

Supplementary Material:

Global glacier mass loss during the GRACE satellite mission (2002-2016)

1 SUPPLEMENTARY TABLES AND FIGURES

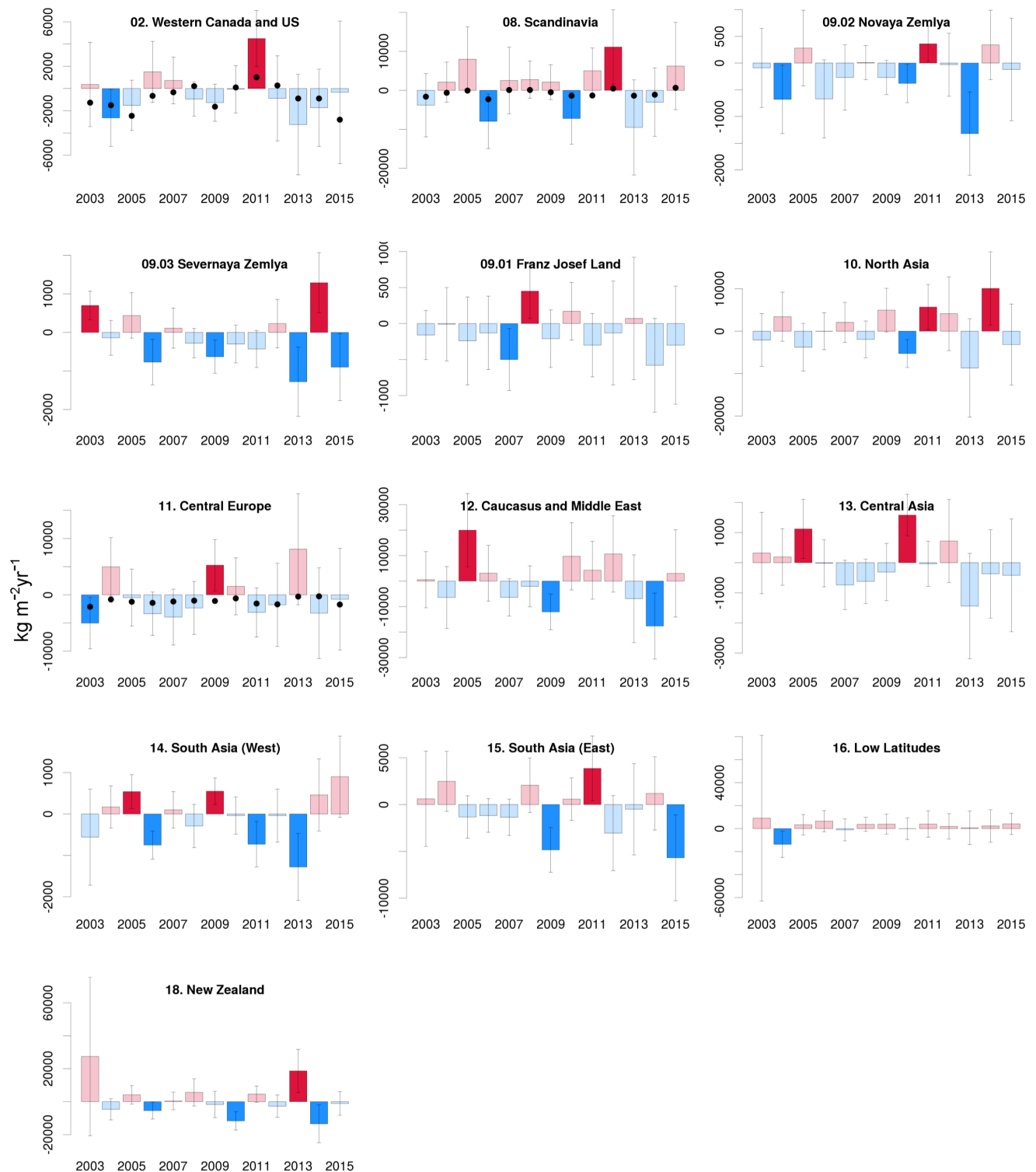


Figure S1. Annual specific mass balance for the smaller RGI (sub)regions. Mass balance years run from October 1 to September 31 for regions in the Northern Hemisphere, and April 1 to March 31 for regions in the Southern Hemisphere. Note the difference in range on the Y-axis between the different sub-figures. Values which are not significantly different from zero are plotted in pale colors. Black dots indicate the annual mass balance derived from in-situ observations, where available.

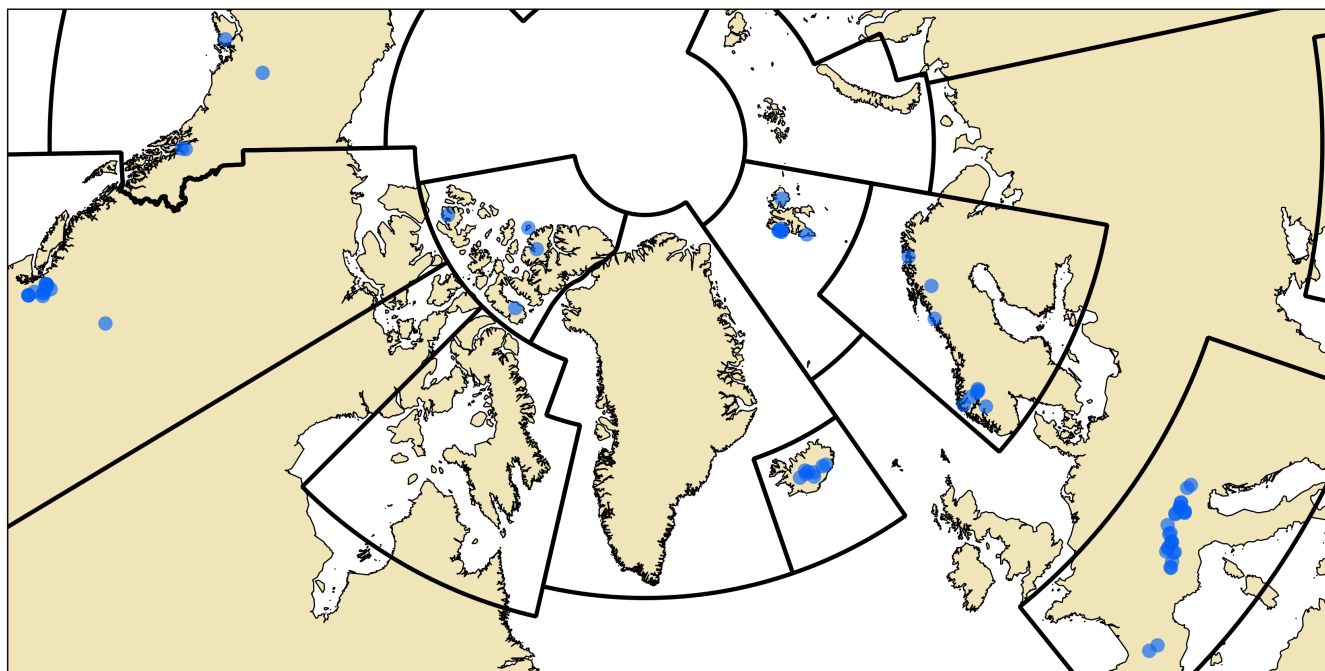


Figure S2. Locations of the WGMS stations used to derive the in-situ based annual mass balances.

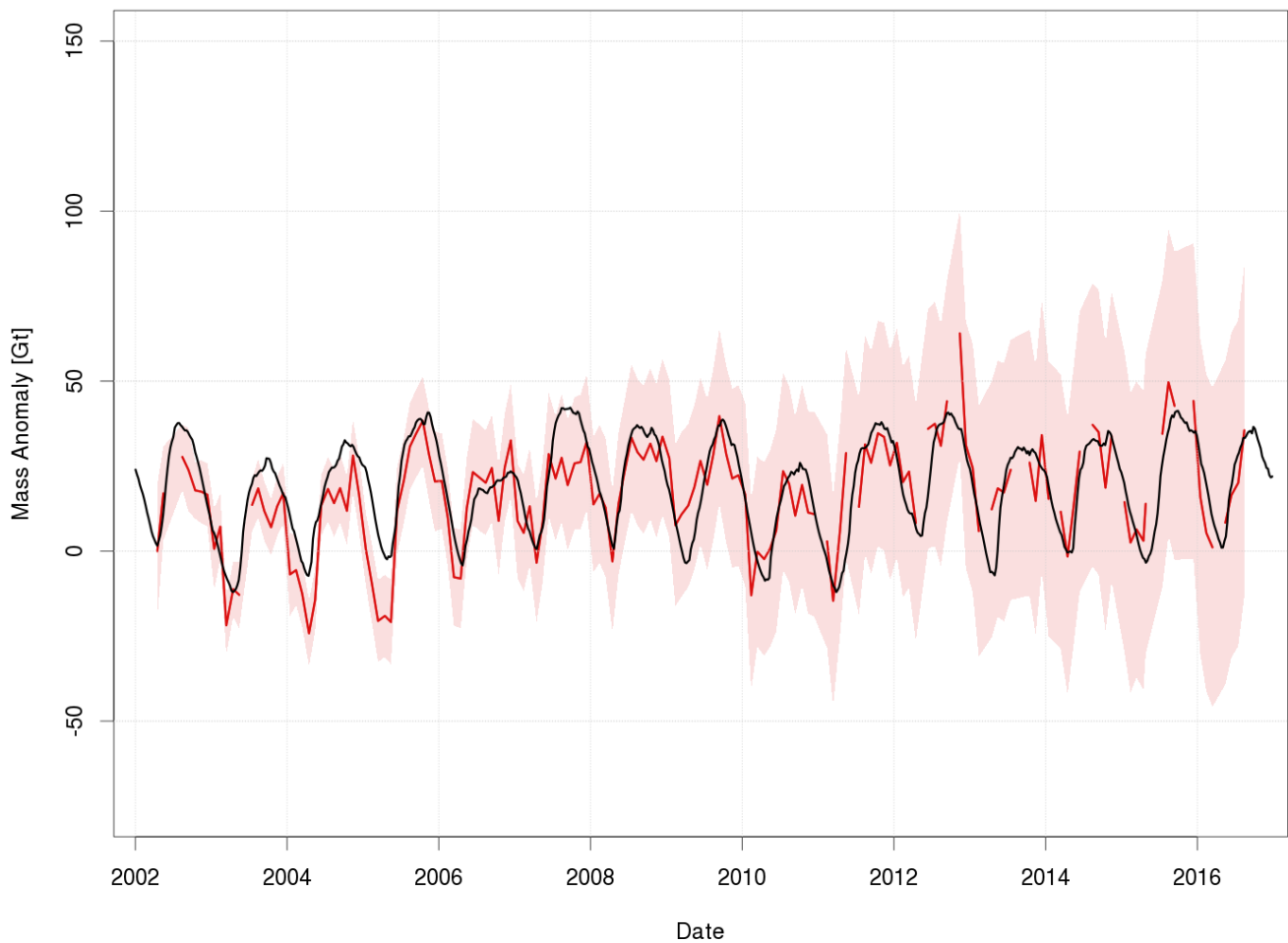


Figure S3. Time series of cumulative mass anomalies for hydropower reservoirs in Norway plotted in black together with the relevant GRACE time series for Scandinavia from Fig. 2 in red (RGI region 08). Note that some reservoirs are located outside of the GRACE glacier mascons and that additional impact is expected from reservoirs in western Sweden, where about 10% of the total glacier area in Scandinavia is located, the remainder being in Norway.

RGI region number and region	Area [km ²]	Glacier mass budget [Gt yr ⁻¹] [kg m ⁻² yr ⁻¹]		GRACE only [Gt yr ⁻¹]	Solid Earth correction		Hydrology correction	
					GIA [Gt yr ⁻¹]	LIA [Gt yr ⁻¹]	GLDASV2.1 [Gt yr ⁻¹]	PCR-GLOBW 2* [Gt yr ⁻¹]
01. Alaska	86725	-49.3 ± 15.7	-570 ± 180	-38.9 ± 11.8	1.8 ± 8.6	7 ± 4	1.6 ± 5.7	0.8 ± 4.4
02. Western Canada and US	14524	-5.9 ± 21.7	-410 ± 1500	-4.4 ± 10.3	11.3 ± 16.6	0 ± 0	-9.8 ± 6.6	-1.5 ± 5.8
03. Arctic Canada North	105111	-41.3 ± 3.7	-390 ± 30	-37 ± 2.3	4 ± 2.8	0 ± 0	0.3 ± 0.3	0.6 ± 0.2
04. Arctic Canada South	40888	-38.6 ± 8.7	-940 ± 210	-35.1 ± 6.7	4.1 ± 5.4	0 ± 0	-0.6 ± 0.6	-1.7 ± 0.8
06. Iceland	11060	-10.1 ± 2.1	-910 ± 190	-6.6 ± 0.9	-0.1 ± 1	3.1 ± 1.5	0.4 ± 0.4	0.3 ± 0.2
07. Svalbard	33959	-6.9 ± 1.6	-200 ± 50	-4.9 ± 1.4	1.9 ± 0.6	0 ± 0	0.1 ± 0.1	0.5 ± 0.2
08. Scandinavia	2949	0.7 ± 11.3	230 ± 3820	6.8 ± 10.4	5.9 ± 3.4	0 ± 0	0.2 ± 2	-2.1 ± 2.4
09. Arctic Russia	51592	-10.5 ± 2	-200 ± 40	-7.3 ± 1.7	3.1 ± 0.6	0 ± 0	0.1 ± 0.2	1.1 ± 0.4
09.1 Novaya Zemlya	22128	-4.4 ± 1.2	-200 ± 50	-3.1 ± 1	1.3 ± 0.4	0 ± 0	0 ± 0.1	0.4 ± 0.2
09.2 Severnaya Zemlya	12762	-3.8 ± 1.2	-300 ± 100	-3.3 ± 1	0.5 ± 0.2	0 ± 0	0 ± 0.1	0.7 ± 0
09.3 Franz Josef Land	16701	-2.3 ± 1.1	-140 ± 60	-0.9 ± 1	1.3 ± 0.4	0 ± 0	0.1 ± 0.1	0 ± 0.2
10. North Asia	2410	2.1 ± 4.5	890 ± 1850	0.9 ± 4.4	-1.2 ± 0.2	0 ± 0	-0.1 ± 0.9	0.5 ± 0.6
11. Central Europe	2092	0.2 ± 1.1	100 ± 510	-0.2 ± 0.9	-0.5 ± 0.2	0 ± 0	0.1 ± 0.7	-0.1 ± 0.6
12. Caucasus	1307	-0.9 ± 3.9	-650 ± 3000	-3.8 ± 3.7	-0.5 ± 0.2	0 ± 0	-2.5 ± 0.9	-1.5 ± 0.6
13. Central Asia North	49303	-0.5±7.4	-10±150	3.9±6.1	2.4±0.8	1±0.5	1±2.9	-2.5±2
14. South Asia West	33568	-4±6.2	-120±180	-1.8±3.7	-0.2±0.2	1±0.5	1.4±2.2	6.1±2
15. South Asia East	14734	-6.4±10.1	-440±680	-7.6±4.9	0.8±5.4	1±0.5	-2.9±2.8	3.7±2
13.+14.+15. HMA	97606	-10.9±14.0	-110±140	-5.5±8.7	3±5.5	3±1	-0.5±4.6	7.3±3.4
16 Low Latitudes	2341	3.6 ± 1.2	1560 ± 510	2.5 ± 1.3	-0.4 ± 0.1	0 ± 0	-0.7 ± 1	-1 ± 1
17. Southern Andes	29429	-31.4 ± 6.9	-1070 ± 240	-22.4 ± 1.3	1.5 ± 0.4	9 ± 5	-1.6 ± 0.8	-6.2 ± 0.7
18. New Zealand	1162	0.1 ± 0.9	110 ± 780	0 ± 0.2	0.4 ± 0.1	0 ± 0	-0.5 ± 0.1	-1.4 ± 0.3
Global Total	483153.0	-199.1±35.0	-410±70	-155.9±22.8	34.3±20.7	22.1±6.7	-13.5±10.3	-4.4±8.6

Table S1. Same as Table 1, but for the mass balance years 2006-2015.

RGI Region	Spherical harmonics	JPL Mascons
01 Alaska	-53.4 ± 13.8	-59.2 ± 6.6
02 Western Canada and US	-4.2 ± 19	-4.0 ± 14.9
03 Arctic Canada North	-35.8 ± 3.5	-40 ± 3.0
4 Arctic Canada South	-32.5 ± 7.8	-35.2 ± 6.6
6 Iceland	-10.1 ± 2	-9.3 ± 1.8
7 Svalbard	-7.2 ± 1.4	-9.1 ± 4.1
8 Scandinavia	1.3 ± 11.4	1.5 ± 4.3
9 Arctic Russia	-10.6 ± 1.7	-9.2 ± 8.0
10 North Asia	1.8 ± 3.4	-1.1 ± 2.0
11 Central Europe	-0.3 ± 1.6	-0.2 ± 1.7
12 Caucasus	-0.1 ± 2.9	NA \pm NA
13 Central Asia	-3.2 ± 4.5	-7.2 ± 9.1
14 South Asia West	-5.3 ± 4.9	-1.7 ± 2.9
15 South Asia East	-9.2 ± 9.1	-10.6 ± 3.7
13+14+15 High Mountain Asia	-17.7 ± 11.3	-19.5 ± 10
16 Low Latitudes	1.2 ± 3.5	-0.8 ± 3.4
17 Southern Andes	-30.3 ± 11	-28.3 ± 6.8
18 New Zealand	-0.5 ± 0.9	0.1 ± 1.5
Global Total	-198.5 ± 32.4	-211.8 ± 24.4

Table S2. Mass trends in the 17 RGI regions for 2002–2016, based on the spherical harmonic solutions used in this study, and JPL mascons following Reager et al. (2016)), using the ICE-6.D (VM5a) model (Peltier et al., 2018) for the GIA correction at the mascon level.

Name	WGMS ID	Latitude	Longitude
RGI 01 Alaska (4 locations)			
Gulkana	90	63.281	-145.427
Wolverine	94	60.41734	-148.9039
Taku	124	58.651	-134.278
Lemon creek	3334	58.38735	-134.3458
RGI 02 Western Canada and US (14 locations)			
Peyto	57	51.65991	-116.5638
Yawning	75	48.4474	-121.031
Columbia	76	47.9637	-121.3485
Lower Curtis	77	48.8259	-121.622
Rainbow	79	48.8	-121.77
Lynch	81	47.57	-121.18
Ice Worm	82	47.55	-121.17
Daniels	83	47.57	-121.17
Easton	1367	48.759	-121.8253
North Klawatti	1664	48.5729	-121.093
Silver	1665	48.9769	-121.24
Noisy Creek	1666	48.6735	-121.527
Sandalee	1667	48.41	-120.79
Sholes	3295	48.8139	-121.7701
RGI 03 Arctic Canada North (4 locations)			
White	0	79.45	-90.695
Meighen Ice Cap	16	79.95	-99.13
Devon Ice Cap NW	39	75.42	-83.25
Melville South Ice Cap	3690	75.4	-115
RGI 06 Iceland (8 locations)			
Bruarjokull	3067	64.67	-16.17
Eyjabakkajokull	3069	64.65	-15.58
Hofsjokull E	3088	64.8	-18.58
Hofsjokull N	3089	64.95	-18.92
Hofsjokull SW	3090	64.72	-19.05
Koldukvislarj.	3096	64.58	-17.83
Tungnaarjokull	3126	64.32	-18.07
Langjokull Ice Cap	3660	64.67	-20.1
RGI 07 Svalbard (7 locations)			
Midtre Lovenbreen	291	78.881	12.048
Austre Broeggerbreen	292	78.8876	11.8309
Hansbreen	306	77.077	15.63
Kongsvegen	1456	78.8	12.98
Waldemarbreen	2307	78.6774	12.0692
Irenebreen	2669	78.6651	12.1249
Etonbreen	3619	79.7292	22.9730
RGI 08 Scandinavia (10 locations)			
Rembesdalskaaka	2296	60.539	7.368
Nigardsbreen	290	61.72	7.13
Engabreen	298	66.65	13.85
Graasubreen	299	61.657	8.6
Hellstugubreen	300	61.56	8.44
Storbreen	302	61.57	8.13
Austdalsbreen 321	61.815	7.352	
Hansebreen	322	61.75	5.68
Langfjordjoekelen	323	70.128	21.735
Storglaciaeren	332	67.903	18.568

Table S3. Overview of WGMS stations used to derive the in-situ based annual mass balances.

Name	WGMS ID	Latitude	Longitude
RGI 11 Central Europe (28 locations)			
Gebroulaz	352	45.2979	6.6288
Argentiere	354	45.9535	6.9846
Saint Sorlin	356	45.1604	6.1602
Sarennes	357	45.11562	6.12853
Gries	359	46.4446	8.3398
Corbassiere	366	45.98	7.3
Gietro	367	46	7.38
Allalin	394	46.05	7.93
Schwarzberg	395	46.02	7.93
Silvretta	408	46.85	10.08
Basodino	463	46.42	8.48
Jamtal F.	480	46.85805	10.15564
Vernagt F.	489	46.88	10.82
Hintereis F.	491	46.8	10.77
Kesselwand F.	507	46.8383	10.7933
Wurten K.	545	47.0388	13.0054
Stubacher Sonnblick K.	573	47.13	12.6
Careser	635	46.4512	10.7085
La Mare (Vedretta de)	636	46.4301	10.6303
Malavalle (Vedr. di) / Uebeltalf.	672	46.948	11.185
Pendente (Vedr.) / Hangenderf.	675	46.9656	11.2247
Maladeta	942	42.649	0.6393
Ciardoney	1264	45.5181	7.3898
Timorion	1282	45.5579	7.2818
Fontana Bianca / Weissbrunnf.	1507	46.4838	10.771
Claridenfirn	2660	46.8464	8.9006
Ossoue	2867	42.7712	-0.14344
Hohlaub	3332	46.059	7.9178

Table S3. - Continued Overview of WGMS stations used to derive the in-situ based annual mass balances.

REFERENCES

- Peltier, R. W., Argus, D. F., and Drummond, R. (2018). Comment on “An Assessment of the ICE-6G_C (VM5a) Glacial Isostatic Adjustment Model” by Purcell et al. *Journal of Geophysical Research: Solid Earth* 123, 2019–2028. doi:10.1002/2016JB013844
- Reager, J. T., Gardner, A. S., Famiglietti, J. S., Wiese, D. N., Eicker, A., and Lo, M.-H. (2016). A decade of sea level rise slowed by climate-driven hydrology. *Science* 351, 699–703. doi:10.1126/science.aad8386