**Title**

Towards Small-Baseline InSAR Time Series Analysis for Volcanic Monitoring on Saba and St. Eustatius

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**Abstract**

Over the years, InSAR has become an indispensable tool in the study of ground deformation, including volcanic deformation, and this continues to be the case in times of improved technology. Since the volcanoes on the Caribbean islands of Saba and St. Eustatius are active, the implementation of an InSAR-based monitoring system is crucial to enhance the spatial resolution of volcano monitoring beyond the capabilities of the ground-based monitoring network, for instance in the case of localized deformations such as dike intrusions. However, technical challenges arise in these tropical settings, caused by dense rainforest, atmospheric artifacts and terrain variability, posing serious challenges to the use of InSAR. Time series InSAR, including SBAS and PSI, can be used to overcome these limitations. A previous study has explored the use of PSI for monitoring, using the already available DePSI software. In this research, an SBAS approach within the Delft InSAR software framework is developed using state-of-the-art Python packages, including (sar)xarray, dask and zarr, and is used to assess whether there is capability to develop SBAS into a volcanic monitoring tool for Saba and St. Eustatius. In addition, a preliminary comparison between the SBAS and PSI methodologies is performed based on a theoretical and (semi-)quantifiable approach. This study combines data from two satellites operating at different wavelengths: Sentinel-1 (C-band) and ALOS-2 (L-band).

Assuming no ongoing deformation, based on GNSS results, the variability of the results around zero can be used as an indicator of precision. The results obtained through SBAS are promising, in particular for L-band, on account of e.g., extensive spatial coverage, efficiency and relatively low variability even with the presence of atmospheric and DEM components. Overall, the results reveal mm order deviations. In the event of volcanic activity, the expected deformation signals are in the range of cm-dm's and can therefore be detected, i.e., with an estimated minimal detectable deformation of 1.5 cm/year in the worst-case scenario. The implementation of three different coherence-based masking approaches-water, single and individual-give an indication of the level of robustness and reliability of the results. Generally, a relatively high level of consistency can be observed among the different masking results of ALOS-2 for both islands, for St. Eustatius following the correction of the unwrapping errors using two testing approaches: an interferogram removal approach and an adaptive approach based on the DIA procedure. The latter procedure allows for retaining all observations and their residuals and is therefore preferred. In contrast, the Sentinel-1 results reveal a lower level of consistency. It is suspected that this inconsistency mainly arises on account of the numerous unwrapping errors within the single masking approach. The individual masking approach appears to be less susceptible to unwrapping errors, however is more prone to outliers than the single masking approach. Further research, following the correction of the atmospheric component and DEM errors, may offer insights into the preferred masking approach. Overall, the use of L-band imagery shows potential, offering spatial coverage where C-band does not, even with limited ALOS-2 data availability and large temporal baselines. The preliminary comparative analysis with the PSI approach, based on the respective strengths and limitations from literature, spatial coverage, processing steps, precision and computational requirements, suggests that a hybrid method could prove to be advantageous to minimize (potential) signal loss, e.g. either from limited spatial coverage or spatial resolution, and enhance volcanic risk assessment. SBAS excels in the extensive spatial coverage, especially using L-band, providing nearly homogeneous coverage of St. Eustatius, even on the flanks of the Quill, and on the outer flanks Mt. Scenery on Saba. However, regardless of the mask, wavelength or method, acquiring coverage around the summit of Mt. Scenery on Saba remains challenging.

The study contributes to advancing InSAR time series analysis for the volcanic monitoring on Saba and St. Eustatius through the successful implementation of an SBAS approach within the Delft InSAR software framework based on state-of-the-art packages, the implementation and evaluation of new approaches to enhance the method in terms of the efficiency and robustness and a comparison with existing software. In addition, the software can be applied in a generic sense for various applications and can be extended for further improvements.