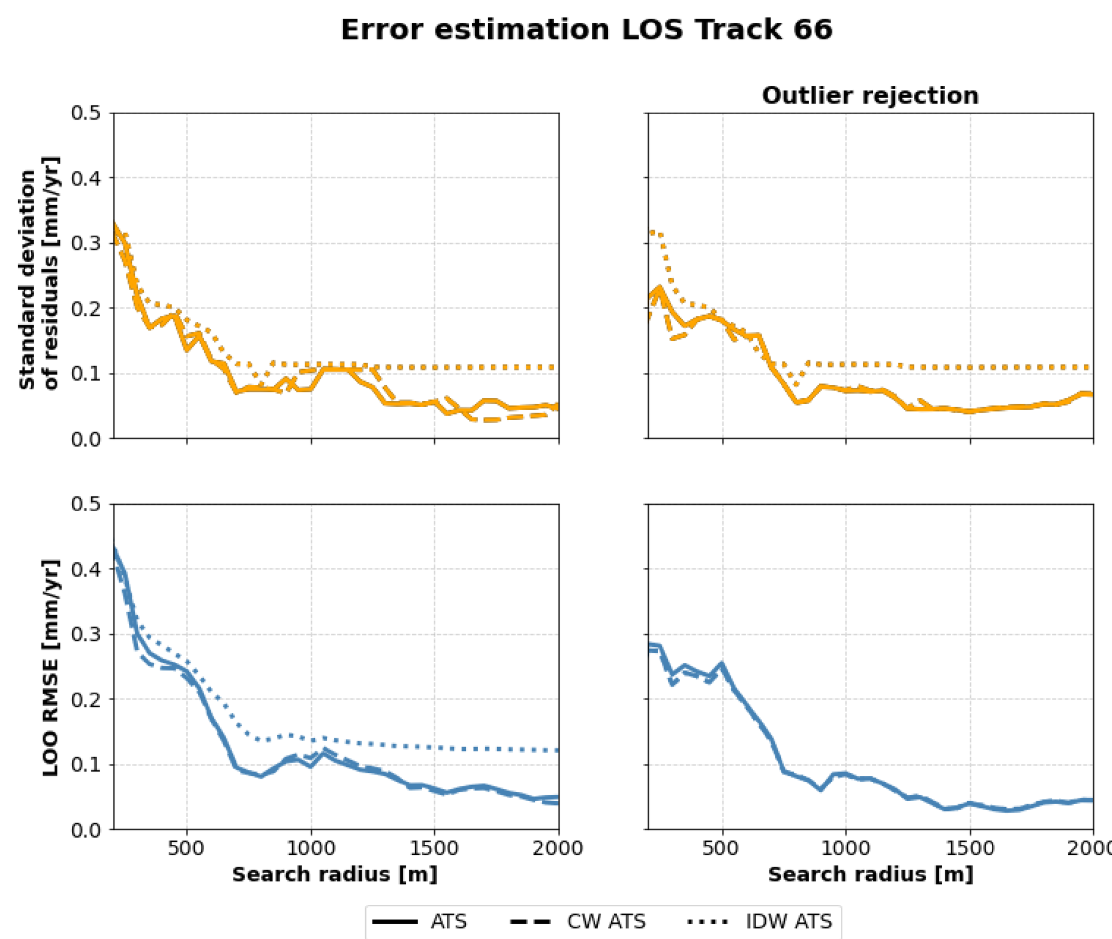

Figure 5: Error estimation of the planar calibration models for LOS track 66 using different weighting criteria with or without outlier rejection.

Conclusions

Based on the results of this study it is concluded that applying a distance criterion for randomly occurring radar reflectors nearby GNSS-stations of approx. 1000 m for 2D and approx. 500-800 m for LOS yields the best InSAR-GNSS-ties. Furthermore, it is concluded that various criteria for outlier rejection and weighted averaging have little importance compared to the distance criterion.

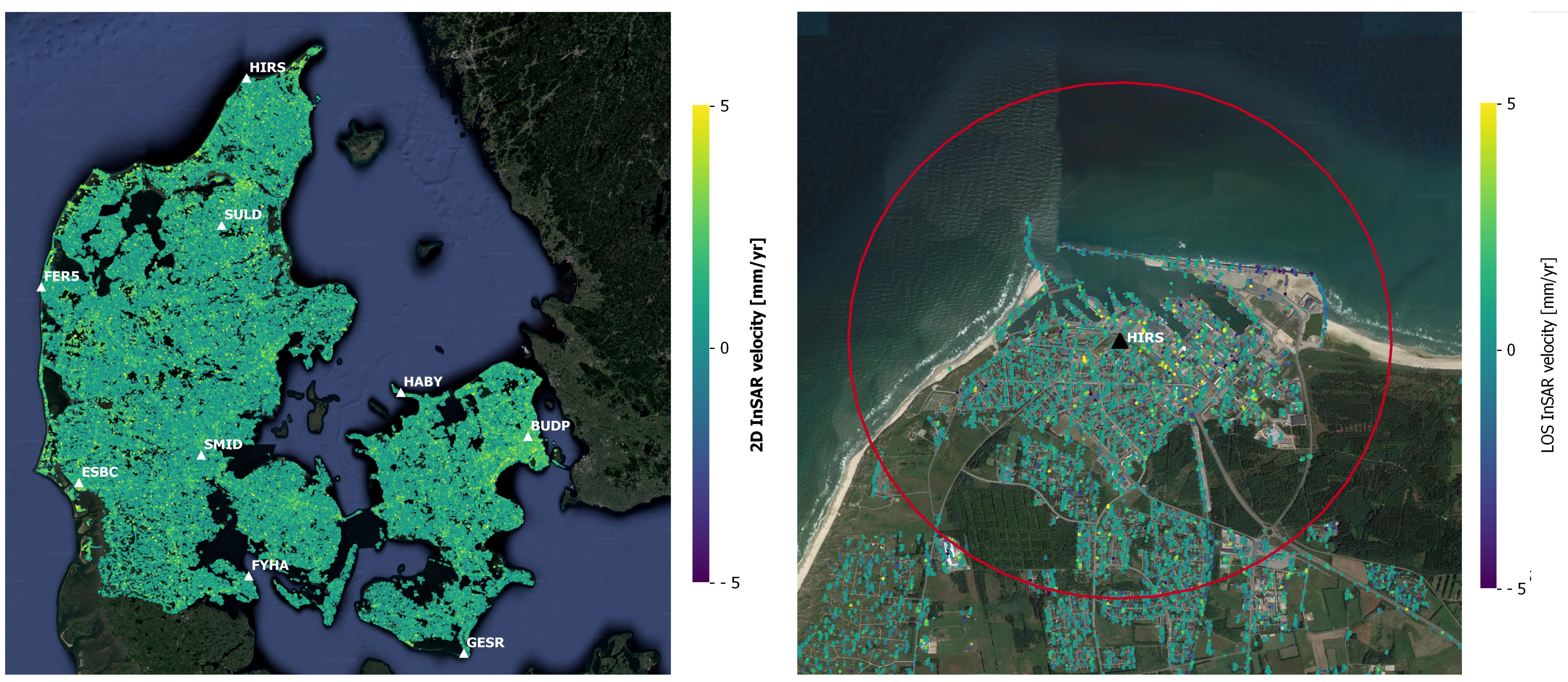

Figure 1: InSAR deformation maps with GNSS stations. **Left:** The uncalibrated nationwide 2D east deformation map together with GNSS stations used in the study. Deformation maps of the Danish islands also exist but are not used in this study. **Right:** The uncalibrated LOS deformation map (all tracks) zoomed in on the HIRS GNSS station. The red circle indicates a 2 km distance from the GNSS station. Background layer: Google satellite (left) and SDFI Orthophoto (right).

References

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