Monitoring short-term ice dynamics across the grounding zone of Priestley Glacier, Antarctica using Terrestrial Radar Interferometry

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DFG Deutsche Forschungsgemeinschaft

Keypoints

1. **Terrestrial radar interferometry (TRI) at Priestley Glacier, Antarctica, provides first spatial context for sub-daily ice-flow changes at the grounding zone and beyond**
2. **Variability of ice speed at the grounding line is > 50 %, and ice-dynamic changes can be observed more than 14 km farther upstream**
3. **Ice-flow can be detected at cm-level, is spatially heterogeneous and includes components of tidal forcing and changes in subglacial hydrology**

Summary - Ice flow near the grounding zone of polar outlet glaciers varies on sub-daily timescales due to changes in the subglacial hydrological system and ocean tides. Understanding this behaviour is important to constrain processes that depend on peak rather than average velocities (e.g. glacial erosion). We demonstrate application of Terrestrial Radar Interferometry (TRI) for closing the observational gap between temporally well resolved GNSS measurements and spatially well resolved satellite observations. TRI observations over an 8 day period at Priestley Glacier, Antarctica, provide spatial flow fields every 3h explaining much of the variance measured at three GNSS receivers. Differential tidal bending in the grounding zone is detected hourly and at the cm-level over multiple complete tidal cycles. Sudden ice dynamic changes in localized areas upstream of the groundling line suggest episodic movement of cascading subglacial water pockets. TRI therefore enables monitoring of grounding-zone dynamics with unique temporal and spatial coverage, providing a new observational baseline to understand grounding-zone dynamics and related processes.

Overview

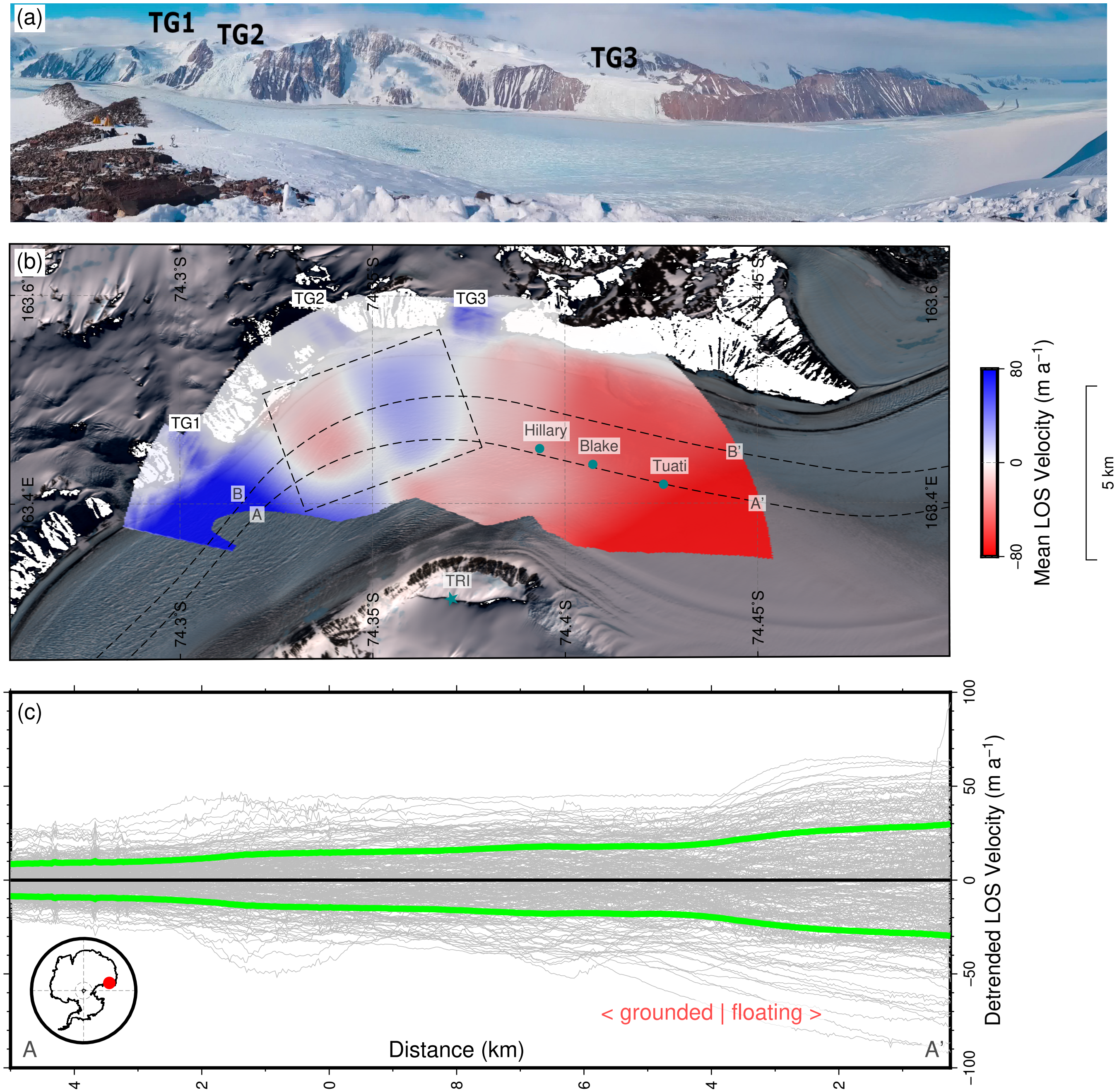

Figure 1: (a) Panoramic view from TRI location overlooking Priestley glacier with three marked tributary glaciers (TG 1-3). Ice flow direction is from left (south) to right (east). (b) Mean ice flow in the line-of-sight (LOS) direction with positive values marking ice movement towards the TRI. Hillary, Blake and Tuati are GNSS stations. Dashed lines and dashed rectangle mark locations referred to in the main text. (c) Deviation from the mean of ice-flow along A-A' over an 8 day period. Gray lines are taken approximately every 0.5 hours and each line represents a temporal average LOS ice flow over 3h. Green lines a ± one standard deviation.

Validation with GPS: It works at 6 h timescales and at all stations (shown here for Tuati). Smaller time scales are not reliabel with the GNSS anymore.

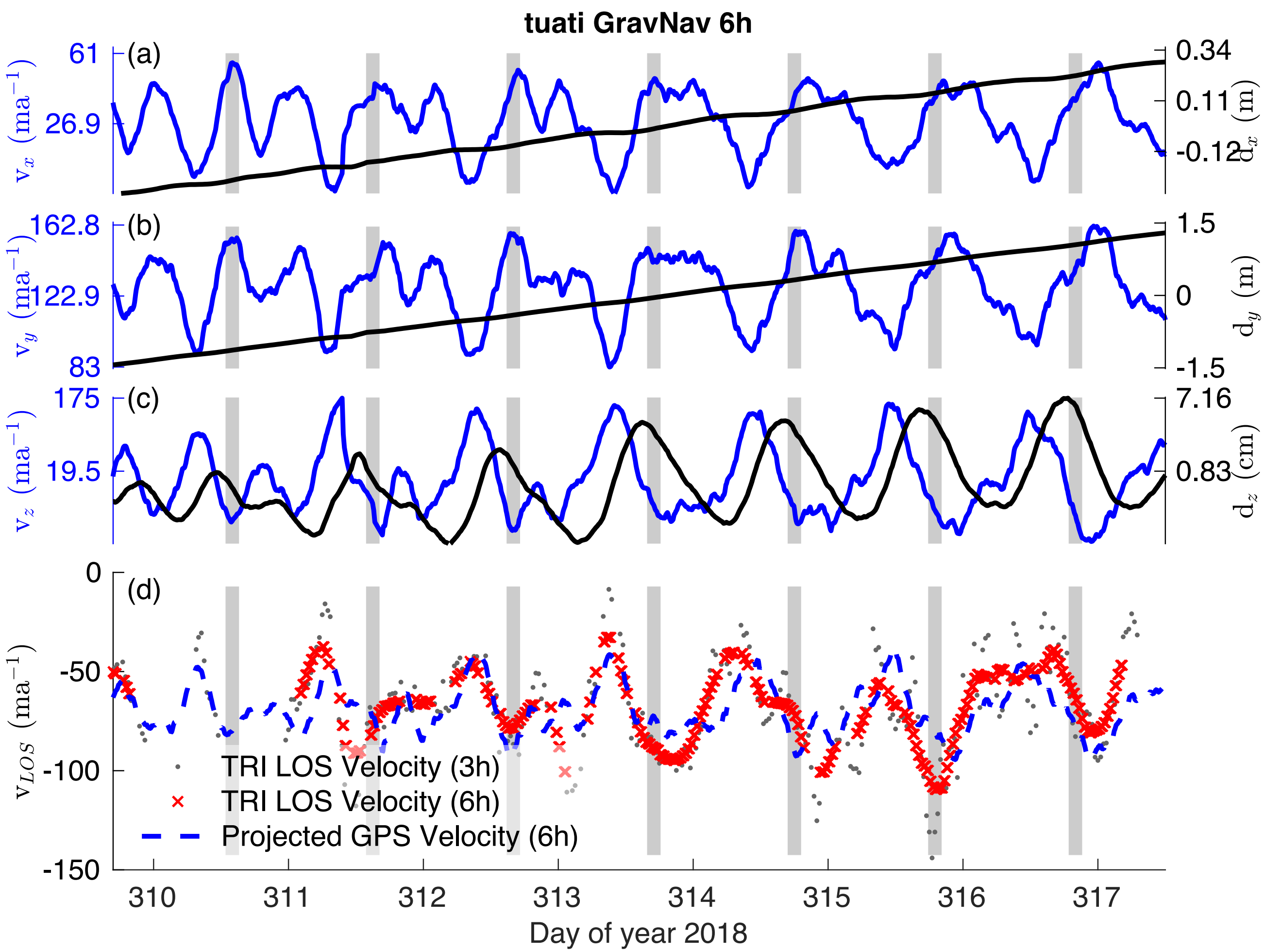

Figure 2: Time series over 8 days of 3D ice flow measured with GNSS in a terrestrial reference frame (a-c). A transformation into the the line-of-sight reference frame of the TRI demonstrates that the TRI captures much of the ice-flow variance measured at the specific GNSS location. Gray vertical bars mark times of high-tide

Monitoring tidal displacement at cm-level and at hourly timescales using differential interferometry

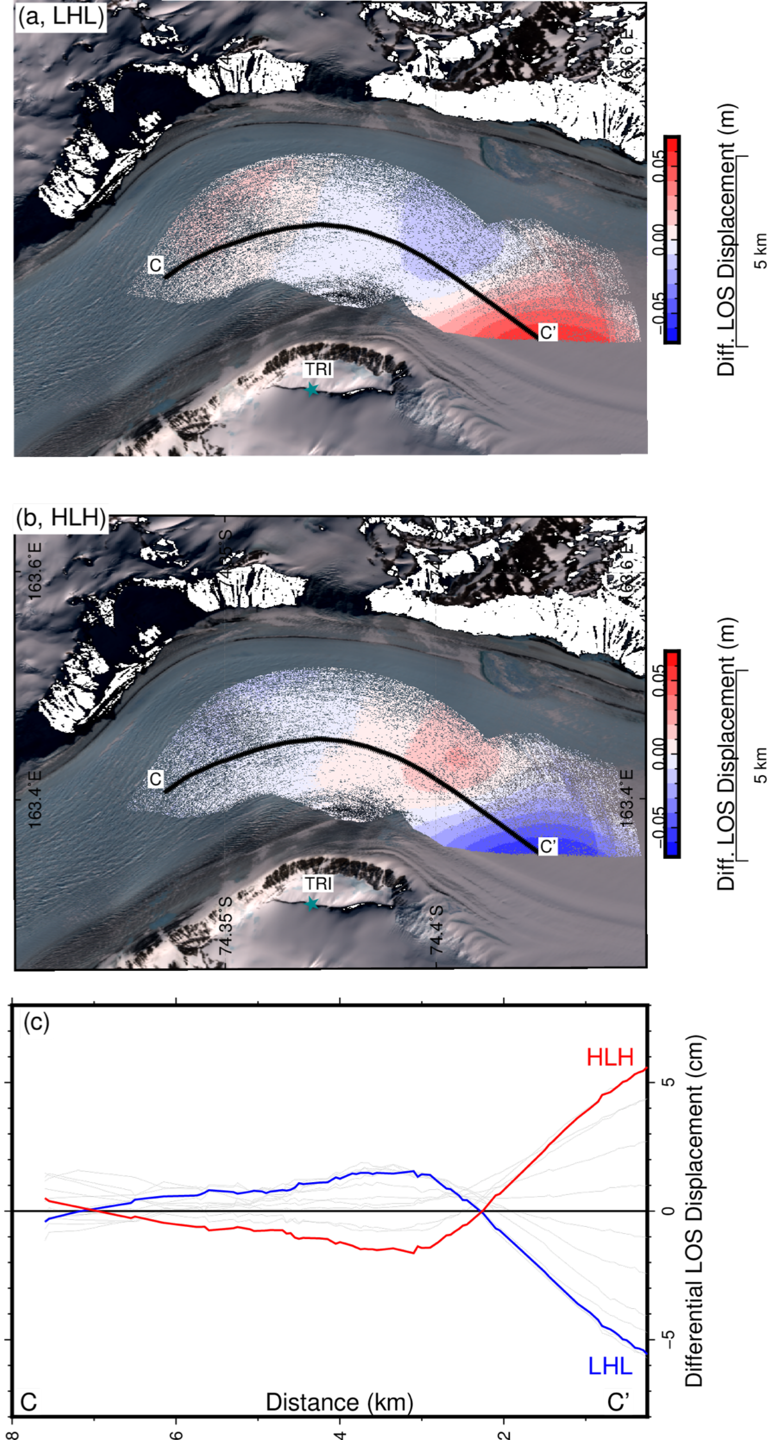

Figure 3: LOS displacement derived from differential interferograms with a 12h time difference. Differential displacement is shown for a low tide, high tide, low tide cycle (LHL, a), a high tide, low tide, high tide cycle (HLH, b), and along profile C-C' for the entire tidal cycle at 1h increments. Differential displacement contains differential tidal uplift at distances $<$ 2.2 km and an anti-phase pattern at distances $>$ 2.2~km that can be explained by residual horizontal motion caused by bending effects upstream of the grounding line.

Eight day time series with episodic, localized variability near bull‘s eye pattern

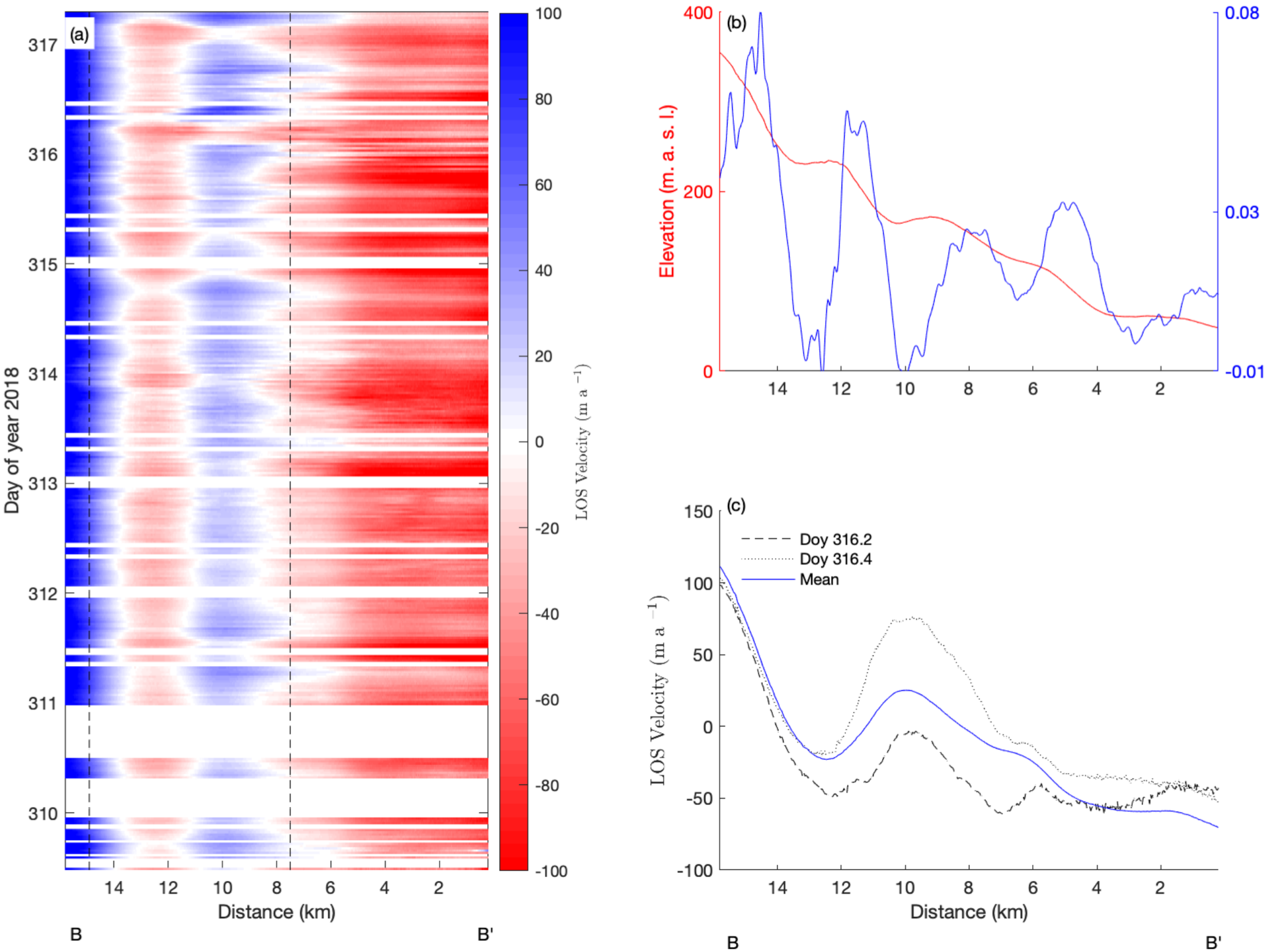

Figure 4 (a) Time series along profile B-B' with the vertical dashed lines marking the bi-polar pattern outlined with rectangle in Fig.~1. This pattern is linked to changes in surface slope resulting in descending and ascending components of ice-flow that are projected onto the LOS geometry, respectively (b). This area shows sudden changes in LOS velocity (c) that we link to abrupt changes in the subglacial hydrology.

Sensitivity of the TRI to vertical, along-flow and across flow velocities

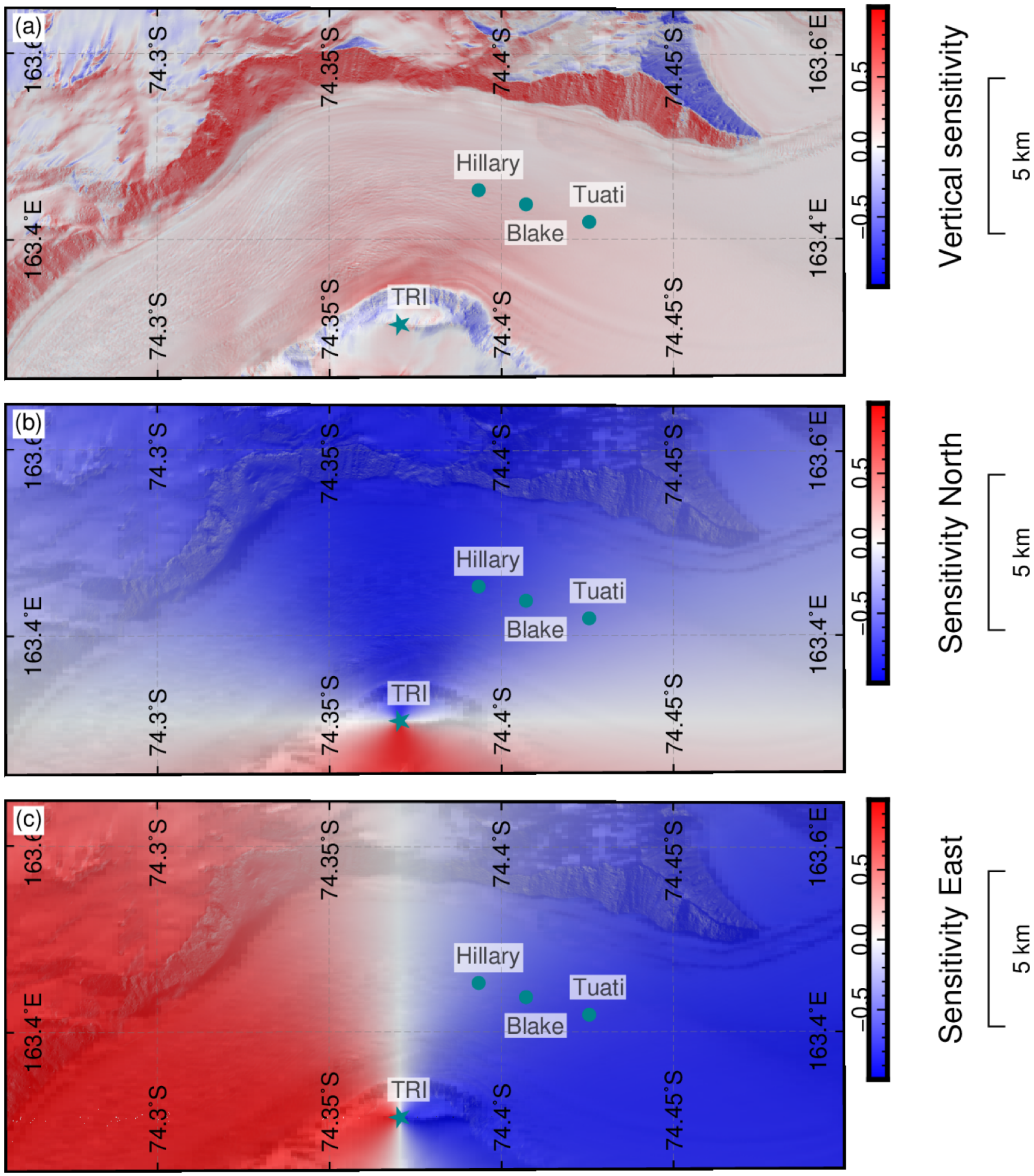

Figure 5 Sensitivity of the TRI measurements to vertical velocities (a), across-flow (or east-west) velocities (b) and, along-flow (or north-south) velocities. The sensitivities are dictated by the viewing geometry and enable the transformation from 3D GNSS velocities measured in a terrestrial reference frame, to the local LOS reference frame.

Subglacial Topography (Thanks Operation IceBridge!)

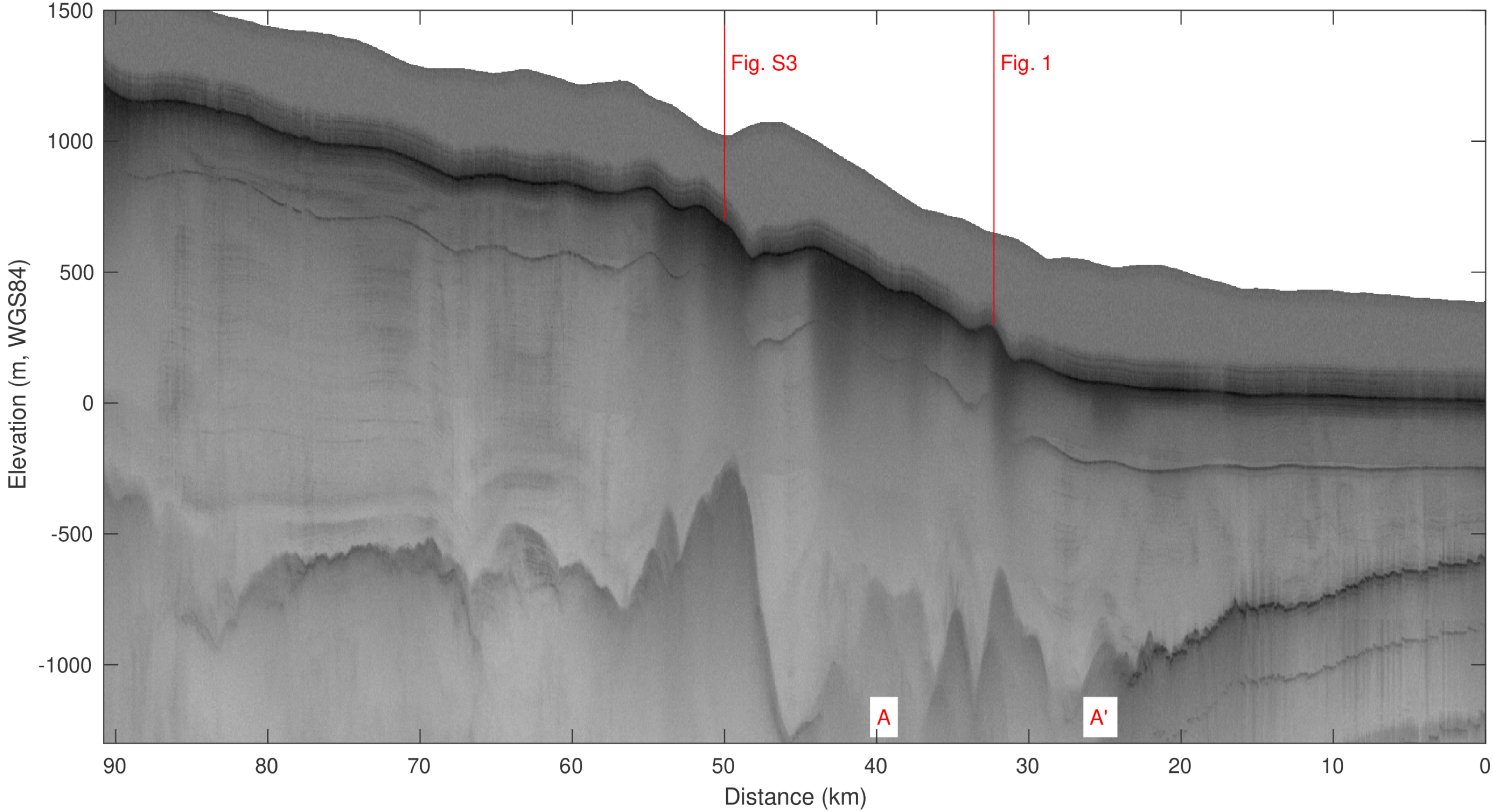

Figure 6 Airborne ice-penetrating radar profile from operation IceBridge along A-A' marked in Fig. 1. The bipolar pattern in Fig.~1 and Fig.~4 corresponds to a topographic high in the subglacial topography. A more pronounced topographic high at 50 km distance may act as a Riegel to subglacial waterflow causing intermittent and abrupt drainage of subglacial water that can be observed in the Bull's eyes pattern observed in Fig. 7.

InSAR Bull's eyes and cascading subglacial water pockets

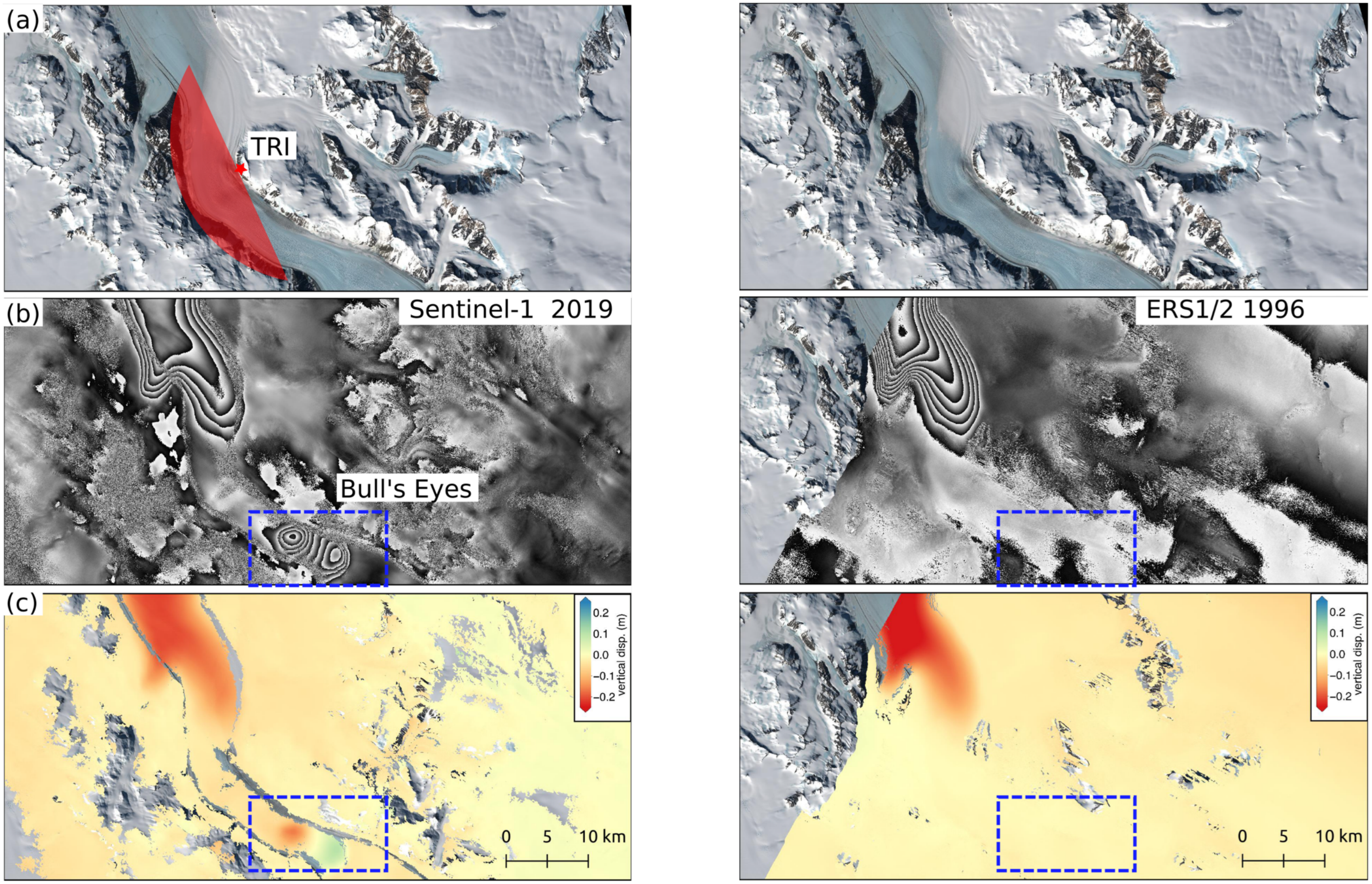

Figure 7 Detection of transient Bull's eyes pattern using satellite InSAR outside the temporal and spatial range of the TRI (a). Differential interferograms from Sentinel 2 in 2019 and ERS1/2 in 1996 both image the differential tidal uplift of the grounding zone. The upstream limit of tidal bending is similar in both time frames. The differential Sentinel interferogramms additionally show development of a Bull's eys patterns approximately 20 km upstream of the grounding line (b). The unwrapped displacement links this Bull's eyes pattern to vertical displacement of $\pm$20 cm. We associate this pattern with drainage and re-filling of waterfilled, subglacial lakes.

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