

1 Sea-level contribution of Thwaites Glacier doubles in a
2 observation-constrained ice-sheet model - Supplementary
3 Information

4 Mattia Poinelli,^{1,2,*} Eric Rignot,¹, H el ene Seroussi³,
 Josh Cuzzone⁴, Tyler Pelle⁵, Eric Larour²

¹Department of Earth System Science, University of California, Irvine, CA, USA

²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

³Thayer School of Engineering, Dartmouth College, Hanover, NH, USA

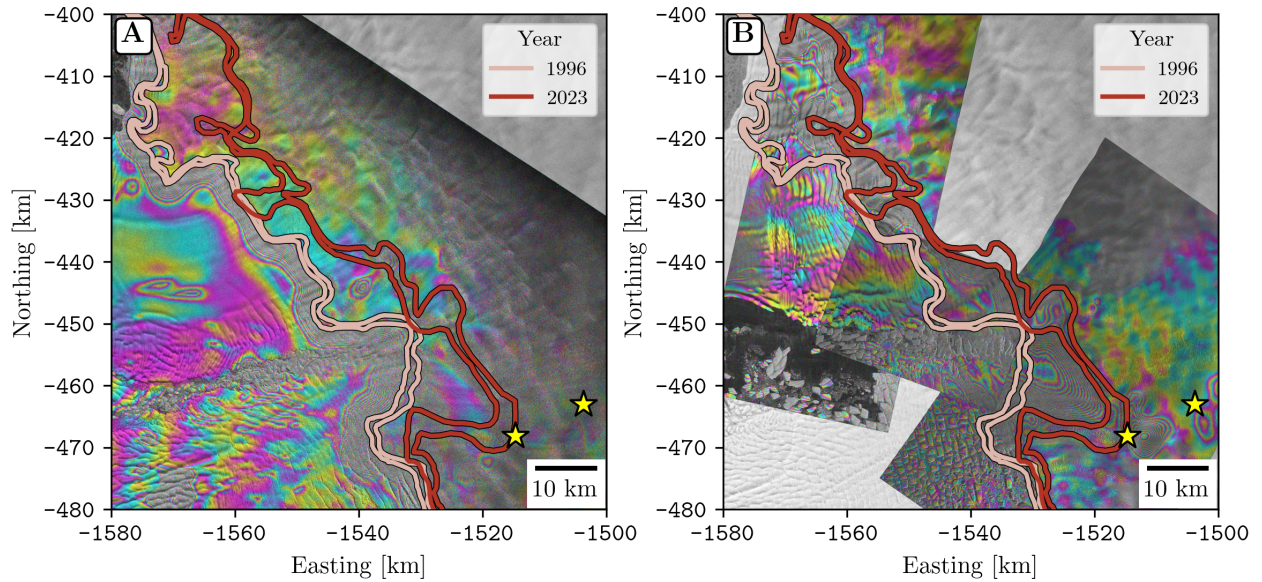
⁴Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, CA, USA

⁵Scripps Institute of Oceanography, University of California, San Diego, CA, USA

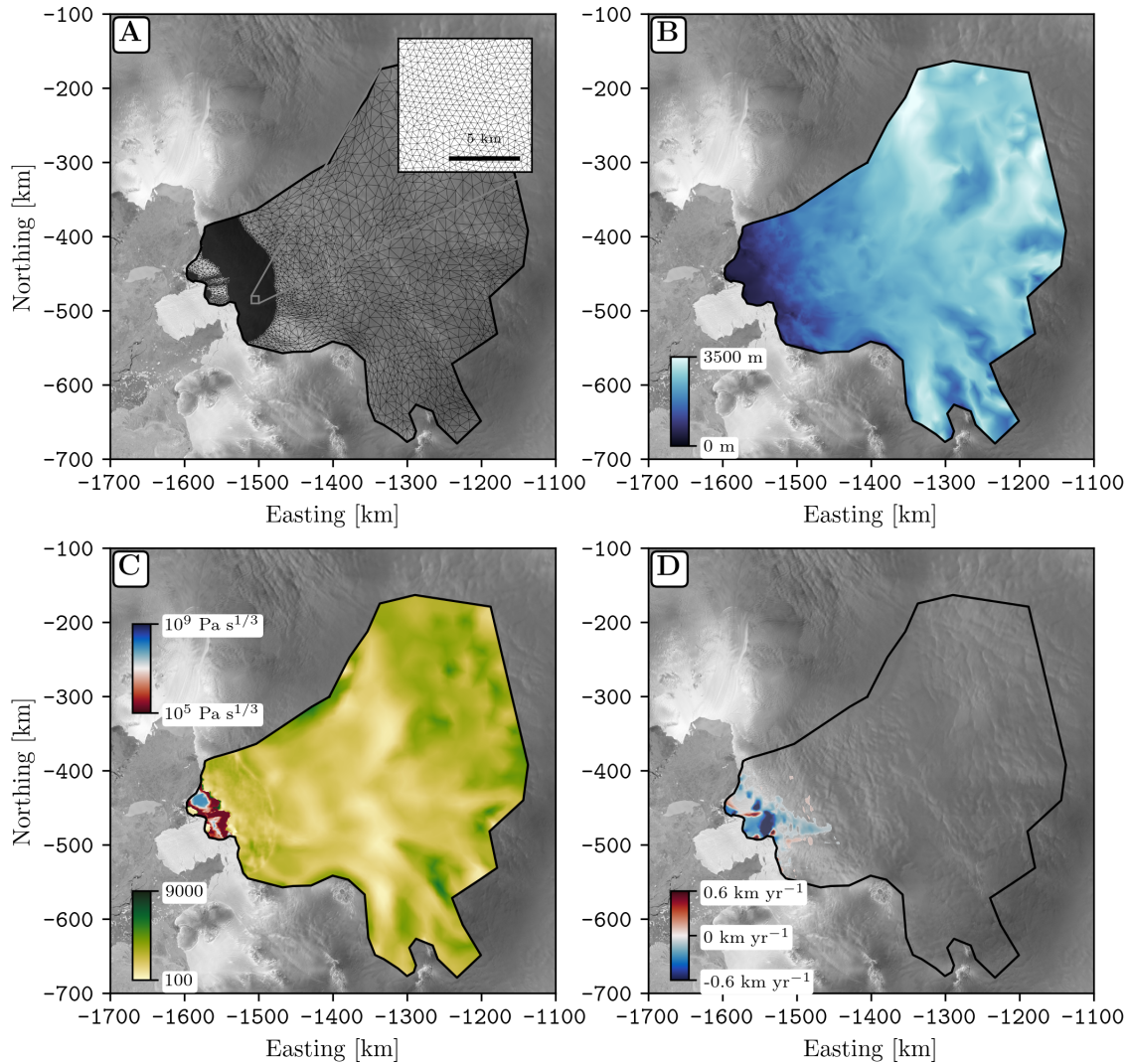
 *To whom correspondence should be addressed; E-mail: poinellimattia@gmail.com

5 **This PDF contains:**

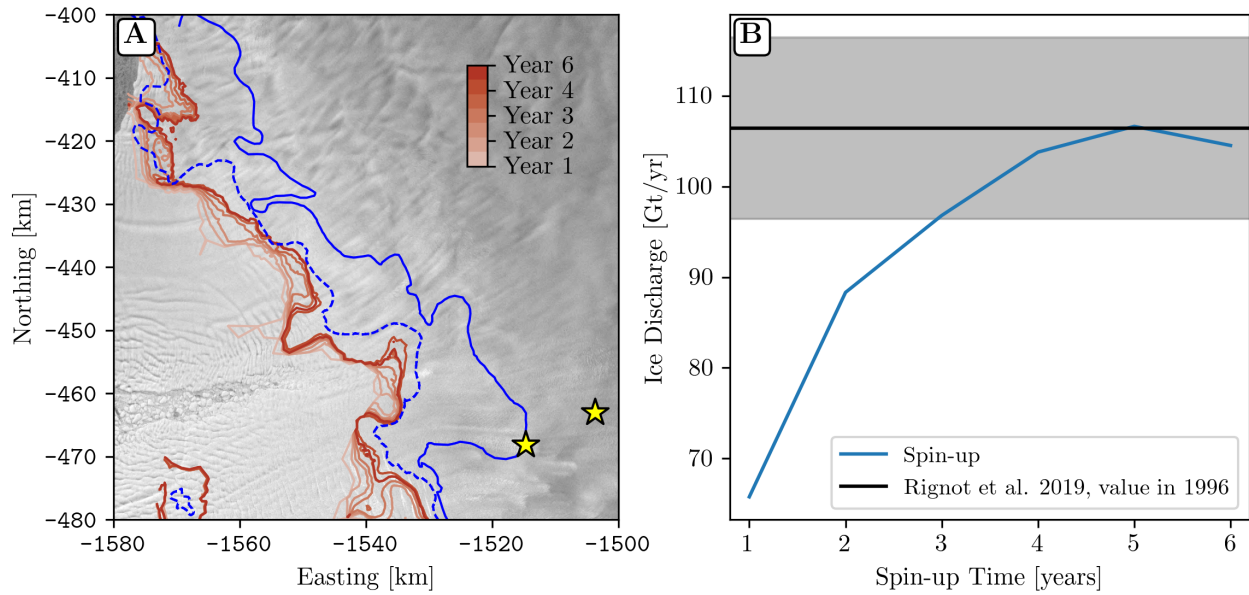
- 6 • Supplementary Figures 1 to 3
7 • Supplementary Tables 1 to 4
8 • References



Supplementary Figure 1. Retreat of Thwaites Glacier from satellite observations. Grounding-zone extents of Thwaites Glacier inferred for A) year 1994-1996 (light red boundaries) using Earth Remote Sensing satellite 1 and 2 interferometric SAR data at the C-band frequency (5.6 cm wavelength) overlaid on a differential interferogram from 1994 combining orbits 13726, 13769, 13812, 13855, Frames 5193 5211 acquired March 01, 03, 07, and 10 1994; B) year 2023 (dark red boundaries) using RADARSAT Constellation Mission C-band SAR data and ICEYE US X-band (3.1 cm wavelength) SAR data acquired over a period of several months overlaid on a composite set of differential interferograms from ICEYE (May 12, 13, 14, 2023) on the Thwaites Main Trunk and RCM (April 19, 23 and 27, 2023) on the Thwaites Eastern Ice Shelf. Copyright ESA, CSA, and ICEYE US.



Supplementary Figure 2. Model configuration and inversion. A) Finite element mesh plotted on the model domain. (B) Ice sheet thickness at the beginning of the spin-up. (C) Results of the inversion: ice hardness B on floating ice and friction coefficient C on grounded ice. (D) Model-data misfit in terms of ice velocity after the inversions for friction and ice rheology. Black line is the model domain. Background is the RADARSAT-1 mosaic of Antarctica.



Supplementary Figure 3. Model spin-up. A) Modeled grounding line retreat during the spin-up phase (color-coded). Dashed blue line is the grounding line location in 1996 (1), solid blue line is the grounding line location in 2023 (2). Yellow stars are the location of Ridge Mouginit and Ridge South. Background is the RADARSAT-1 mosaic of Antarctica. (B) Ice discharge during the spin-up phase. Black line is observed ice discharge in 1996 and shaded area is the standard deviation (3).

Table 1. RMSE values for TEIS Retreat [km²]. RMSE is the root-mean-square error between modeled results and observed grounding line retreat for TEIS, $y = 379 \pm 25$ km² (4). Minimum RMSE highlighted in bold.

Melt Rate	Grounding zone length						
	0 m	1000 m	2000 m	3000 m	4000 m	5000 m	6000 m
10 m yr ⁻¹	207.1	187.8	180.8	176.7	173.3	170.2	167.3
20 m yr ⁻¹	199.3	179.7	172.2	167.3	162.8	158.6	154.9
30 m yr ⁻¹	190.8	169.7	160.1	154.0	148.8	144.1	140.1
40 m yr ⁻¹	182.3	158.6	147.7	140.0	133.7	129.1	125.0
50 m yr ⁻¹	171.1	145.2	132.4	125.0	117.7	110.3	103.0
60 m yr ⁻¹	160.2	119.2	106.9	98.7	91.4	82.8	75.7
70 m yr ⁻¹	146.4	105.6	92.2	82.5	75.0	68.0	60.8
80 m yr ⁻¹	134.6	96.9	82.1	72.9	63.0	51.7	36.4
90 m yr ⁻¹	124.6	92.1	74.4	61.2	39.3	18.6	2.1
100 m yr ⁻¹	117.5	83.7	65.5	34.7	3.9	21.1	40.5
110 m yr ⁻¹	114.2	77.6	46.6	1.3	30.9	51.3	66.1
120 m yr ⁻¹	111.6	72.0	17.1	30.1	54.4	73.0	88.9
130 m yr ⁻¹	109.6	65.9	12.6	50.7	75.2	94.2	108.4
140 m yr ⁻¹	107.8	52.6	35.0	69.0	94.3	110.3	124.4
150 m yr ⁻¹	106.4	30.6	51.2	87.2	108.1	124.2	147.4

Table 2. RMSE values for TMT retreat [km²]. RMSE is the root-mean-square error between modeled results and observed grounding line retreat for TMT, $y = 567 \pm 25$ km² (4). Minimum RMSE is underlined.

Melt Rate	Grounding zone length						
	0 m	1000 m	2000 m	3000 m	4000 m	5000 m	6000 m
10 m yr ⁻¹	552.2	545.7	542.3	540.3	538.8	537.7	536.6
20 m yr ⁻¹	532.6	520.3	508.6	503.2	499.4	495.0	490.5
30 m yr ⁻¹	511.4	473.6	456.6	448.4	442.6	437.5	432.3
40 m yr ⁻¹	481.9	437.3	424.5	400.5	368.2	344.5	328.6
50 m yr ⁻¹	443.0	404.2	340.7	312.1	297.0	285.9	276.9
60 m yr ⁻¹	413.2	334.2	281.5	265.3	253.1	228.0	207.9
70 m yr ⁻¹	397.5	277.1	248.3	217.3	193.7	162.7	133.5
80 m yr ⁻¹	385.6	248.1	202.1	168.5	112.7	<u>2.5</u>	67.5
90 m yr ⁻¹	375.4	223.5	161.7	49.8	79.3	169.5	235.3
100 m yr ⁻¹	364.8	180.2	86.6	115.4	237.3	297.4	327.8
110 m yr ⁻¹	354.7	146.4	89.6	258.5	329.9	371.6	407.4
120 m yr ⁻¹	309.9	125.5	206.1	342.3	399.8	444.1	476.1
130 m yr ⁻¹	279.1	42.2	318.4	407.3	465.1	497.7	509.4
140 m yr ⁻¹	259.1	98.7	375.1	466.9	504.7	514.3	584.4
150 m yr ⁻¹	244.1	189.8	429.9	504.4	517.0	591.8	848.8

Table 3. RMSE values for glacier thinning [m]. RMSE is the root-mean-square error between modeled results and observed glacier thinning between 1996 and 2020, $y = -12.84 \pm 0.92$ m (5). Minimum RMSE is underlined.

Melt Rate	Grounding zone length						
	0 m	1000 m	2000 m	3000 m	4000 m	5000 m	6000 m
10 m yr ⁻¹	6.3	6.7	6.8	6.8	6.7	6.7	6.6
20 m yr ⁻¹	6.1	6.4	6.4	6.4	6.3	6.2	6.1
30 m yr ⁻¹	5.9	6.1	6.2	6.0	5.9	5.7	5.5
40 m yr ⁻¹	5.7	5.9	5.8	5.7	5.6	5.4	5.2
50 m yr ⁻¹	5.7	5.8	5.8	5.6	5.3	5.0	4.6
60 m yr ⁻¹	5.7	5.9	5.7	5.3	4.9	4.4	4.0
70 m yr ⁻¹	5.7	5.7	5.3	4.9	4.4	3.8	3.1
80 m yr ⁻¹	5.7	5.5	5.0	4.4	3.7	2.9	1.8
90 m yr ⁻¹	5.7	5.3	4.6	3.7	2.6	1.3	0.1
100 m yr ⁻¹	5.7	5.1	4.0	2.7	1.1	0.3	1.5
110 m yr ⁻¹	5.7	4.8	3.4	1.3	0.3	1.8	3.1
120 m yr ⁻¹	5.7	4.4	2.2	0.0	1.8	3.3	4.6
130 m yr ⁻¹	5.7	3.9	1.2	1.2	3.0	4.6	6.1
140 m yr ⁻¹	5.7	3.5	0.2	2.3	4.3	6.0	7.6
150 m yr ⁻¹	5.6	2.9	0.8	3.4	5.6	7.4	9.2

Table 4. RMSE values for glacier speed-up [m yr⁻¹]. RMSE is the root-mean-square error between modeled results and the mean observed glacier speed-up along the along the fastest moving sector of Thwaites (dashed line in Fig. 1A), from 1996 to 2022, $y = 145 \pm 18.3$ m yr⁻¹ (4). Minimum RMSE is underlined.

Melt Rate	Grounding zone length						
	0 m	1000 m	2000 m	3000 m	4000 m	5000 m	6000 m
10 m yr ⁻¹	160.0	158.9	158.2	157.8	157.5	157.2	157.0
20 m yr ⁻¹	155.4	152.7	149.9	148.7	147.8	146.8	145.8
30 m yr ⁻¹	150.0	140.6	135.5	133.6	132.5	131.5	130.7
40 m yr ⁻¹	142.8	130.5	128.4	126.9	125.2	123.5	121.7
50 m yr ⁻¹	132.2	124.5	121.6	119.0	117.2	115.6	114.2
60 m yr ⁻¹	125.6	118.6	113.7	111.2	109.6	106.7	104.1
70 m yr ⁻¹	121.1	112.1	108.1	105.0	100.9	86.8	78.8
80 m yr ⁻¹	118.2	107.5	102.6	96.1	73.3	15.5	35.2
90 m yr ⁻¹	115.9	104.0	94.1	60.9	48.6	78.6	104.6
100 m yr ⁻¹	113.3	99.3	70.9	71.8	114.9	146.3	158.2
110 m yr ⁻¹	111.5	91.5	62.3	134.0	167.7	180.6	186.8
120 m yr ⁻¹	109.6	85.7	119.9	180.0	193.4	200.3	208.3
130 m yr ⁻¹	106.4	64.2	174.3	200.2	211.9	227.2	230.5
140 m yr ⁻¹	104.0	27.6	200.6	215.6	236.2	233.7	247.2
150 m yr ⁻¹	102.3	115.6	210.9	239.5	237.4	253.9	581.9

9 References

- 10 1. E. Rignot, J. Mouginot, M. Morlighem, H. Seroussi, B. Scheuchl, Widespread, rapid grounding line retreat of Pine
11 Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011. *Geophysical Research Letters*
12 **41** (10), 3502–3509 (2014).
- 13 2. E. Rignot, *et al.*, Widespread seawater intrusions beneath the grounded ice of Thwaites Glacier, West Antarctica.
14 *Proceedings of the National Academy of Sciences* **121** (22), e2404766121 (2024).
- 15 3. E. Rignot, *et al.*, Four decades of Antarctic ice sheet mass balance from 1979–2017. *Proceedings of the National*
16 *Academy of Sciences of the United States of America* **116** (4), 1095–1103 (2019).
- 17 4. E. Rignot, J. Mouginot, B. Scheuchl, S. Jeong, Changes in Antarctic Ice Sheet Motion Derived From Satellite Radar
18 Interferometry Between 1995 and 2022. *Geophysical Research Letters* **49** (23), e2022GL100141 (2022).
- 19 5. J. Nilsson, A. S. Gardner, F. S. Paolo, Elevation change of the Antarctic Ice Sheet: 1985 to 2020. *Earth System*
20 *Science Data* **14** (8), 3573–3598 (2022).