tracking, offsets were converted from slant to ground range coordinates. The displacements were filtered in space: first by a ~~signal to noise~~ signal-to-noise ratio based on the cross-correlation of image patches ~~,~~ and then again using deviation from the mean displacement within a neighbourhood. The results were geocoded to a polar stereographic projection (EPSG:3031) and the range and azimuth displacements reprojected to present them relative to grid north. Conversion to ground-range coordinates and geocoding was completed using the REMA DEM (Howat et al., 2019) gap-filled with the RAMP DEM (Liu et al., 2015).

3 Results

TanDEM-X DEM heights above flotation for November 2020 (Fig. 1a) show little retreat from the DInSAR-derived grounding lines from 2016/17, with the exception of the small region upstream of the cavity. This region, similar to the lobed region on the opposite eastern side of the glacier close to the black star in Fig. A1, is apparent and expands throughout the time series. In 2011 and 2017 the DEM-derived grounding lines match the DInSAR ones in the region of the cavity and near the fast-flowing central part of the glacier. To the east of the glacier the 2011 DInSAR grounding lines skirt locations that appear as disconnected pinning points (Fig. A1a) that have disappeared by 2017 in both the DInSAR and DEM (Fig. A1c). The largest discrepancies between ~~DInSAR and DEM derived~~ DInSAR- and DEM-derived grounding lines are in 2011 to the west of the main glacier trunk. This discrepancy may be due to acquisition time – the ERS-2 data were from April 2011 and the TanDEM-X data are 22/23 June 2011, and this is a location of grounding line retreat.

Surface elevation losses of 50 to 60 m between 2014 and 2017 over the cavity location (Fig. 1b) confirm those presented by Milillo et al. (2019) (their Fig. S6). The ice here was inferred to have gone afloat during 2014, and basal melt rates were estimated to be up to 200 m a^{-1}. Elevation changes between 2017 and 2020 (Fig. 1c) show that the earlier cavity erosion process has slowed but that the cavity has persisted~~,~~; in other words only small changes in thickness have taken place.

We extracted profiles of surface elevation and ice base along a ~~flowline~~ flow line and a cross-flow transect. The ~~flowline~~ flow line was based on the mean velocity direction and was constructed to pass through the area of maximum thickness change. Both profile locations are shown in Fig. 1b and c. The ice base was obtained by subtracting the hydrostatic thickness from the surface elevation. Where the ice is grounded the plots show the ice base below bedrock~~,~~; this is simply a device to indicate height above flotation scaled by $\rho_w/(\rho_w - \rho_i) \approx 8$ (Fig. 2)TS3. We found a good agreement between the range of 2016/17 interferometric grounding lines and the locations where the inferred ice base is close to the bedrock between 115 and 118.5 km along the ~~flowline. The flowline~~ flow line. The flow line profiles (Fig. 2a) show that the ungrounding evolves spatially in the up-flow direction. As early as 2011 a small cavity apparently existed at 115 km along the ~~flowline~~flow line; we have no evidence that this cavity connected to the ocean until June 2013. A second cavity develops by April 2015, by which time we can identify a path to the ocean in a direction perpendicular to the flow. By June 2016 the cavities have merged, and in January 2017 they connect with the existing downstream ice shelf. Beyond 2017 and up to the end of 2020 the cavity remains stable. The temporal evolution can be seen more easily in the supplementary animation.

The cross-flow profiles (Fig. 2b) show the cavity expanding steadily inland from 2011 to 2019 with a good agreement to DInSAR grounding line locations in 2011 and 2016/17 and confirming the > 2 km grounding line migration zone after 2014. Our estimated cavity depths along both profiles are up to 200 m. Our 2016/17 DEM-based grounding lines alongside the cavity do not show the large spatial variation indicated by the DInSAR method but delineate the most retreated location (Fig. 2a), probably as the ice here is so close to flotation and the DInSAR lines migrate across a grounding zone.

Thwaites Glacier and floating tongue continue to accelerate from 2012 to 2020. Over much of the fast-flowing region speeds are 400 m a^{-1} greater in January 2021 than in January 2012 – an increase of more than 10 % (Fig. A2a). Velocities at a point about 5–10 km upstream of the cavity location (Fig. 1c) increase at an average annual rate of 70 m a^{-1} with steeper acceleration since ~~mid 2015~~ mid-2015 and intra-annual variability of the order of 0.1 (Fig. 3). Observed thinning at this location is about 1.5 m a^{-1}, but this is likely to be an underestimate owing to the temporally changing bias in elevation uncertainty, and the thinning rate could be as great as 2.0 m a^{-1}.

4 Discussion

Our results show that the cavity beneath the newly floating region along the western border of Thwaites Glacier has not continued to deepen beyond 2017. The stability of the grounding lines, which are now in regions of prograde bed slopes, indicates that the advection of ice here is matched by high thinning rates, ~~either due to~~ due to either melt or dynamic thinning. Extremely high melt rates, up to 200 m a^{-1} (Milillo et al., 2019), were detected in the cavity between 2014 and 2017 and may now contribute to maintaining the new grounding line positions. However, this melt has not continued to increase the cavity depth, a fact that is consistent with observations and model studies showing that high melt rates within shallow cavities are restricted to the vicinity of the grounding line. For example, new cavities exposed since 1993 beneath ASE ice shelves remain on average just 112 m

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