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Brief Communication – InSAR Svalbard Ground Motion Service: Observing Surface Displacements in the High Arctic

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Abstract. The InSAR Svalbard Ground Motion Service (GMS) provides open-access surface displacement maps and time series in the Svalbard archipelago, derived from Sentinel-1 Interferometric Synthetic Aperture Radar (InSAR). The service provides seasonal products capturing short-term 2016–2024 displacements and interannual products documenting long-term 2018–2024 velocity trends. InSAR Svalbard covers five areas on Spitsbergen Island (Longyearbyen, Ny-Ålesund, Svea, Hornsund and Kapp Linné). The service consists in a web-based visualisation tool at https://svalbard.insar.no. The products are also distributed at https://doi.org/10.5281/zenodo.18442696. InSAR Svalbard establishes a foundation for geohazard assessment in Arctic regions and interdisciplinary research on permafrost dynamics, ground stability, and environmental changes.

1 Introduction

Spaceborne Interferometric Synthetic Aperture Radar (InSAR) is an established tool used to measure ground motion caused by natural and anthropogenic processes. InSAR is especially valuable in remote and harsh environments such as permafrost regions in polar and high-mountain settings, where in-situ measurements are logistically challenging and costly to acquire (Zwieback et al., 2024). Since its launch in 2014, the Copernicus Sentinel-1 satellite mission has provided C-band radar imagery with a global coverage, a consistent acquisition strategy, and a short revisit time (6–12 days). Thanks to its open data policy, the mission has enabled the development of operational InSAR Ground Motion Services (GMS) for the large-scale documentation of surface displacement. In Norway, the InSAR Norway service has provided nationwide, open-access InSAR data since 2018 at https://insar.no. At the continental scale, comparable datasets are available through the European Ground Motion Service (EGMS) at https://egms.land.copernicus.eu. However, neither service currently covers the Svalbard archipelago.

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Previous InSAR studies in Svalbard have demonstrated the potential of the technique for mapping geohazards, inferring ground frost-susceptibility and ice content, and documenting seasonal freeze–thaw cycles using subsidence–heave time series (Rouyet et al., 2019; Wendt et al., 2026). Comparable investigations conducted in other Arctic regions further demonstrate the growing application of InSAR for both hazard management and permafrost research (Scheer et al., 2023; Zwieback and Meyer, 2021). However, most previous studies have focused on small areas, short time periods, and/or targeted applications, resulting in datasets that are spatially and temporally fragmented. A consistently processed and open-access InSAR GMS tailored to cold-climate environments has so far been lacking. The InSAR Svalbard GMS aims to fill this gap by providing displacement products for both research and operational use in the High Arctic. The development phase of the service spanned three years and included several rounds of interaction between InSAR experts and end-users throughout the design and implementation phases (see Acknowledgements) to define the user requirements and product specifications (Rouyet et al., 2024). In this paper, we briefly introduce the properties of the first InSAR Svalbard data release at https://svalbard.insar.no (Bredal et al., 2026a).

2 Study areas

Svalbard is a dynamic High Arctic environment where glacial, periglacial, fluvial, and anthropogenic processes continuously shape the landscape and influence ground stability. Approximately 60% of the archipelago is covered by glaciers, while most of the remaining terrain is underlain by permafrost beneath an active layer that freezes and thaws seasonally (Hanssen-Bauer et al., 2019). The Arctic is warming three to four times faster than the global average and Svalbard is among the fastest-warming Arctic regions. Consequently, permafrost temperature and active layer thickness are also increasing (Strand and Christiansen, 2025). Such rapid warming leads to major environmental changes and enhanced ground dynamics. Permafrost degradation can result in an increased frequency, magnitude, and velocity of mass movement, as well as long-term subsidence caused by ground ice melting (Streletskiy et al., 2025).

Svalbard hosts a rich cultural heritage and diverse present-day human activities. Unstable ground conditions pose a threat to historical sites, modern infrastructure, and population at the main settlements, research stations, and tourist destinations (Aga et al., 2025; Nicu et al., 2026). Mapping surface displacement is therefore relevant for hazard assessment and management. In addition, Svalbard is a key location for many polar and climate science disciplines due to its unique climatic and environmental setting. Because the ground dynamics respond to environmental drivers, systematically measured displacement time series have the potential to serve as climate change indicators (Duchossois et al., 2018).

The InSAR Svalbard pilot products are available for five study areas on Spitsbergen Island: Longyearbyen (LY), Ny-Ålesund (NY), Kapp Linné (KL), Svea (SV) and Hornsund (HS) (**Fig. 1**). These areas were selected due to their societal and scientific relevance, as they include the main Norwegian settlements, research stations, tourist destinations and cultural heritage sites (Rouyet et al., 2024).

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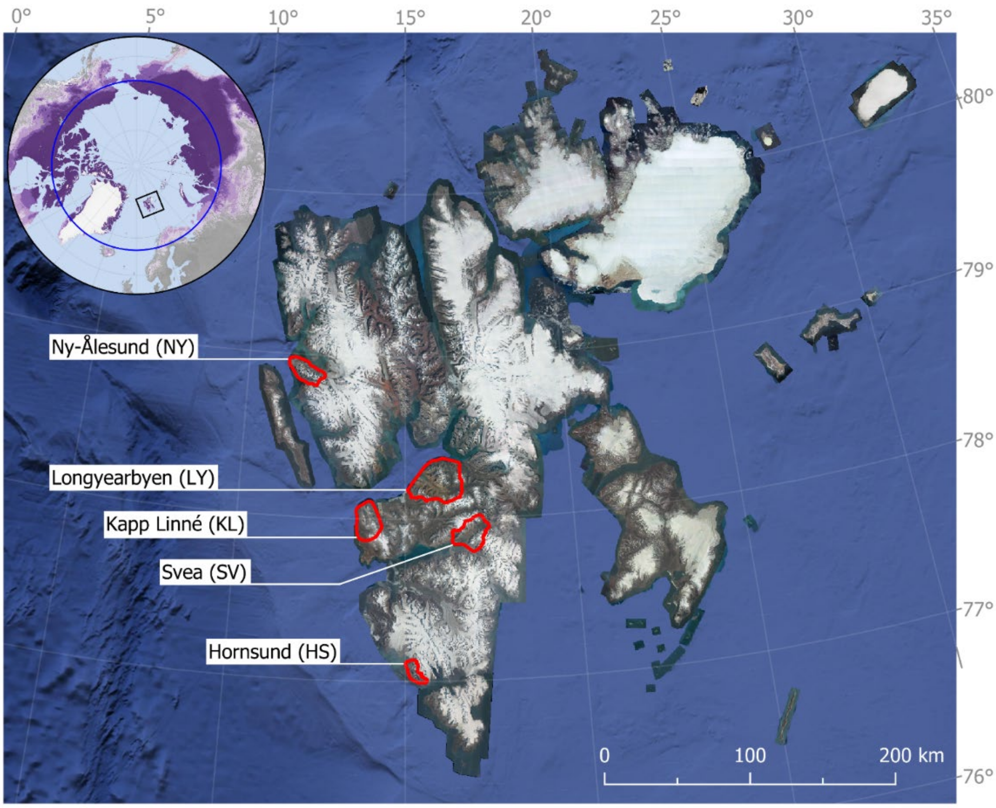

Figure 1. Overview of the five InSAR Svalbard study areas: Longyearbyen (LY), Ny-Ålesund (NY), Svea (SV), Hornsund (HS) and Kapp Linné (KL). Background maps: Svalbard Orthophoto (NPI, 2026) and Google Satellite Orthoimages (map data © 2026 Google). The circular polar-centred map in the upper left corner shows the location of Svalbard (black rectangle) in the northern hemisphere (> 55° latitude). The blue line shows the Arctic circle (66° 34'). The purple shades show the permafrost distribution, from continuous (dark purple) to isolated (light purple) zones, based on modelled results from Obu et al. (2019).

3 Method

InSAR Svalbard results are based on C-band Synthetic Aperture Radar (SAR) data acquired by the Copernicus Sentinel-1 satellites, operating at a wavelength of ~5.6 cm. Interferometric SAR (InSAR) exploits the phase of the radar signal, which is proportional to the two-way travel path between the satellite sensor and the ground. By differencing the phase of two satellite images acquired at different times, it is possible to measure changes in the sensor-to-ground distance along the radar line-of-sight (LOS). Such phase differences are represented by interferograms. By combining multiple interferograms, cumulative displacement time series can be estimated.

The InSAR Svalbard products were generated using a Distributed Scatterer InSAR approach, based on a Small Baseline Subset (SBAS) algorithm (Berardino et al., 2002). The SBAS approach uses a network of interferograms selected according to predefined spatial and temporal baseline thresholds to minimize geometric and temporal decorrelation. By combining multiple,

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partially overlapping interferograms, the method increases redundancy, which reduces atmospheric noise and improves the accuracy of the displacement estimates. Details about the processing settings and the related limitations are available in the InSAR Svalbard user manual (Bredal et al., 2026b).

Two complementary SBAS processing strategies were applied to generate two types of InSAR Svalbard products, capturing both short-term (seasonal) and long-term (interannual) surface displacement patterns. This dual processing approach enables InSAR Svalbard products to capture ground dynamics across multiple timescales.

The seasonal products document cumulative short-term surface displacements within each snow-free period. The time series span 2016–2024 for products based on images acquired with an ascending orbit, and 2018–2024 for products based on images acquired with a descending orbit. Interferograms were generated using image pairs with short time intervals (6–48 days). Each season was processed separately. Potential movement occurring before the start date is not captured and any ongoing long-term trends are not reflected in these results. The time series were used to extract the maximum seasonal displacement and the timing of this maximum displacement. The seasonal products are well suited for identifying rapid changes (up to a couple of decimetres) that occur within a single snow-free season, such as active layer dynamics or slope movement.

The interannual products document cumulative long-term surface displacements occurring between consecutive snow-free periods. The time series span 2018–2024 for both ascending and descending products, to provide an easily comparable period. Interferograms were generated using image pairs separated by approximately one year (340–390 days). These products are not intended to document seasonal patterns. The time series were used to estimate the interannual mean velocity along the LOS. The products enable the documentation of slow, gradual displacement patterns over multiple years (up to a couple of cm/yr), e.g., subsidence from permafrost degradation, heave from ice aggradation, or downslope movement from permafrost creep.

4 Results

4.1 Seasonal InSAR Svalbard results

The seasonal InSAR Svalbard results provide an information about the distribution of the seasonal ground surface dynamics. By default, the InSAR Svalbard maps display the maximum seasonal displacement expressed in mm. Each documented pixel includes a comprehensive cumulative displacement time series within each seasonal observation time window (**Fig. 2**). The users can change the visualisation settings and interact with the data according to their needs. Examples of WebGIS functions and concrete applications are described in the InSAR Svalbard user manual (Bredal et al., 2026b).

On slopes, the magnitude of the observed maximal displacements varies due to the large diversity of periglacial landforms in the study areas (e.g., solifluction sheets, rock glaciers, rock slope instabilities, debris-covered glaciers, etc.). InSAR Svalbard products can contribute to map and inventory the distribution and kinematic characteristics of such landforms at the regional scale. The results can also be used to perform a detailed analysis of the seasonal displacement time series for selected landforms and specific seasons (**Fig. 2A**).

In flat terrain, such as in valley bottoms filled with sediments (**Fig. 2B**), the magnitude of the observed maximal displacements is highly variable, depending on the sediment frost susceptibility (Rouyet et al., 2019). Such information can be used as a proxy to map the distribution of the ground ice content (Wendt et al., 2026; Zwieback and Meyer, 2021). The time series show various levels of cyclic subsidence and heave patterns during the periods when the active layer is thawing and refreezing (**Fig. 2B**). The timing of the transition between the subsidence and heave patterns provides a proxy of the seasonal freeze-onset, for years with little snow-covered surface in the fall (Rouyet et al., 2019).

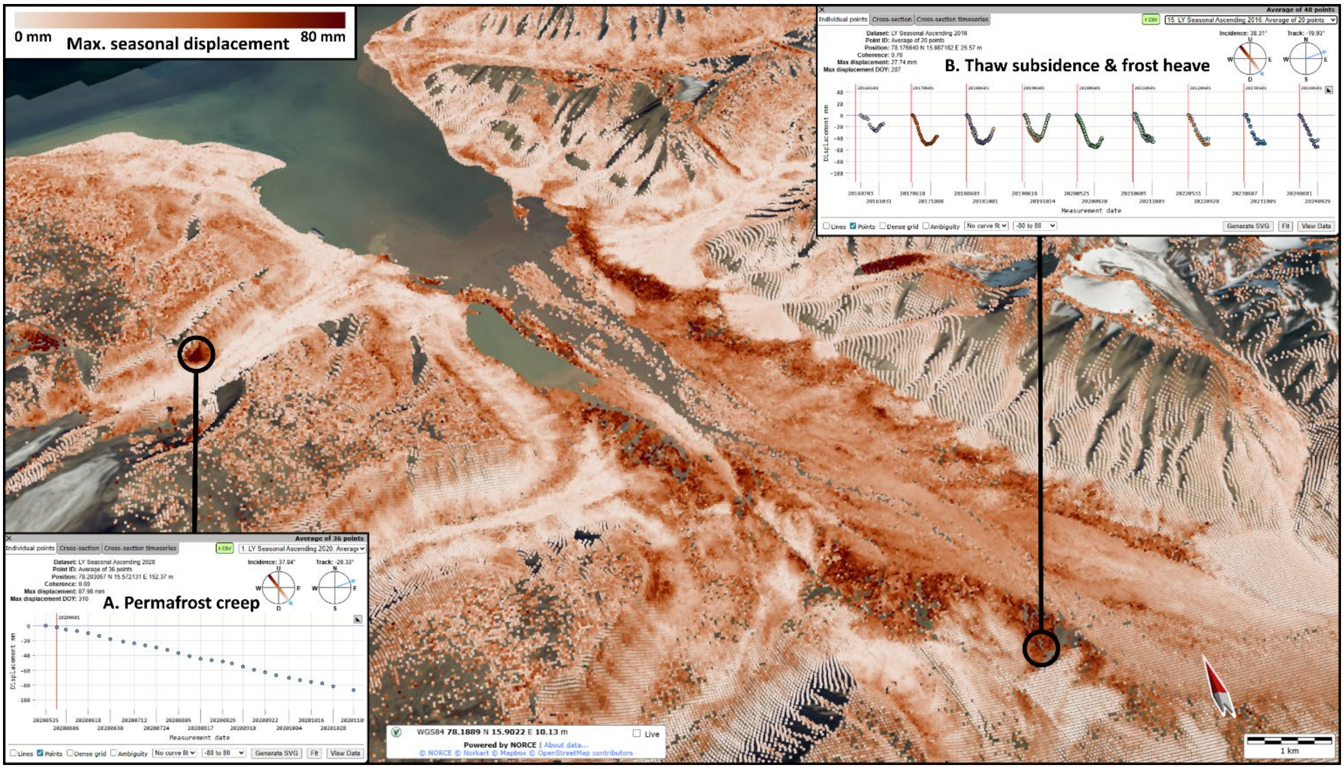

Figure 2. Example of seasonal InSAR Svalbard results in the Longyearbyen (LY) study area. The map displays the maximum seasonal displacement expressed in mm (here for 2020, using an ascending SAR geometry). **A.** When analysing one SAR geometry and one season, the seasonal time series provide information on the short-term displacement pattern during the spring–fall snow-free period (here on a rock glacier). **B.** When all seasons and geometries are viewed all together, the time series provide information about the magnitude and timing of the displacement patterns during multiple seasons (here cyclic subsidence–heave patterns in an ice-rich part of the Advent valley). The results are shown in the InSAR Svalbard WebGIS tool. Background: Svalbard Orthophoto (NPI, 2026).

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4.2 Interannual InSAR Svalbard results

The interannual InSAR Svalbard results are complementary to the seasonal products. Spatially, they provide an information about the distribution of the ground surface dynamics at an interannual scale, allowing the identification of areas affected by long-term changes. By default, the InSAR Svalbard maps display the interannual velocity trends in mm/year. Each documented pixel includes a cumulative displacement time series ranging from 2018 to 2024 (**Fig. 3**). The users can change the visualisation settings and interact with the data according to their needs. Examples of WebGIS functions and concrete applications are described in the InSAR Svalbard user manual (Bredal et al., 2026b).

On slopes, fast-moving landforms, such as rock glaciers or debris-covered glaciers are likely to be decorrelated due to the long time intervals used to generate the interferometric pairs (see **Sect. 3**). However, slow and gradual displacement patterns over multiple years (up to a couple of cm/year) can be documented, for instance on solifluction sheets or lobes (**Fig. 3A**).
In flat terrain, such as in lowland coastal areas (**Fig. 3B**), the results highlight similar spatially variability as the seasonal products, due to the contrasting sediment types, frost susceptibilities and ground ice contents. However, due the different timescale, the interannual changes are representing different processes, such as long-term subsidence due to ice melt at the top of the permafrost (**Fig 3B**). The time series allows to identify and differentiate areas depicting relatively linear patterns from those affected by accelerating or decelerating trends. Such results can contribute to understand the evolution of landforms affected by permafrost degradation or aggregation (Liu et al., 2015; Samsonov et al., 2016) and further support the assessment of hazard potentially threatening modern infrastructure and cultural heritage sites (Nicu et al., 2026).

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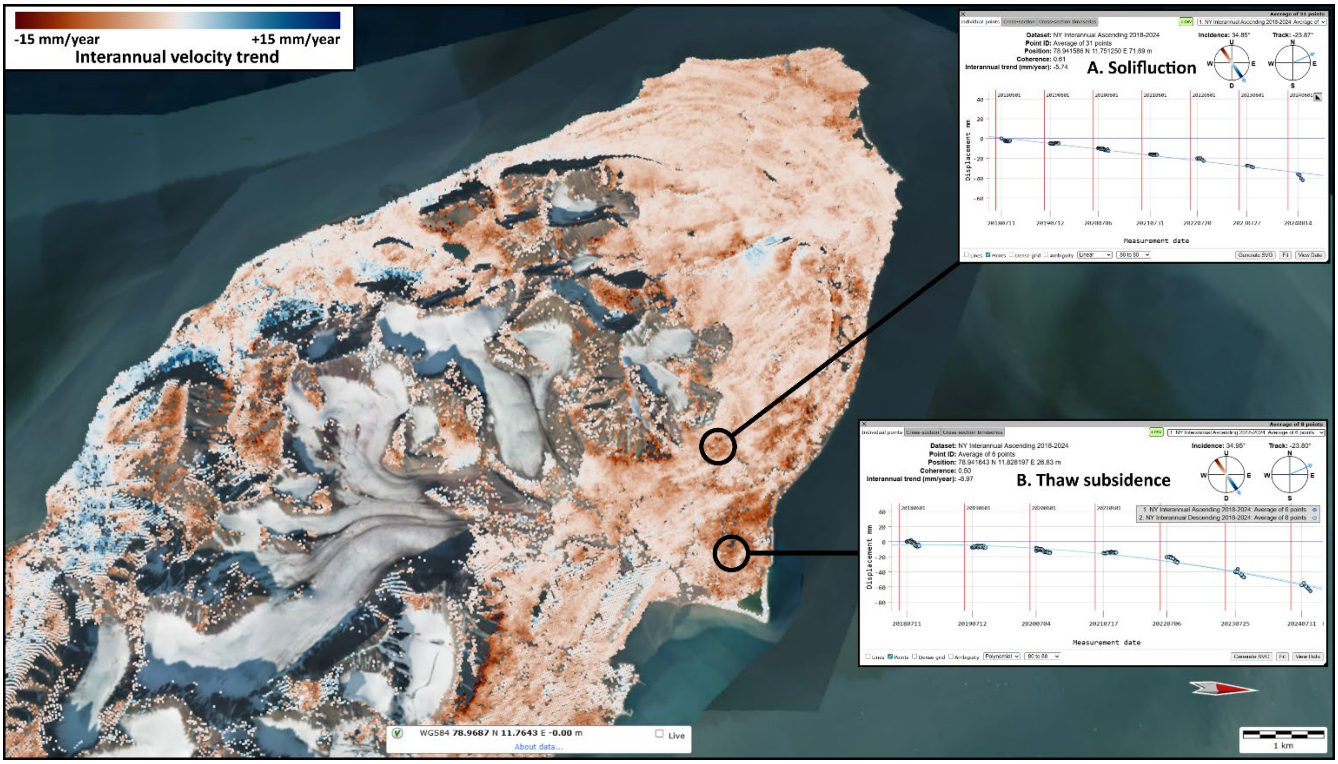

Figure 3. Example of interannual InSAR Svalbard results in the Ny-Ålesund (NY) study area. The map displays the mean annual velocity expressed in mm/yr (here for 2018–2024 using an ascending SAR geometry). **A.** The interannual displacement time series provide information on long-term gradual displacements occurring on mountain slopes (here due to solifluction). **B.** In flat terrain, the results provide information on interannual changes of surface levels (here accelerating thaw subsidence, likely due to top-of-permafrost ice melt). The results are shown in the InSAR Svalbard WebGIS tool. Background: Svalbard Orthophoto (NPI, 2026).

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6 Potential applications and future perspectives

During the three first years of the InSAR Svalbard development phase, we focused on collecting user requirements, defining the product specifications and designing the web-based 3D visualisation tool. This phase is ending with the first release of InSAR Svalbard pilot products in five study areas at https://svalbard.insar.no. The data has the potential to support several operational and research activities. Relevant applications of the current InSAR Svalbard products include (non-exhaustive list of examples):

- Detection, mapping and monitoring of thaw subsidence and frost heave patterns to better understand the state and evolution of the active layer and permafrost.
- Detection, mapping and monitoring of slow-moving slope processes (e.g., landslides, rock glaciers, solifluction).
- Estimation of the spatial distribution of the ground ice content and the changes in water balance.
- Assessment of terrain stability for land-use planning and infrastructure management.
- Hazard assessment and prioritisation of mitigation measures for cultural heritage sites and polluted areas.
- Mapping of glacier forefields and monitoring of geomorphic adjustments in recently deglaciated areas.

InSAR Svalbard is designed as a long-term service rather than a static data release. The WebGIS will be regularly updated as new Sentinel-1 images are becoming available. In the next years, the development is expected to continue to upscale the production to cover more areas in the Svalbard archipelago. New products may also become available. Currently, InSAR Svalbard relies on Sentinel-1 images, but future data sources will be explored. Particularly, the use of L-band SAR, thanks to the new NISAR mission, a NASA and ISRO collaboration, and the upcoming ESA Copernicus Sentinel-12 mission ROSE-L, could enhance InSAR applications in Svalbard. L-band SAR is valuable to improve signal stability over complex surfaces and increase the maximum detectable velocity to study fast-moving processes. However, coverage limitations (NISAR has a left-looking SAR configuration and only covers up to 77.5°N) and mission schedules (ROSE-L is expected to launch earliest in 2028) necessitate exploring alternative data sources in the coming years. To maximise the societal and scientific value of InSAR Svalbard, several future tasks are planned in the coming years:

- Refinement of processing routines and filtering threshold, for reducing uncertainties and designing sustainable strategies for automated production at larger scale.
- Expansion of study areas toward full Svalbard coverage, enabling comparison of several regions with diverse geological, topographic and climatic characteristics.
- Adjustment of product types and potential development of complementary products, based on user feedback and accounting for various needs.
- Data validation and interpretation, by comparing the products with complementary datasets, such as in-situ meteorological and permafrost measurements, geological maps, or geodetic measurements from in-situ data or optical remote sensing.

- Further development of the training material and documentation of use cases to enhance user uptake among local stakeholders, national authorities and polar researchers.

InSAR Svalbard provides a robust foundation for long-term ground motion observations in the Arctic. On the way further, we hope InSAR Svalbard may contribute to set a baseline for development of similar InSAR services tailored for polar conditions and permafrost terrain (Duchossois et al., 2024). As new Sentinel-1 images get available and other satellite missions become operational, the platform might evolve into a flexible, service-oriented system supporting research, hazard assessment, and sustainable land-use planning in permafrost regions.

Data availability

The data are openly available in the Zenodo repository at https://doi.org/10.5281/zenodo.18442696 (Bredal et al., 2026), where all products are distributed as CSV files. The products can be viewed in the InSAR Svalbard GMS web portal at https://svalbard.insar.no (release date: 02 February 2026, last access: 13 May 2026).

Author contributions

MB – Conceptualisation, Investigation, Funding acquisition, Project administration, Supervision, Visualisation, Writing – original draft.
LR – Conceptualisation, Data Curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Visualisation, Writing – original draft.
LW – Conceptualisation, Data Curation, Formal analysis, Investigation, Methodology, Software, Writing – review and editing.
HH – Data Curation, Software, Writing – review and editing.
DS – Data Curation, Software, Visualisation, Writing – review and editing.
TRL – Data Curation, Software, Writing – review and editing.
JvO – Software, Writing – review and editing.
YL – Software, Writing – review and editing.
GA – Project administration, Writing – review and editing.
EH – Project administration, Writing – review and editing.
JD – Funding acquisition, Resources, Writing – review and editing.
AS – Project administration, Writing – review and editing.
AO – Project administration, Writing – review and editing
DAM – Project administration, Writing – review and editing.

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Competing interests

The authors declare that they have no conflict of interest.

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