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Net retreat of Antarctic glacier grounding lines

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Supplementary information to

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This document contains supplementary figures S1, S2, and S3, supplementary table S1 and the caption for supplementary table S2 (provided as a separate file).

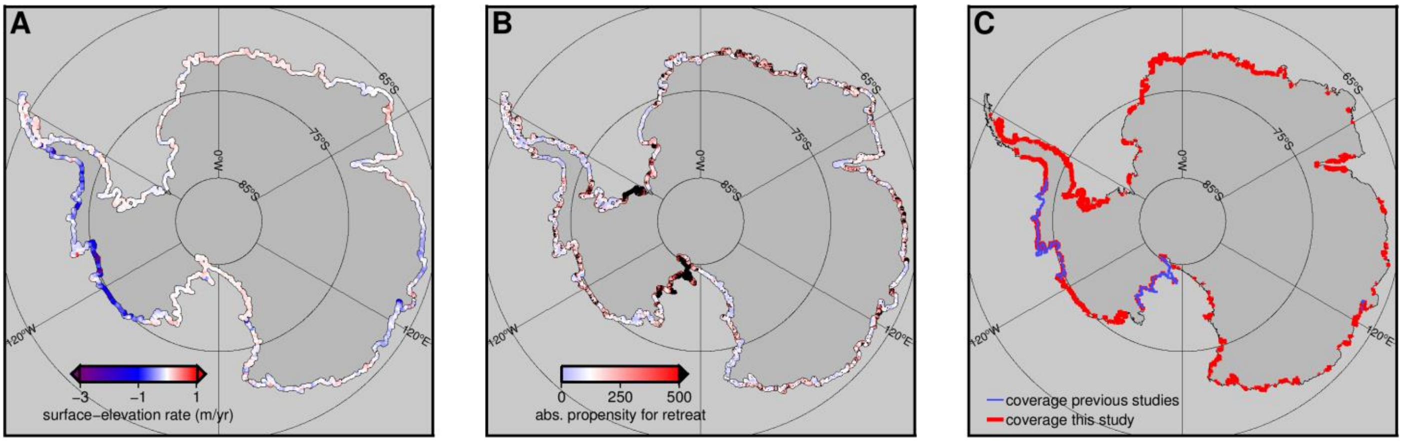

Fig. S1. Surface-elevation rate between 2010 and 2016 (A) and propensity for retreat (B) at the Antarctic ice-sheet margin (Rignot *et al.*, 2013). Surface-elevation rates are computed from CryoSat-2 measurements. Propensity for retreat is a quantity related to bedrock and surface gradients (from Fretwell *et al.*, 2013 and McMillan *et al.*, 2014, respectively), and the assumed direction of grounding-line migration (see main text and Methods); high and low values mark areas where elevation changes translate into fast and slow grounding-line migration, respectively. On average, ice at the grounding line thinned by 10 ± 9 cm/yr between 2010 and 2016 at the Antarctic Peninsula and by 22 ± 7 cm/yr in West Antarctica. In contrast, the surface overall stagnated in East Antarctica, manifesting in a highly insignificant thickening of 0.3 ± 9 cm/yr. C: Sections of grounding-line migration covered by previous studies (Horgan and Anandakrishnan, 2006; Park *et al.*, 2013; Rignot *et al.*, 2014; Li *et al.*, 2015; Christie *et al.*, 2016; 12.2% of the total grounding line) and respective coverage by our study (33.4%).

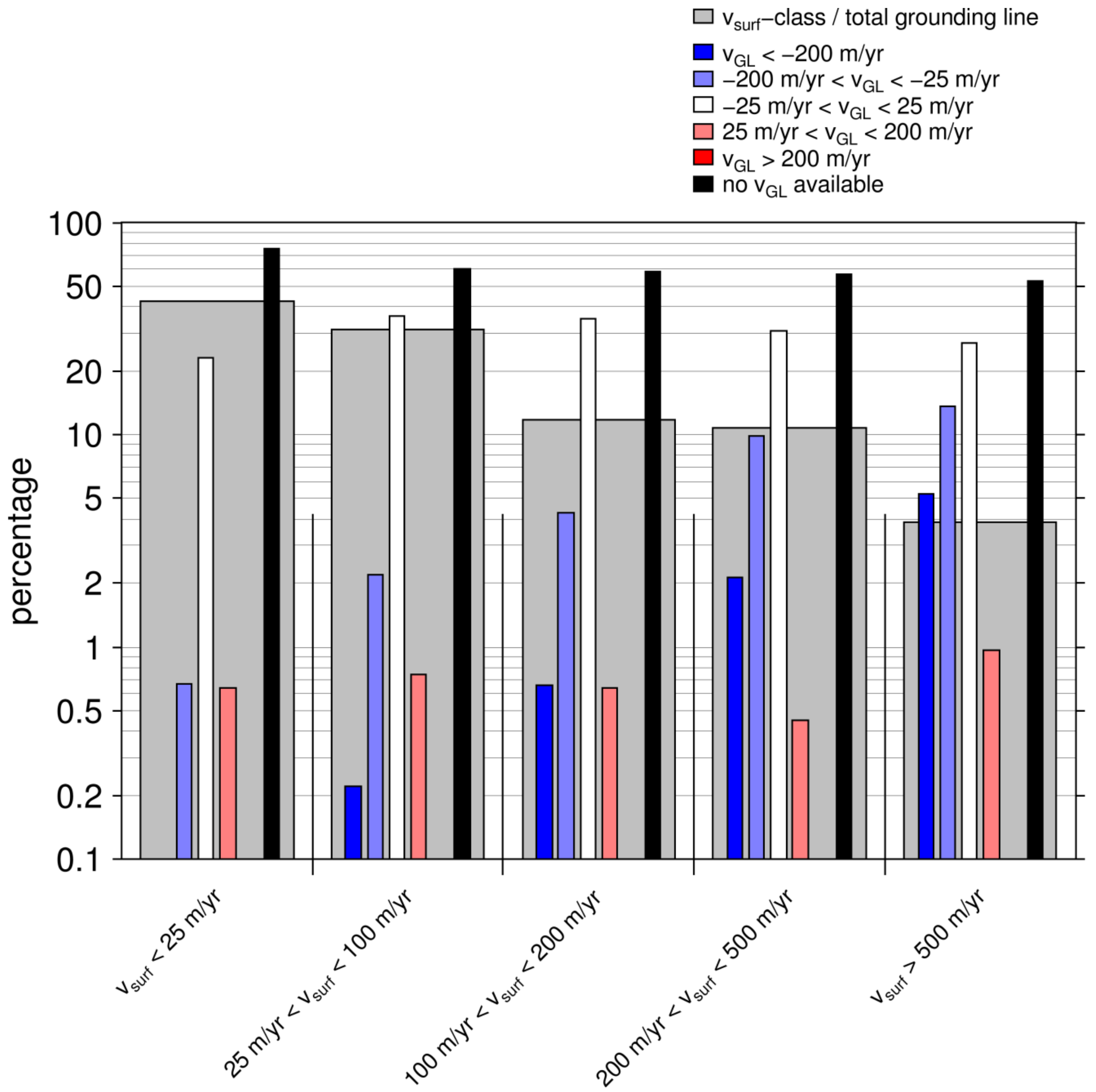

Fig. S2. Distribution of ice surface velocities (from Mouginot *et al.*, 2012; wide gray bars), overlaid by the distribution of our rates of grounding-line migration (narrow multi-colored bars) along sections of the Antarctic grounding line falling within pre-defined velocity classes (see x-axis), i.e. a two-level histogram. Note the logarithmic scale of the y-axis.

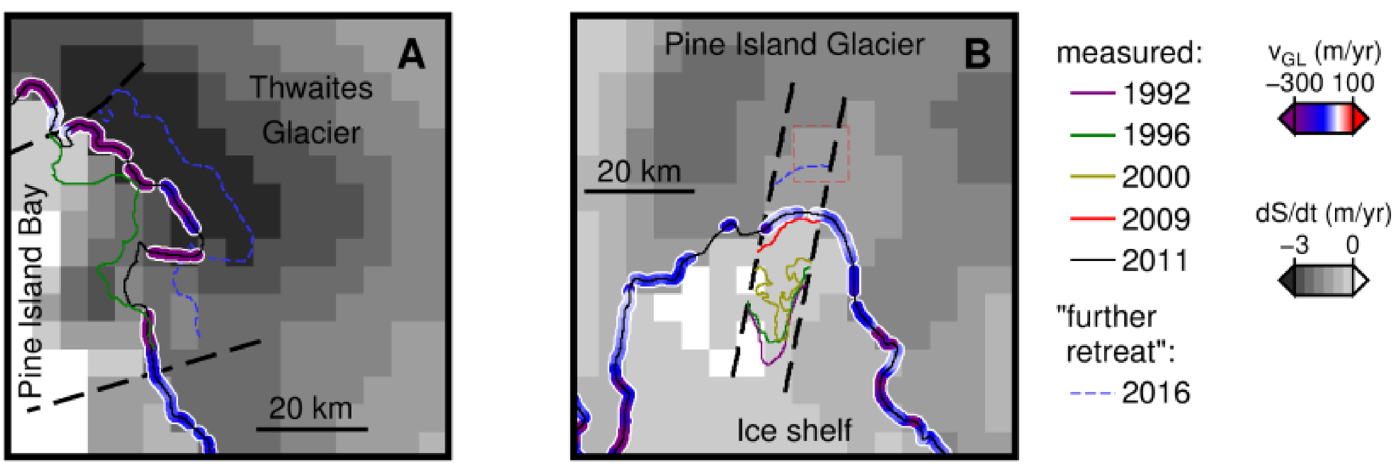

Fig. S3. InSAR-derived grounding-line positions (colored lines) and altimeter-derived grounding-line migration rates along the 2011 position (graded color lines) superimposed on a map of surface-elevation rates determined from CryoSat-2 (grey shading) for Thwaites Glacier (A) and Pine Island Glacier (B). Also shown are the along-flow swaths (dashed black lines) across which retreat is evaluated as shown Figure 2, the area from which the time series of elevation rates in Figure 2B originates (red dashed square in B; from Konrad *et al.*, 2017), and the ultimate grounding-line position in the 'further retreat' scenario (blue dashed).

	Retreating	Advancing	Total area change (km^2/yr)
East Antarctic Ice Sheet	3.3%	2.2%	-6±42
Antarctic Peninsula	9.5%	3.5%	-26±24
West Antarctic Ice Sheet	21.7%	0.7%	-177±48
Weddell Sea	1.1%	0.8%	1±7
Ross Sea	4.7%	0.8%	-7±7
Amundsen Sea	59.4%	0.8%	-162±31
Bellingshausen Sea	17.4%	0.1%	-9±4
Total	10.7%	1.9%	-209±113

Table S1. Fractions of the grounding line retreating or advancing faster than 25 m/yr in the various parts of Antarctica, as well as grounded area change rates in our surveyed sections.

Table S2 (provided as a separate file). Average rates of surface elevation and of grounding-line migration in Antarctic drainage basins (Rignot et al. 2008), and 5- and 95-percentiles in the case of grounding-line migration. Averages are computed for two different surface velocity thresholds (25 m/yr and 800 m/yr). The 'qualified coverage' indicates which part of the section is available based on CryoSat-2 and InSAR grounding-line coverage, our other criteria for retaining data points (see Methods), and the enforcement of the respective surface velocity thresholds. Grey background indicates that the respective absolute average values exceed the average uncertainties. Also given are length of grounding line in the basins and coverage by CryoSat-2 and InSAR grounding-line locations. Basins for which we provide the first estimate of rates of grounding-line migration during the satellite era are marked with an asterisk.

References

Christie, Frazer D W, Robert G Bingham, Noel Gourmelen, Simon F B Tett, and Atsuhiro Muto. 2016. "Four-Decade Record of Pervasive Grounding Line Retreat along the Bellingshausen Margin of West Antarctica." *Geophys. Res. Lett.* 43 (11):5741–49. https://doi.org/10.1002/2016GL068972.

Fretwell, P, H D Pritchard, D G Vaughan, J L Bamber, N E Barrand, R Bell, C Bianchi, et al. 2013. "Bedmap2: Improved Ice Bed, Surface and Thickness Datasets for Antarctica." *The Cryosphere* 7

(1):375–93. https://doi.org/10.5194/tc-7-375-2013.

Horgan, H. J., and S. Anandakrishnan. 2006. “Static Grounding Lines and Dynamic Ice Streams: Evidence from the Siple Coast, West Antarctica.” *Geophysical Research Letters* 33 (18):1–6. https://doi.org/10.1029/2006GL027091.

Konrad, Hannes, Lin Gilbert, Stephen Cornford, Antony Payne, Anna Hogg, Alan Muir, and Andrew Shepherd. 2017. “Uneven Onset and Pace of Ice-Dynamical Imbalance in the Amundsen Sea Embayment, West Antarctica.” *Geophysical Research Letters* 44 (2):910–18. https://doi.org/10.1002/2016GL070733.

Li, Xin, Eric Rignot, Mathieu Morlighem, Jeremie Mouginot, and Bernd Scheuchl. 2015. “Grounding Line Retreat of Totten Glacier, East Antarctica, 1996 to 2013.” *Geophys. Res. Lett.* 42 (19):8049–56. https://doi.org/10.1002/2015GL065701.

McMillan, M, A Shepherd, A Sundal, K Briggs, A Muir, A Ridout, A Hogg, and D Wingham. 2014. “Increased Ice Losses from Antarctica Detected by CryoSat-2.” *Geophysical Research Letters* 41 (11):3899–3905. https://doi.org/10.1002/2014GL060111.

Mouginot, Jeremie, Bernd Scheuchl, and Eric Rignot. 2012. “Mapping of Ice Motion in Antarctica Using Synthetic-Aperture Radar Data.” *Remote Sensing* 4 (9):2753–67. https://doi.org/10.3390/rs4092753.

Park, J W, N Gourmelen, A Shepherd, S W Kim, D G Vaughan, and D J Wingham. 2013. “Sustained Retreat of the Pine Island Glacier.” *Geophys. Res. Lett.* 40 (10):2137–42. https://doi.org/10.1002/grl.50379.

Rignot, E, J L Bamber, M R van den Broeke, C Davis, Y Li, W J van de Berg, and E van Meijgaard. 2008. “Recent Antarctic Ice Mass Loss from Radar Interferometry and Regional Climate Modelling.” *Nature Geosci.* 1 (2):106–10. https://doi.org/10.1038/ngeo102.

Rignot, E, S Jacobs, J Mouginot, and B Scheuchl. 2013. “Ice-Shelf Melting Around Antarctica.” *Science* 341 (6143):266–70.

Rignot, E, J Mouginot, M Morlighem, H Seroussi, and B Scheuchl. 2014. “Widespread, Rapid Grounding Line Retreat of Pine Island, Thwaites, Smith, and Kohler Glaciers, West Antarctica, from 1992 to 2011.” *Geophys. Res. Lett.* 41 (10):3502–9. https://doi.org/10.1002/2014GL060140.