Detection of winter lake drainage events in Antarctica from SAR imagery

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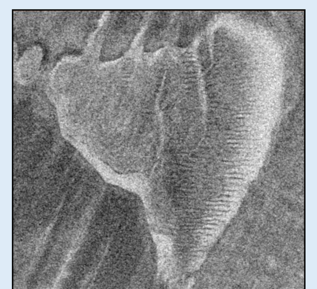
Motivation

Meltwater ponds are more widespread on Antarctica's surface than was previously thought (Kingslake, Ely et al. 2017) and monitoring their development will become increasingly important under the projected rising temperatures. **Meltwater movement** can directly affect the dynamic component of the ice sheet mass balance depending on the **location** and **timing** of drainage events (Nienow, Sole et al. 2017), with **rapid drainages** usually occurring via hydrofracture within hours to days (Tedesco 2013). Over the past decade, drainage events have mainly been detected over the Greenland ice sheet, while **observations remain rare in Antarctica**. Much of what we know about rapid lake drainage events comes from the analysis of optical satellite imagery which is **limited to the summer months**. This project aims to fill in the gap of the **winter months** and extensively map for the first time their spatial and temporal evolution **across Antarctic Ice shelves** by using Sentinel-1 **Synthetic-Aperture Radar (SAR) imagery** which is not affected by light and cloud condition, and thus enables **monitoring throughout the year.**

Methodology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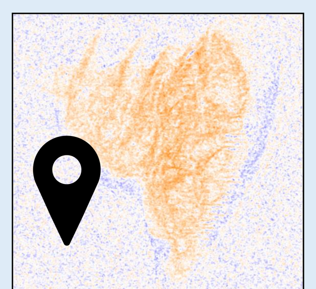
Data: Sentinel-1 (2017-2022)

Observations of lake drainages can be challenging when the first snowfalls or lids of ice cover the liquid water, and more difficult to identify in winter months due to low light levels and clouds.

A study conducted over the Greenland ice sheet in the winter months (Benedek and Willis 2021) **detected different modalities of lake drainages** proving the potential for a **SAR-based** approach to monitor lake behavior.

Radar signals can **penetrate through the ice cover** with different depths dependent on the system wavelength. C-band signals can penetrate solid ice by 1–2 m and fresh snow up to 10 m (Rignot, Echelmeyer et al. 2001), with the potential to reveal liquid water hidden under an ice lid or relatively thick snow layers.

A recent study (Warner, Fricker et al. 2021) revealed a supraglacial lake ice lid collapse on the Amery Ice Shelf using optical imagery. This event took place in June 2019, hinting that lake drainages can occur during the **winter months.**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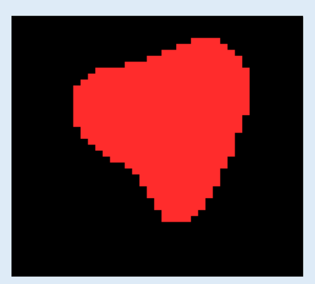
Change Detection

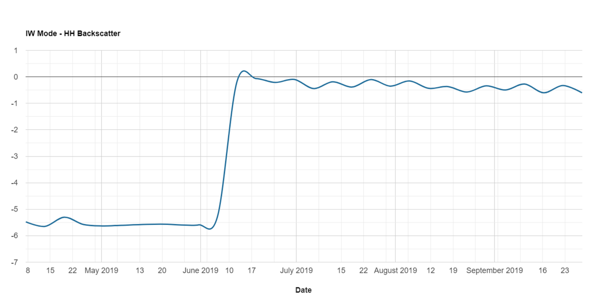
The radar signal scattered back from an ice sheet depends on dielectric properties of the substance, but also on the variations in spatial properties such as surface roughness, grain size and allocation (Fahnestock, Bindschadler et al. 1993).

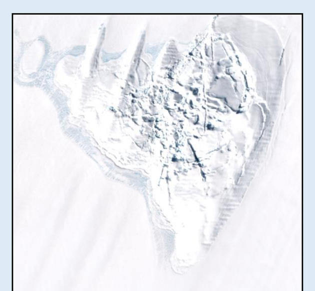
The change detection approach used is based on the difference of backscatter intensity after a **6-day interval (12 in 2022)**, which is the shortest revisit time of Sentinel-1.



Thresholding

The drainage event from 2019 was used to establish a threshold value corresponding to sudden increase in the time series.

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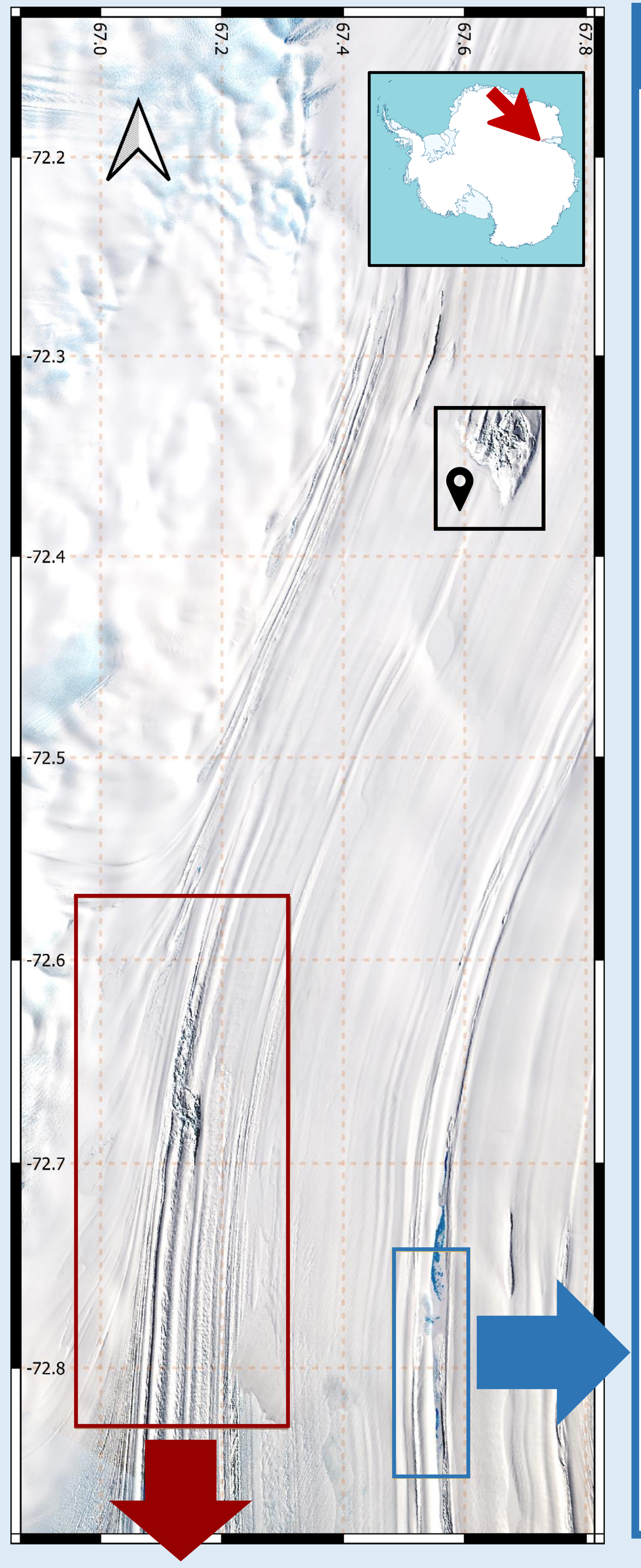
Validation with optical imagery

Optical imagery available after the winter months was used to characterize the drainage aftermath.

Sentinel-1 analysis and its validation with Landsat/8 Sentinel-2 imagery was performed in **Google Earth Engine.**

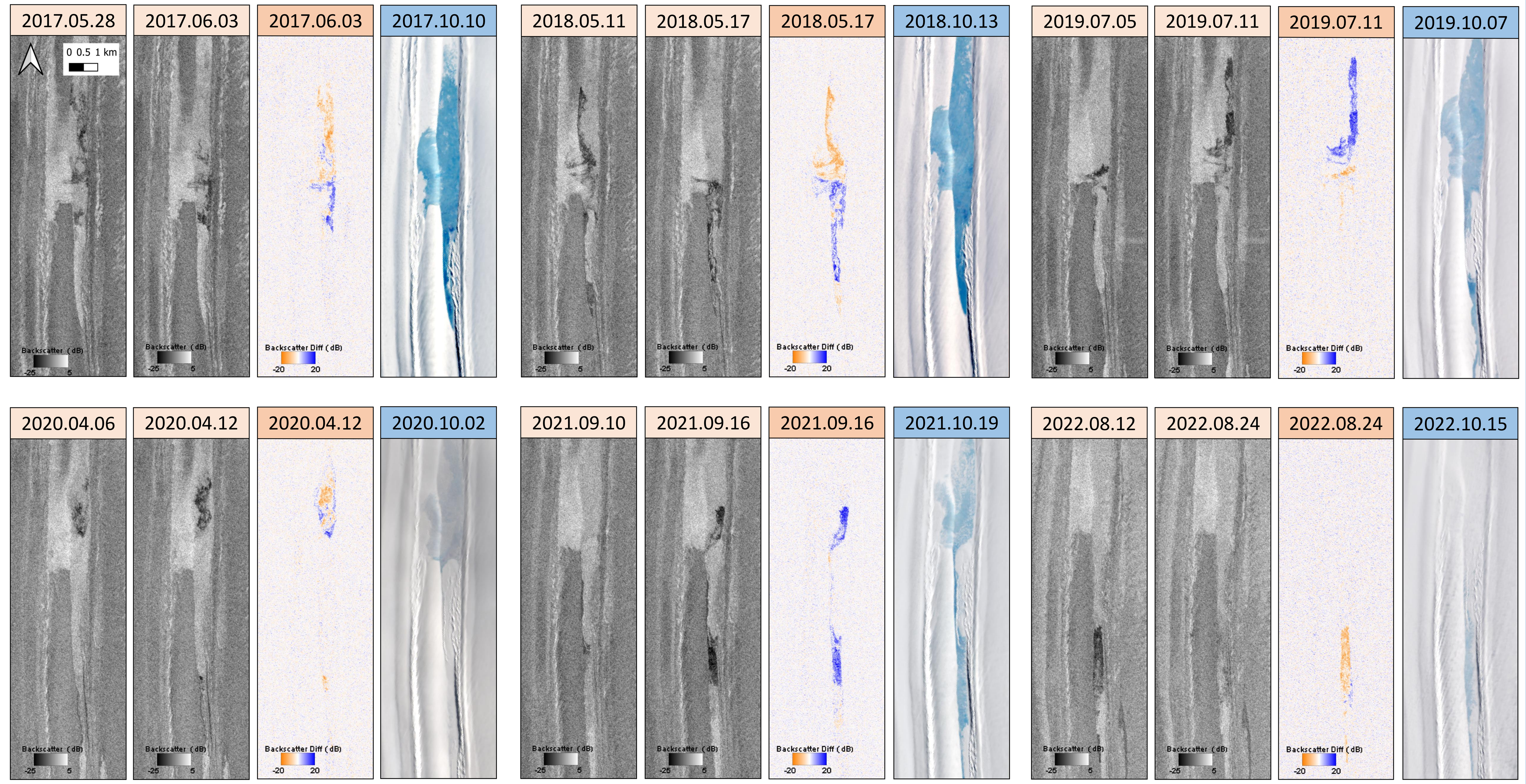
Results



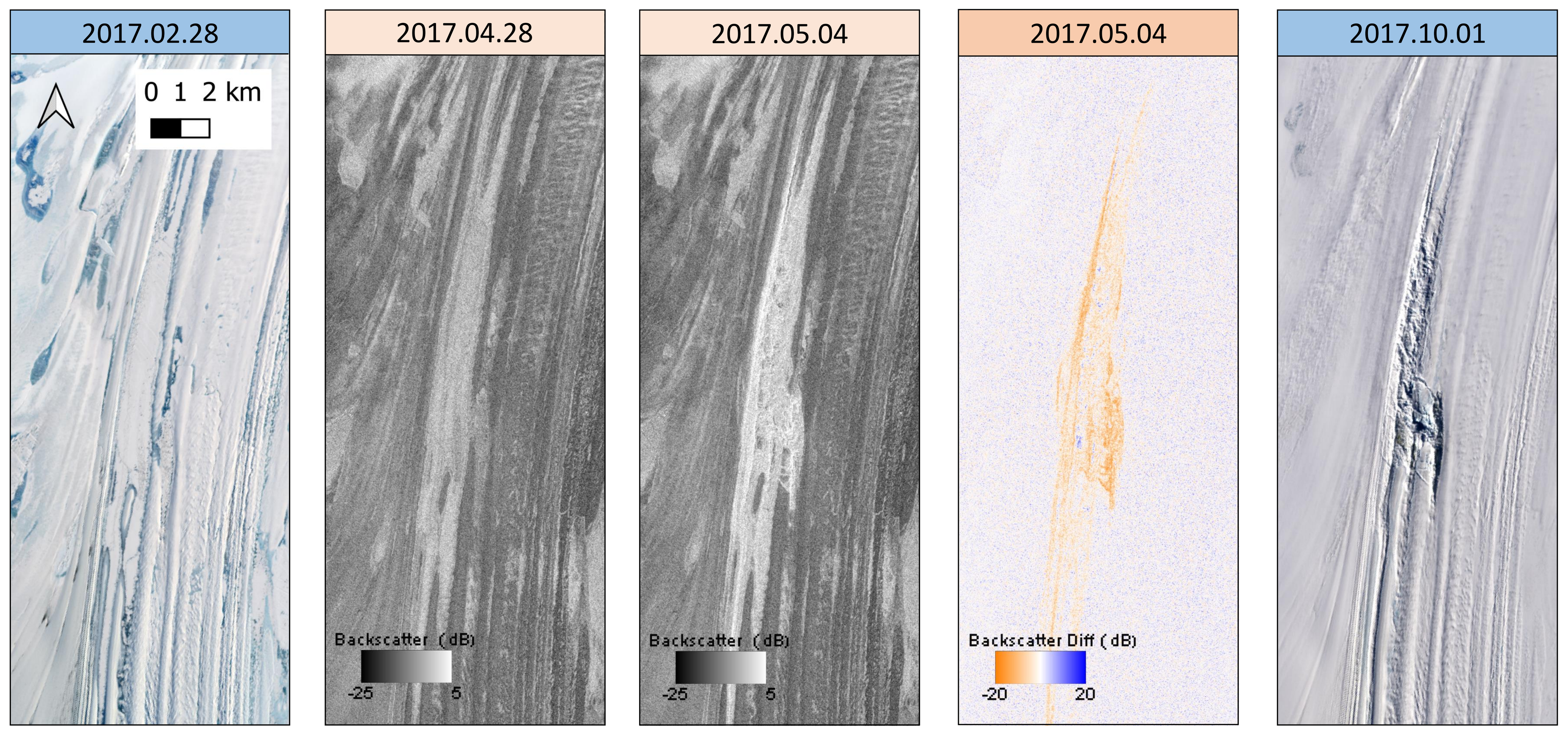
Water body active each winter from 2017 to 2022

The feature presented here shows frequent and highly localised changes in backscatter intensity throughout six consecutive winter seasons (as in the online videos). These are associated with meltwater movement across the ice surface as shown in the late-winter optical images (Landsat-8/Sentinel-2). The backscatter changes suggest ongoing transport of water in the supraglacial hydrological system throughout the winter, but the changes in backscatter are difficult to interpret physically without supporting datasets.

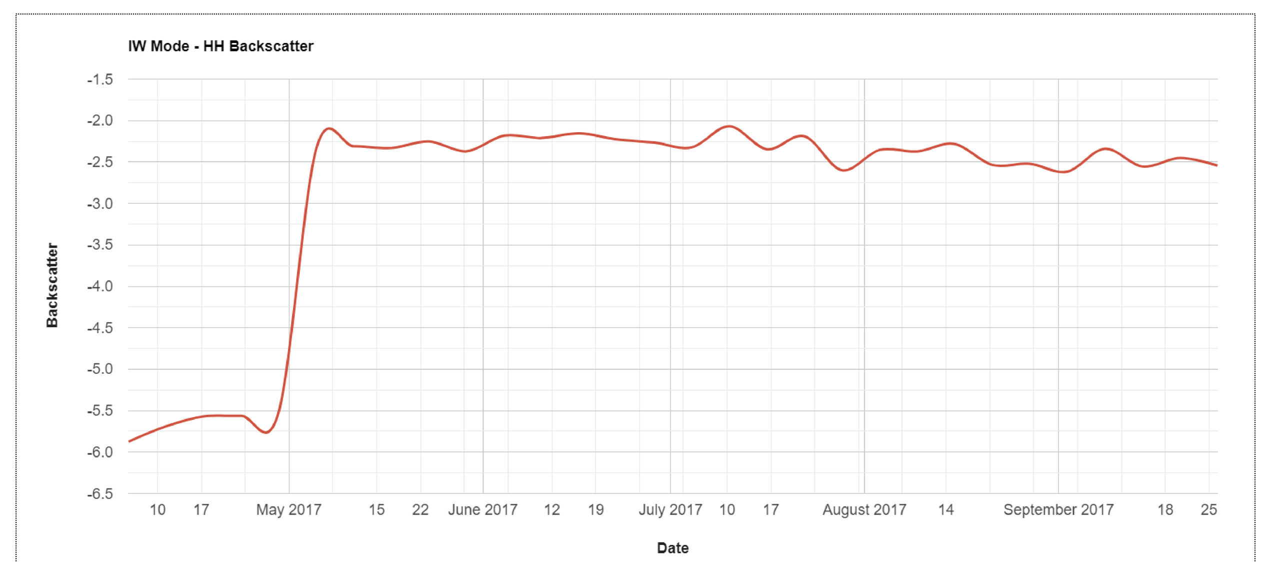
Additional videos



Ice Lid Collapse in 2017



After a lake drainage of an open water body, the signal is reflected from the former lake bottom which is significantly **rougher**, resulting in an **increase in the backscatter**. Drainage events are also the precursor of sudden lid collapse and the intensity of the backscatter will be further enhanced from the resulting ice debris. From the time series of the backscatter intensity over the area of the lid collapse, a steep increase in the signal induced by the collapsed lid can be observed between two relatively stable levels.



Next Steps

The future steps will involve:

(1) Include **TERRASAR-X** imagery to compare results in the X-Band.

(2) **SAR Interferometry** to characterize drainage and freeze-through mechanisms (Li, W. R., et al. 2021).

(3) Optical imagery to expand the observational timespan to the **summer months** and to characterize recurring lake drainages on the Amery Ice Shelf in order to identify potential **inter-seasonal** and **inter-annual relapse**. This imagery will also be used to quantify lake water volume lost during the melt season (Moussavi, Pope et al. 2020).

(4) Datasets including satellite altimetry or REMA DEM will be used to quantify **surface changes** detected on the Amery Ice Shelf.

(5) Radar and optical remote sensing techniques implemented to map drainage events on the Amery Ice Shelf will be applied to other **Antarctic ice shelves** with contrasting meltwater conditions.

References

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