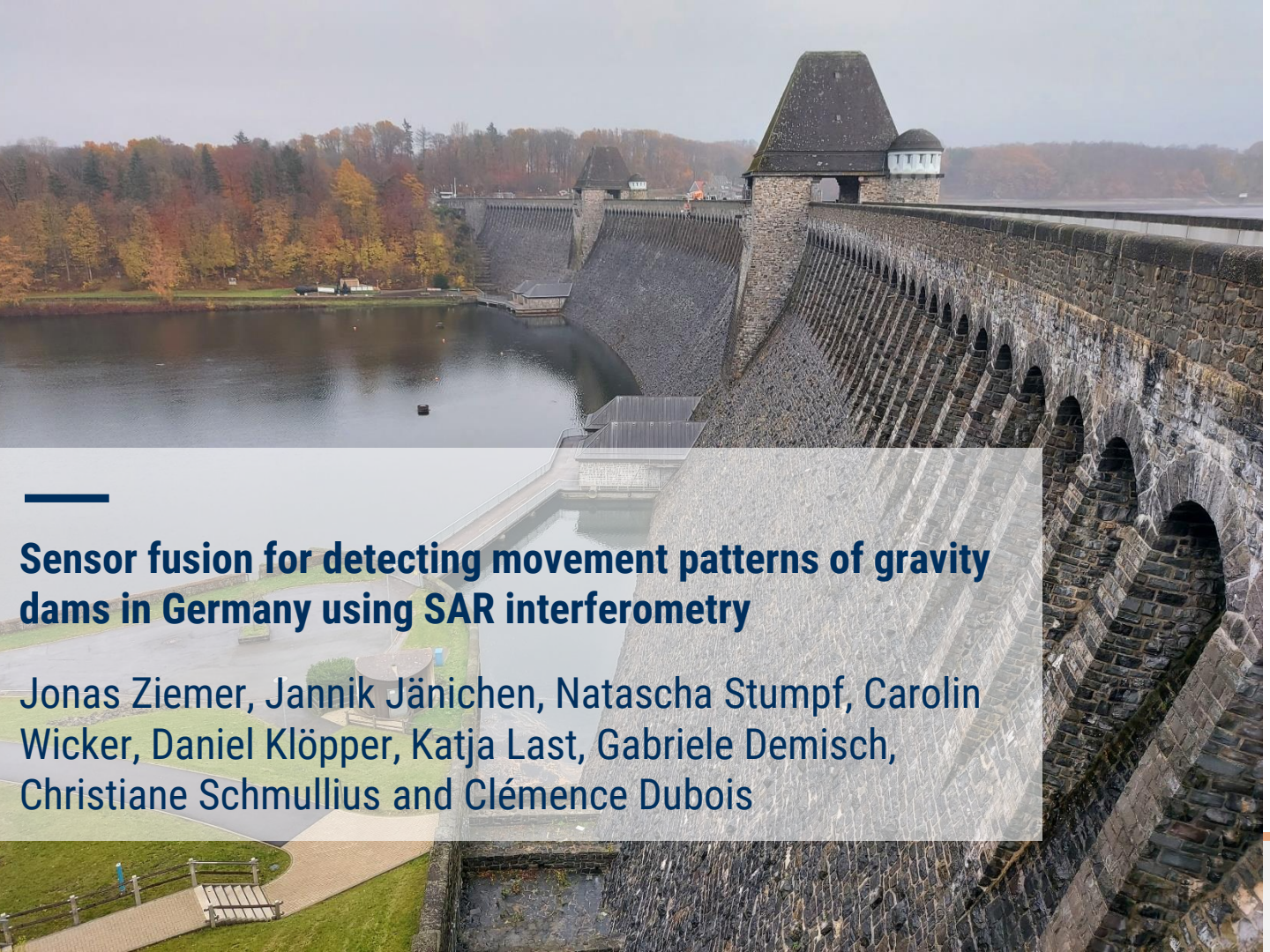

Sensor fusion for detecting movement patterns of gravity dams in Germany using SAR interferometry

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Motivation

- PSI measurements using Sentinel-1 C-band data are already possible at most dams, BUT:
  - With C-band SAR, fewer PS points can be detected than with shorter wavelengths (e.g., X-band)
    - → For analysis of all dam parts, too few PS points are found on some of the dams

→ Use of high-resolution TerraSAR-X Stripmap data in addition to Sentinel-1

Fig.1: Comparison of PS points in line of sight (LOS) on the Möhne gravity dam (top) and the Verse embankment dam (bottom). (Source: Bodenbewegungsdienst Deutschland)

Objectives

1. Impact of additionally used TerraSAR-X data on the number of PS points on the dams?

2. Suitability of Sentinel-1/TerraSAR-X PS data for dam monitoring?

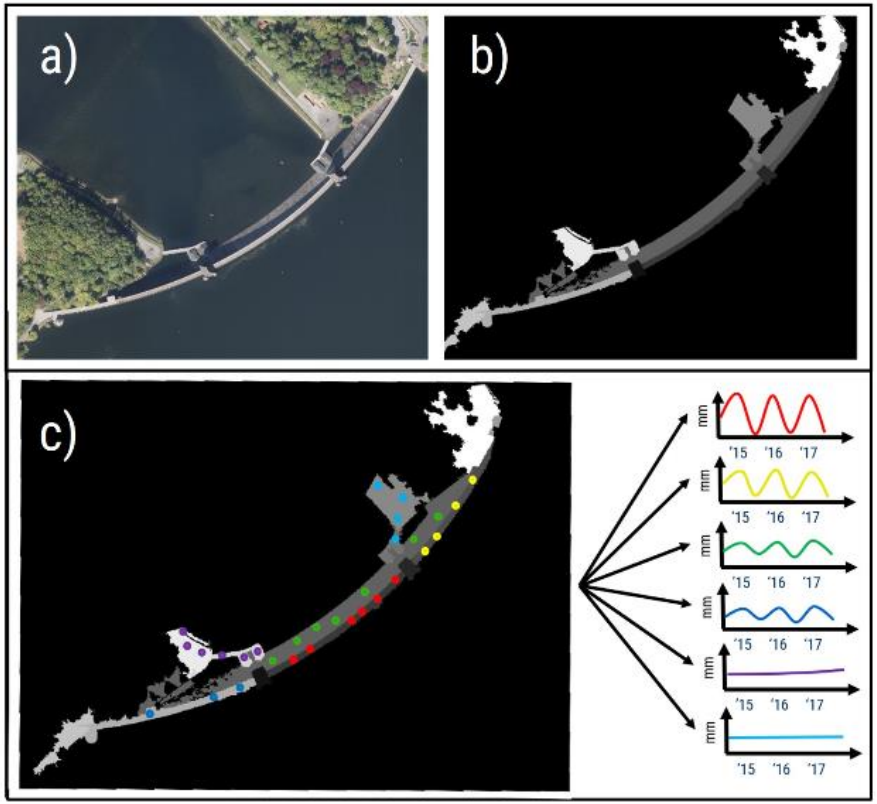


Fig.2: Derivation of distinct displacement patterns per dam segment. a) Digital Orthophoto. b) Dam segments. c) Dam segments with PSI points. (Source photo a: Digital Orthophoto; https://www.geoportal.nrw/)

Study area

- Dams in NRW, Germany
- Monitored by the Ruhrverband

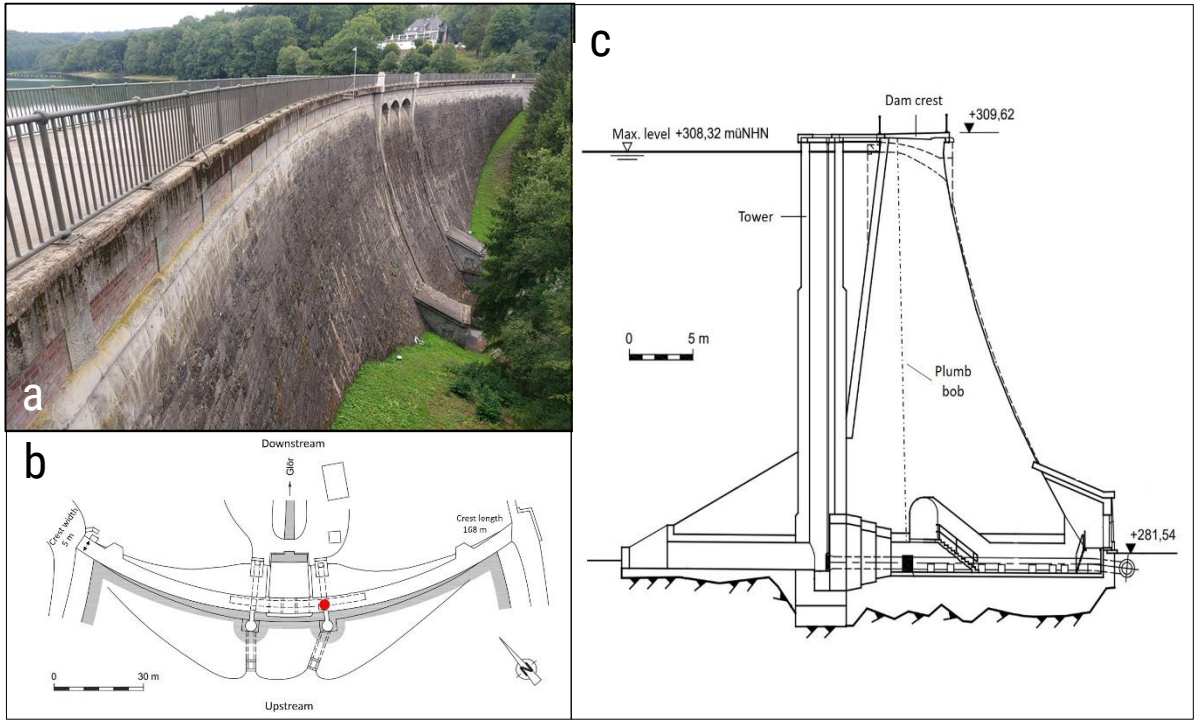


Fig.3: Characteristics of the Glör gravity dam. (a) Side view from the downstream side, (b) Cross-section and (c) layout of the dam. The red dot indicates the position of the plumb system. (Source photo b,c: Ruhrverband 2021)

Sensor fusion

- Data:
  - 145 Sentinel-1 scenes (IW, ascending)
  - 151 TerraSAR-X scenes (Stripmap, ascending)
  - In situ data (plumb system, trigonometry)
- Study period:
  - 11/2017 – 08/2022
- Software:
  - Snap2StaMPS & StaMPS

- TSX2StaMPS: New package for semiautomatic preprocessing of high-resolution stripmap data for further PSI processing
  - https://github.com/jziemer1996/*TSX2StaMPS*
- Snap2StaMPS-v2: Implementation of TSX2StaMPS
  - presented at the FRINGE Workshop 2023 in Leeds, UK [1]

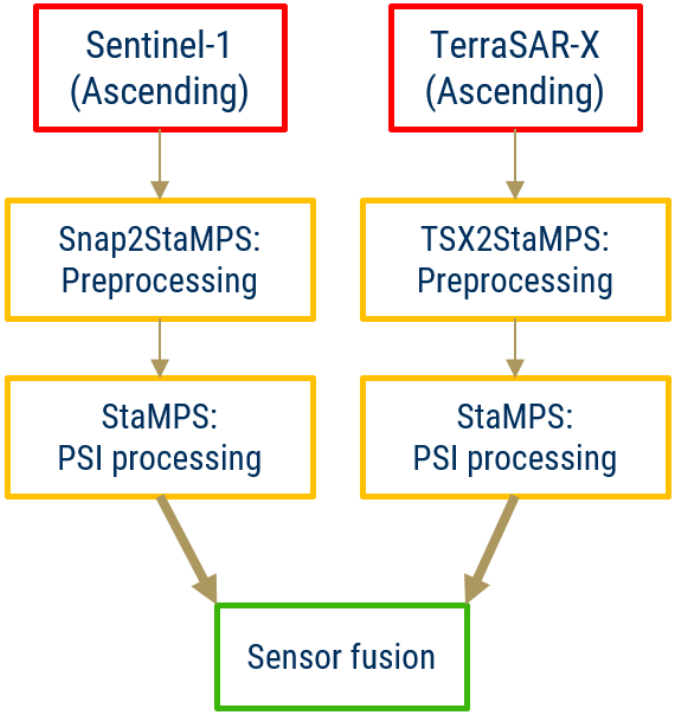


Fig.4: Workflow of the applied method (simplified).

Segmentation

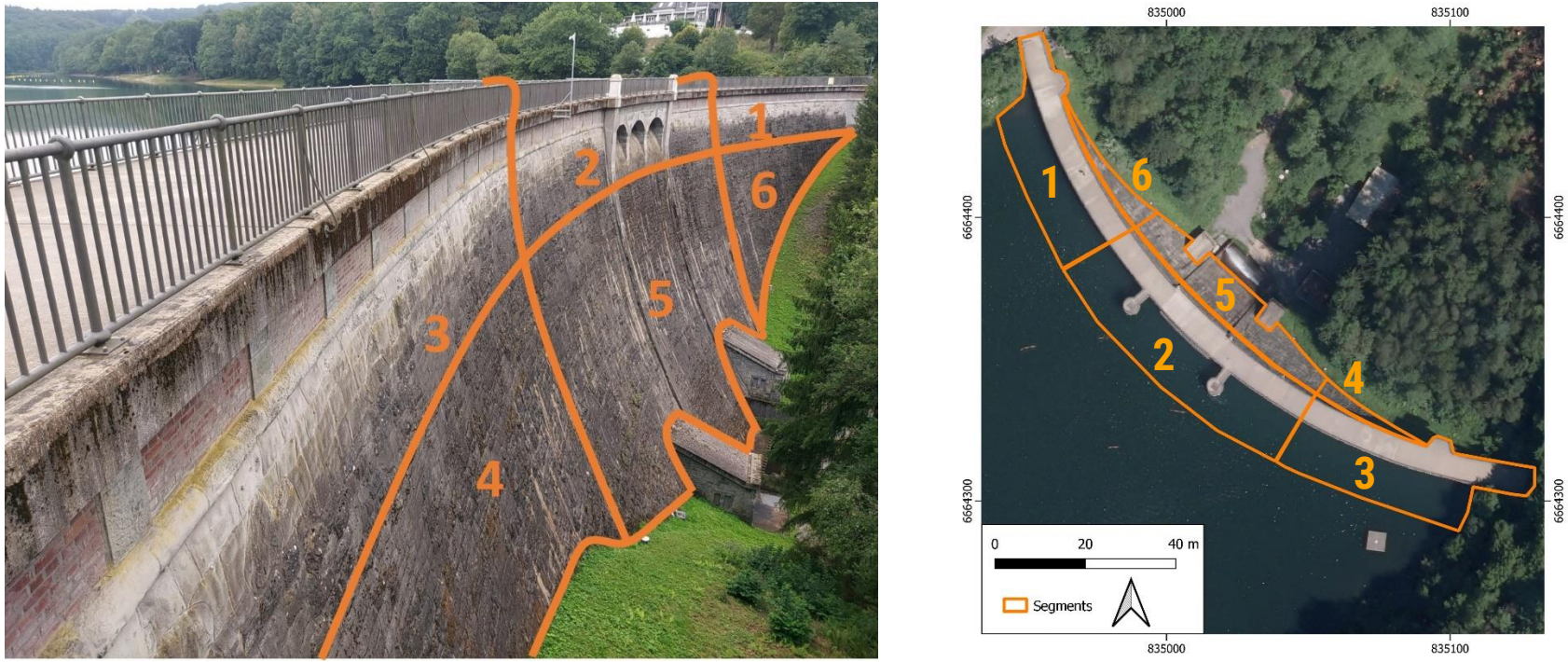


Fig.5: Segmentation of the Glör Dam as viewed from the downstream side (left) and on a digital orthophoto (right). Segments 1-3 cover both sides of the crest. Since the toe segments 4-6 are completely covered by water on the upstream side, they hold no practical importance in the analysis. (Source photo: FSU Jena. Orthophoto: GDI-NRW, EPSG: 4326.)

Results

Tab.1: Number of PS points on selected gravity dams monitored by the Ruhrverband.

	Glör	Fürwigge	Ennepe
Sentinel-1	9	4	3
TerraSAR-X	19	15	36
Sum	28	19	39
Sum (%)	+211%	+375%	+1200%

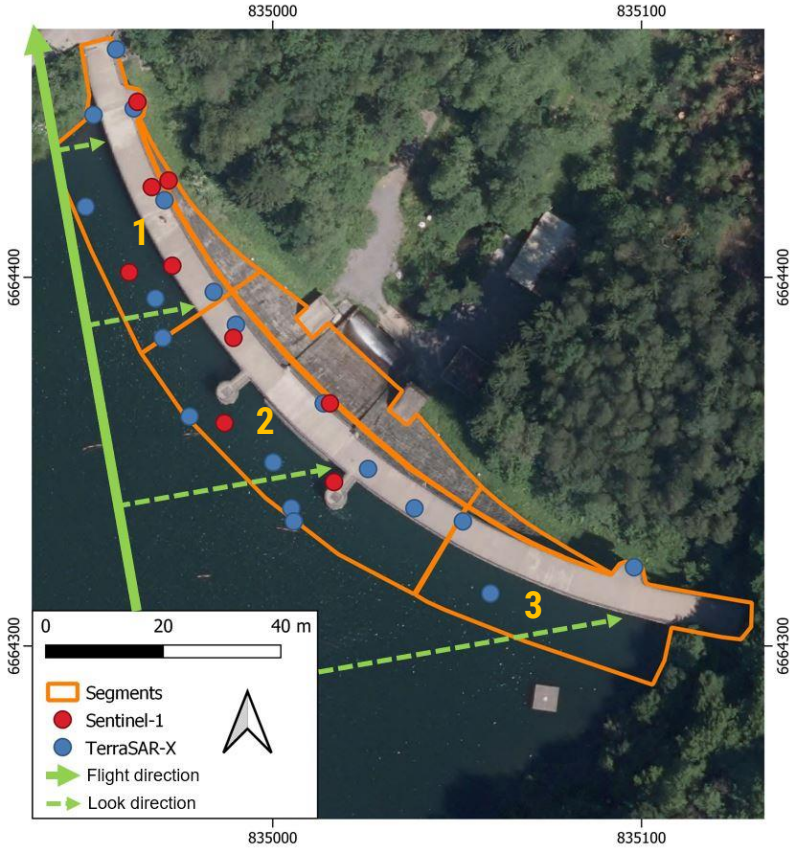


Fig.6: Distribution of PS points along the crest of the Glör Dam.
(Source Orthophoto: GDI-NRW, EPSG: 4326.)

Results

Tab.2: Statistics for the linear regression model of the mean SAR displacement and the plumb data for each crest segment of the Glör Dam. Since no Sentinel-1 PS points were found in segment 3, only the TSX model could be fitted.

PS vs. plumb	Segment 1 (S1/TSX/Fusion)	Segment 2 (S1/TSX/Fusion)	Segment 3 (TSX)
R^2	0.48/**0.62**/0.5	**0.65**/0.53/0.58	0.46
RMSE (mm)	1.59/**1.39**/1.55	**1.26**/1.54/1.43	1.66

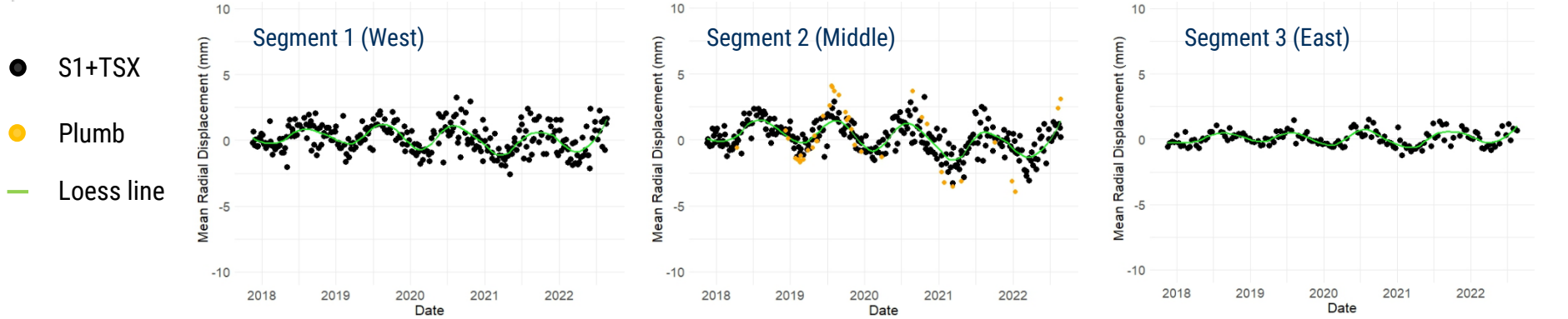


Fig.7: Mean radial displacement for the fused S1/TSX time series with the corresponding Loess line (in green) and plumb data (in orange) on the Glör Dam. Due to the location of the plumb system in the middle of the dam, the plumb data are only shown for segment 2.

Discussion

- Conversion to radial displacements only possible, if no (noticeable) vertical displacements exist

  → dams founded on solid rock formations (e.g., gravity and arch dams)

  - Methodology could NOT be transferred to embankment dams with steady settlement dynamics

- Amplitude of radial displacements dependent on the orientation of the dam and the sensor's look direction

  - Radial displacements: N/S orientation; Tangential displacements: E/W orientation

  - On arched dams, not all parts are equally well suited

- Precision of plumb data is reported with 0.5 mm (Bettzieche 2020)

  - Precision of PSI measurements is lower on most dam segments (0.8-0.9 mm)

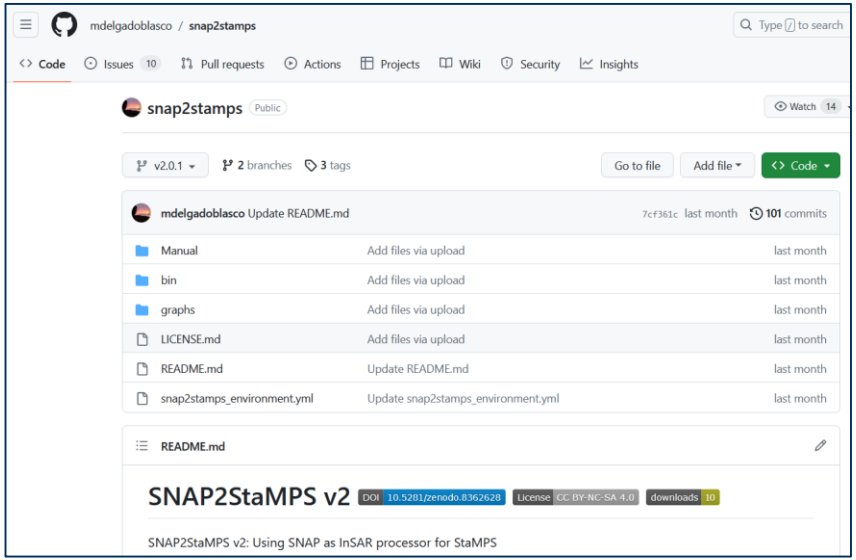
Conclusion

1. Additional TerraSAR-X stripmap data increase point density on dams considerably
    - TSX shows a multiple of Sentinel-1 points (Glör: 19/9; Fürwigge: 15/4; Ennepe: 36/3)
2. Comparison with plumb data shows agreement with PSI measurements on the Glör Dam
    - Application of PSI technology for gravity dam monitoring particularly depends on the dam's orientation to the look direction of the sensor
3. PSI technique cannot replace plumb data in terms of precision BUT…:
    1. Still aligns with the requirements of German DIN standards (DIN 19700-11:2004-07)
    2. Is a valuable alternative on dams where no plumb data are available

Publications

[1] Delgado Blasco, J., Ziemer, J., Foumelis, M, Dubois, C., 2023: SNAP2StaMPS v2: Increasing Features and Supported Sensors in the Open Source SNAP2StaMPS Processing Scheme: Zenodo. https://zenodo.org/record/8331352.

→ https://github.com/mdelgadoblasco/snap2stamps



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