

Supplementary information

Community estimate of global glacier mass changes from 2000 to 2023

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Supplementary Information

Community estimate of global glacier mass changes from 2000 to 2023

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SI Table 1 | Data submissions to GlAMBIE. The submissions are organized by observation method and research team in alphabetical order and provide an overview of sensors or data products used, references to related publications on methods, and regions for which glacier mass changes were calculated. A complete list of data contributors and their affiliations is provided in SI Table 2. Information about temporal coverage, resolution, and gaps of the submitted data are shown for each region in SI Figures 1–19.

Team	Method	Sensors or products	Method references	Regions
Bolch et al.	Altimetry	ICESat	Bolch et al. (2013) ¹	GRL
Foresta et al.	Altimetry	CryoSat-2	Foresta et al. (2016) ²	ISL
Gardner et al.	Altimetry	ICESat	Gardner et al. (2013) ³	ACN, ACS, GRL, SJM, RUA, ANT
Jakob et al.	Altimetry	CryoSat-2	Jakob et al. (2021) ⁴ , Jakob and Gourmelen (2023) ⁵	ALA, ACN, ACS, GRL, ISL, RUA, ASC, ASW, ASE, SAN, ANT
Khan et al.	Altimetry	ICESat/-2	Khan et al. (2022) ⁶	ACN, ACS, GRL, ANT
Menounos et al.	Altimetry	ICESat-2, GEDI, COP30	Menounos et al. (2024) ⁷	WNA
Nilsson et al.	Altimetry	CryoSat-2, Envisat, ERS-1/2, ICESat/-2	Nilsson et al. (2022) ⁸ , Nilsson and Gardner (2024) ⁹	GRL
Tepes et al.	Altimetry	CryoSat-2	Tepes et al. (2021) ¹⁰	ACN, ACS, ISL, SJM, RUA
Treichler et al.	Altimetry	ICESat	Treichler et al. (2019) ¹¹	ASC, ASW, ASE
Abdullahi et al.	DEM differencing	TanDEM-X	Abdullahi et al. (2019) ¹² , Wessel et al. (2016) ¹³	GRL
Andreassen et al.	DEM differencing	Airborne LiDAR	Andreassen et al. (2016) ¹⁴	SCA
Braun et al.	DEM differencing	TanDEM-X	Braun et al. (2019) ¹⁵	TRP, SAN
Brun et al.	DEM differencing	ASTER	Brun et al. (2017) ¹⁶	ASC, ASW, ASE
Dussaillant et al.	DEM differencing	ASTER	Dussaillant et al. (2019) ¹⁷	TRP, SAN
Hugonnet et al.	DEM differencing	ArcticDEM, ASTER, REMA	Hugonnet et al. (2021) ¹⁷	ALA, WNA, ACN, ACS, GRL, ISL, SJM, SCA, RUA, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL, ANT
King et al.	DEM differencing	HMA DEM, SRTM	King et al. (2019) ¹⁸	ASE
Krieger et al.	DEM differencing	SRTM, TanDEM-X	Abdel Jaber et al. (2019) ¹⁹	SAN
Piermattei et al.	DEM differencing	ASTER, ArcticDEM, SPOT-5	Piermattei et al. (2024) ²⁰	ISL
Seehaus et al.	DEM differencing	SRTM, TanDEM-X	Seehaus et al. (2019) ²¹ , Seehaus et al. (2020) ²²	TRP
Sommer et al.	DEM differencing	TanDEM-X	Sommer et al. (2020) ²³ , Sommer et al. (2022) ²⁴	RUA, CEU
Zheng et al.	DEM differencing	ArcticDEM	Zheng et al. (2018) ²⁵	ACN, ACS, GRL, ISL, SJM, SCA, RUA
Menounos et al.	Glaciological	In situ	n.a.	WNA
WGMS	Glaciological	In situ	WGMS (2023) ²⁶	ALA, WNA, ACN, ACS, GRL, ISL, SJM, SCA, RUA, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL, ANT
Harig et al.	Gravimetry	GRACE/-FO	Harig and Simons (2016) ²⁷ , Beveridge et al. (2018) ²⁸	ALA, WNA, ACN, ACS, ISL, SJM, RUA, ASC, SAN, NZL

Jacob et al.	Gravimetry	GRACE	Jacob et al. (2012) ²⁹	ALA, WNA, ACN, ACS, ISL, SJM, RUA, ASC, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL
Pfeffer et al.	Gravimetry	GRACE/-FO	Blazquez et al. (2018) ³⁰	ACN, ACS, ISL, SJM, RUA
Richter et al.	Gravimetry	GRACE	Richter et al. (2019) ³¹	SAN
Sasgen et al.	Gravimetry	GRACE/-FO	Sasgen et al. (2022) ³²	ALA, WNA, ACN, ACS, ISL, SJM, RUA, ASC, ASN, CEU, ASC, ASW, ASE, TRP, SAN, NZL
Sutterley et al.	Gravimetry	GRACE/-FO	Sutterley and Velicogna (2019) ³³ , Sutterley et al. (2020) ³⁴	ALA, ACN, ACS, ISL, SJM, RUA, SAN
Wouters et al.	Gravimetry	GRACE/-FO	Wouters et al. (2019) ³⁵	ALA, WNA, ACN, ACS, ISL, SJM, RUA, ASC, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL
Box et al.	Hybrid	GRACE	Box et al. (2018) ³⁶	ALA, ACN, ACS, ISL, SJM, RUA
Colgan et al.	Hybrid	GRACE, ICESat	Colgan et al. (2015) ³⁷	ACN, ACS, GRL
Dussaillant et al.	Hybrid	In situ, ASTER, SPOT-5/6/7, SRTM, TanDEM-X	Dussaillant et al. (2023) ³⁸ , Dussaillant et al. (2024, in review) ³⁹	ALA, WNA, ACN, ACS, GRL, ISL, SJM, SCA, RUA, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL, ANT
Huss et al.	Hybrid	In situ, ASTER, ArcticDEM, REMA	Zemp et al. (2019) ⁴⁰	ALA, WNA, ACN, ACS, GRL, ISL, SJM, SCA, RUA, ASN, CEU, CAU, ASC, ASW, ASE, TRP, SAN, NZL, ANT
Ke et al.	Hybrid	SRTM, NASADEM, ICESat-2	Fan et al. (2023) ⁴¹	ASC, ASW, ASE
Miles et al.	Hybrid	In situ, ASTER, ITS LIVE	Miles et al. (2021) ⁴²	ASC, ASW, ASE
Pálsson et al.	Hybrid	In situ, Non-surface melt corrections	Aðalgeirsdóttir et al. (2020) ⁴³	ISL

SI Table 2 | Research teams and data contributors to GlAMBIE. Columns are sorted by research team in alphabetical order.

Team	Method	Data contributor (affiliation)
Abdullahi et al.	DEM differencing	S. Abdullahi (DLR), B. Wessel (DLR), C. Keller (DLR), M. Huber (DLR), U. Marschalk (DLR), A. Roth (DLR)
Andreassen et al.	DEM differencing	L. Andreassen (NVE), B. Kjølmoen (NVE), H. Elvehøy (NVE)
Bolch et al.	Altimetry	T. Bolch (TU Graz), L. Sandberg Sørensen (DTU), N. Mölg (ENVEO)
Box et al.	Hybrid	J. Box (GEUS), W. Colgan (GEUS), B. Wouters (TU Delft), D. Burgess (NRCAN), S. O'Neel (USGS), L. Thomson (Queen's Univ)
Braun et al.	DEM differencing	M. Braun (FAU), P. Malz (FAU), C. Sommer (FAU), D. Farías-Barahona (FAU), T. Sauter (FAU), G. Casassa (UMAG, DGA), A. Soruco, P. Skvarca (Glaciarium), T. Seehaus (FAU)
Brun et al.	DEM differencing	F. Brun (UGA), E. Berthier (LEGOS)
Colgan et al.	Hybrid	W. Colgan (GEUS), W. Abdalati (Univ Colorado), M. Citterio (GEUS), B. Csatho (SUNY-Buffalo), X. Fettweis (Univ Liège), S. Luthcke (NASA-GSFC), G. Moholdt (NPI), S.B. Simonsen (DTU), M. Stober (Stuttgart U.)
Dussaillant et al.	DEM differencing	I. Dussaillant (LEGOS, UGA), E. Berthier (LEGOS), F. Brun (UGA), M. Masiokas (IANIGLA), R. Hugonnet (LEGOS), V. Favier (UGA), A. Rabatel (UGA), P. Pitte (IANIGLA), L. Ruiz (IANIGLA)
Dussaillant et al.	Hybrid	I. Dussaillant (UZH), J. Bannwart (UZH), F. Paul (UZH), M. Zemp (UZH)
Foresta et al.	Altimetry	L. Foresta (Univ Edinburgh), N. Gourmelen (Univ Edinburgh)
Gardner et al.	Altimetry	A. Gardner (JPL), G. Moholdt (NPI), B. Wouters (TU Delft), E. Berthier (LEGOS)
Harig et al.	Gravimetry	C. Harig (UA), E. Cicero (UA)
Hugonnet et al.	DEM differencing	R. Hugonnet (UW, LEGOS, ETH, WSL), R. McNabb (Ulster Univ, UiO), E. Berthier (LEGOS), B. Menounos (UNBC, Hakai Inst), C. Nuth (UiO, FFI), L. Girod (UiO), D. Farinotti (ETH, WSL), M. Huss (ETH, WSL, UFR), I. Dussaillant (LEGOS, UZH), F. Brun (IGE), A. Käab (UiO)
Huss et al.	Hybrid	M. Huss (ETH, WSL, UFR), R. Hugonnet (UW), D. Farinotti (ETH, WSL)
Jacob et al.	Gravimetry	T. Jacob (CU), J. Wahr (CU), T. Pfeffer (CU), S. Swenson (NCAR). Data preparation: I. Sasgen (AWI)
Jakob et al.	Altimetry	L. Jakob (Earthwave), N. Gourmelen (Earthwave, Univ Edinburgh), S. Dubber (Earthwave)
Ke et al.	Hybrid	C. Ke (NJU), Y. Fan (NJU), X. Zhou (MTECH), X. Shen (NJU)
Khan et al.	Altimetry	S. Khan (DTU), W. Colgan (GEUS), J. Hassan (DTU)
King et al.	DEM differencing	O. King (NU), A. Bhattacharya (JIS Univ, JISIARS), R. Bhambri (WIHG), T. Bolch (TU Graz)
Krieger et al.	DEM differencing	L. Krieger (DLR, IMF), D. Floricioiu (DLR, IMF)
Menounos et al.	Altimetry	B. Menounos (UNBC), A. Gardner (JPL), C. Florentine (USGS), A. Fountain (PSU)
Menounos et al.	Glaciological	B. Menounos (UNBC), A. Gardner (JPL), C. Florentine (USGS), A. Fountain (PSU)
Miles et al.	Hybrid	E. Miles (UZH, UFR, WSL), M. McCarthy (WSL), A. Dehecq (IGE), M. Kneib (IGE, UIBK), S. Fugger (WSL), F. Pellicciotti (WSL)
Nilsson et al.	Altimetry	J. Nilsson (JPL), A. Gardner (JPL)
Pálsson et al.	Hybrid	F. Pálsson (HI), A. Gunnarsson (Landsvirkjun), G. Aðalgeirsdóttir (HI), E. Magnússon (HI), T. Thorsteinsson (IMO), J. Belart (HI, IMO, LEGOS), T. Jóhannesson (IMO), H. Hannesdóttir (IMO), O. Sigurðsson (IMO), B. Einarsson (IMO), H. Haraldsson (Landsvirkjun), H. Björnsson (HI)
Pfeffer et al.	Gravimetry	J. Pfeffer (Magellium), A. Blazquez (CNES), B. Couprie (Magellium), E. Berthier (LEGOS)
Piermattei et al.	DEM differencing	L. Piermattei (UZH, WSL, UiO), D. Treichler (UiO), E. Mattea (UFR), R. McNabb (Ulster Univ)
Richter et al.	Gravimetry	A. Richter (MAGGIA, CONICET), A. Romero (MAGGIA, CONICET), F. Suad Corbetta (MAGGIA, CONICET), T. Döhne (TUD), M. Horwath (TUD)
Sasgen et al.	Gravimetry	I. Sasgen (AWI), S. Cruz Bacca (AWI)
Seehaus et al.	DEM differencing	T. Seehaus (FAU), M. Braun (FAU), P. Malz (FAU), C. Sommer (FAU)
Sommer et al.	DEM differencing	C. Sommer (FAU), T. Seehaus (FAU), M. Braun (FAU), P. Malz (FAU)
Sutterley et al.	Gravimetry	T. Sutterley (APL-UW), I. Velicogna (UCI, JPL), G. A (UCI), C. Liang (UCI)
Tepes et al.	Altimetry	P. Tepes (Univ Edinburgh), N. Gourmelen (Univ Edinburgh)
Treichler et al.	Altimetry	D. Treichler (UiO), A. Käab (UiO), N. Salzmänn (UFR), C. Xu (UiO)
WGMS	Glaciological	World Glacier Monitoring Service (WGMS), Zurich, Switzerland, staff members (in alphabetic order): P. Alean-Kirkpatrick, J. Bannwart, F. Denzinger, I. Dussaillant, L. Fischer, M. Fischer, R. Frauenfelder, H. Frey, I. Gärtner-Roer, W. Haerberli, M. Hoelzle, F. Hüsler, J. Landmann, R. Le Bris, G. Leysinger Vieli, A. Linsbauer, H. Machguth, N. Mölg, K. Naegeli, J. Noetzli, S. Nussbaumer, F. Paul, P. Rastner, J. Roth, S. Suter, E. Welty, M. Zemp.

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Meneghel (CGI, SAT), L. Mercalli (SMI), S. Mernild (LANL, COSIM, NERSC), L. Miguel, M. Miller (USGS), M. Montini (CGI), L. Moreau: (EDYTEM, GlacioLab), U. Morra di Cella (ARPA, VDA), L. Motta (UTDES), M. Munari (AfBs), Y. Muravyov (IVS, RAS), T. Musaev (CAIAG, Kyrgyzhydromet), A. Muñoz (Ingeniería 75), Y. Narozhniy (TSU), F. Navarro (AMINSA, TUM, ETSIT), H. Navruzshoev (NAST), A. Neureiter (CIMG, ZAMG), S. Niebuhr (UMN, PGC), S. Nikitin (IGRAS), Y. Nocua Ruge (IHMES), G. Nosenko (IGRAS), S. O'Neel (USGS), C. Oberschmied (AfBs), S. Omurbekov (NAS KR, IWP, TShMRC), M. Oreggioni (SGL), M. Ortelli (SGL), A. Osmonov (CAIAG), A. Ospina (IHMES), B. Pan (LZU, WEL), M. Pecci (CGI, ISPESL, PCM, DARA, DARAS), A. Pedrero (Ingeniería 75, SPESA), E. Peitzsch (USGS), B. Pelto (BCP, PC, UNBC, JIRP, NCGCP, USGS), A. Peracino (CGI), I. Peri (SGL), E. Perroy (ISD), M. Petlicki (PASIG), D. Petrakov (MSUFG), M. Petrov (MID, UFR, CICADA), R.

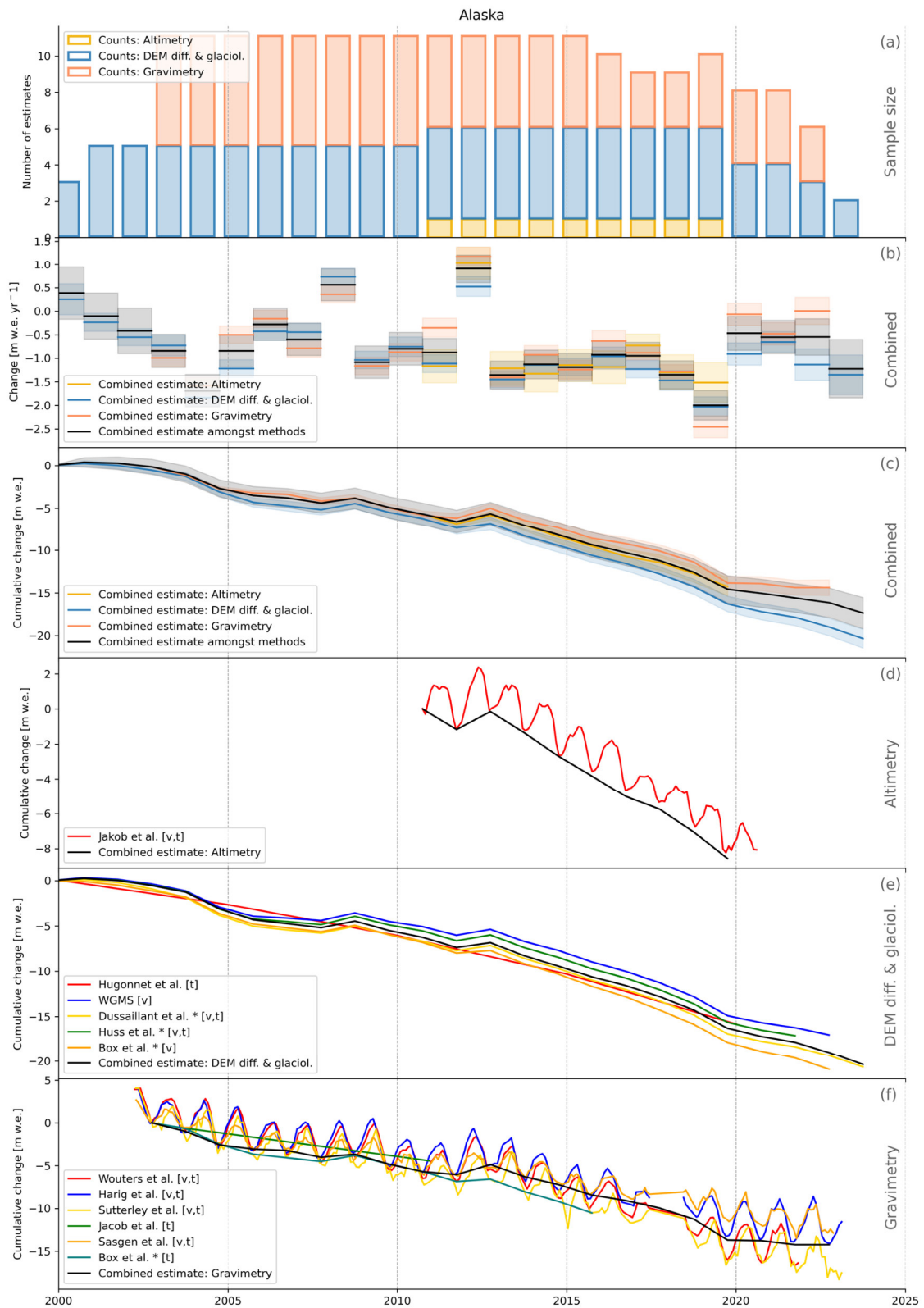
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Wouters et al.	Gravimetry	B. Wouters (UU, TU Delft), A. Gardner (JPL), G. Moholdt (NPI)
Zheng et al.	DEM differencing	W. Zheng (NCU), M. Willis (CU), M. Pritchard (Cornell Univ), I. Howat (OSU)

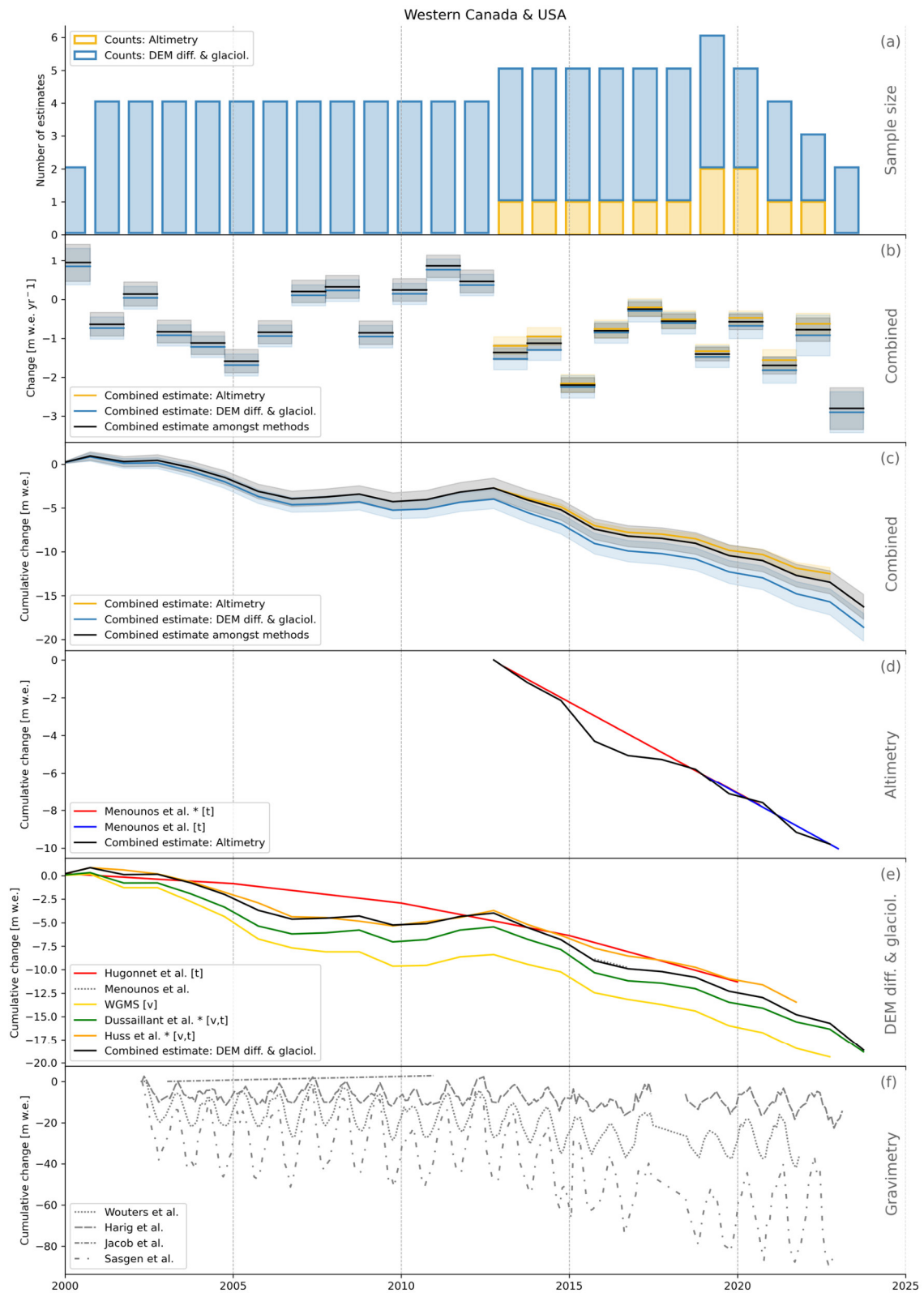
Description of SI Figures 1–19

Supplementary Data Figures 1–19 show data submissions and GlaMBIE results for the 19 glacier regions. The subplots show the sample size of submitted estimates (a) with combined results within and among methods as annual (b) and cumulative (c) specific mass changes. Submitted and combined estimates are shown as cumulative specific mass changes for altimetry (d), DEM differencing & glaciological observations (e), and gravimetry (f). In the legends, we indicate for each data submission if the variability [v] and/or trend [t] were used to calculate the combined estimate. Datasets not used are shown as grey dotted lines. Data submissions from hybrid approaches are marked (*) and shown in subplots of the assigned observation method. Uncertainties are given at 95% confidence intervals.

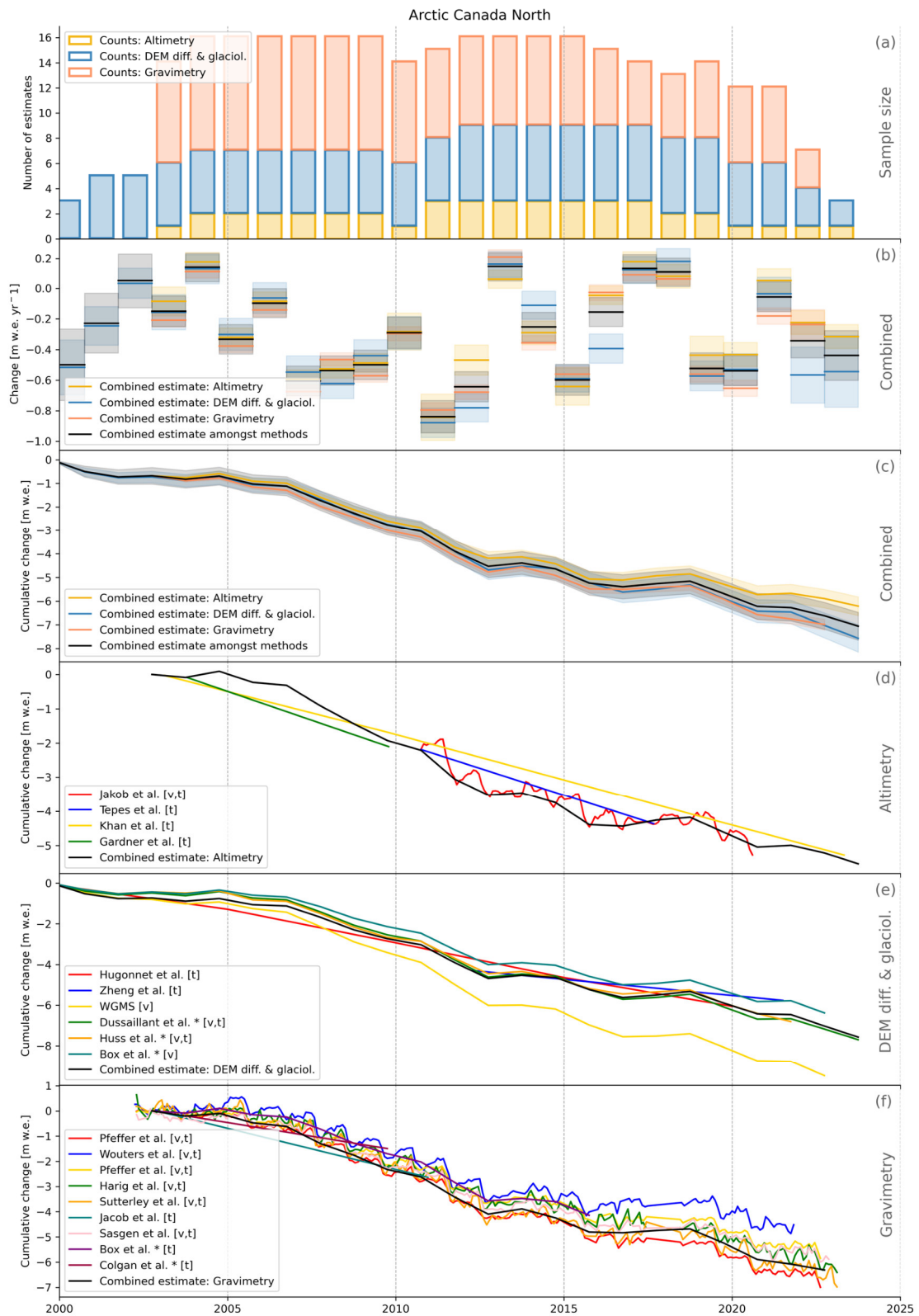
SI Figure 1 | Data submissions and results for Alaska.



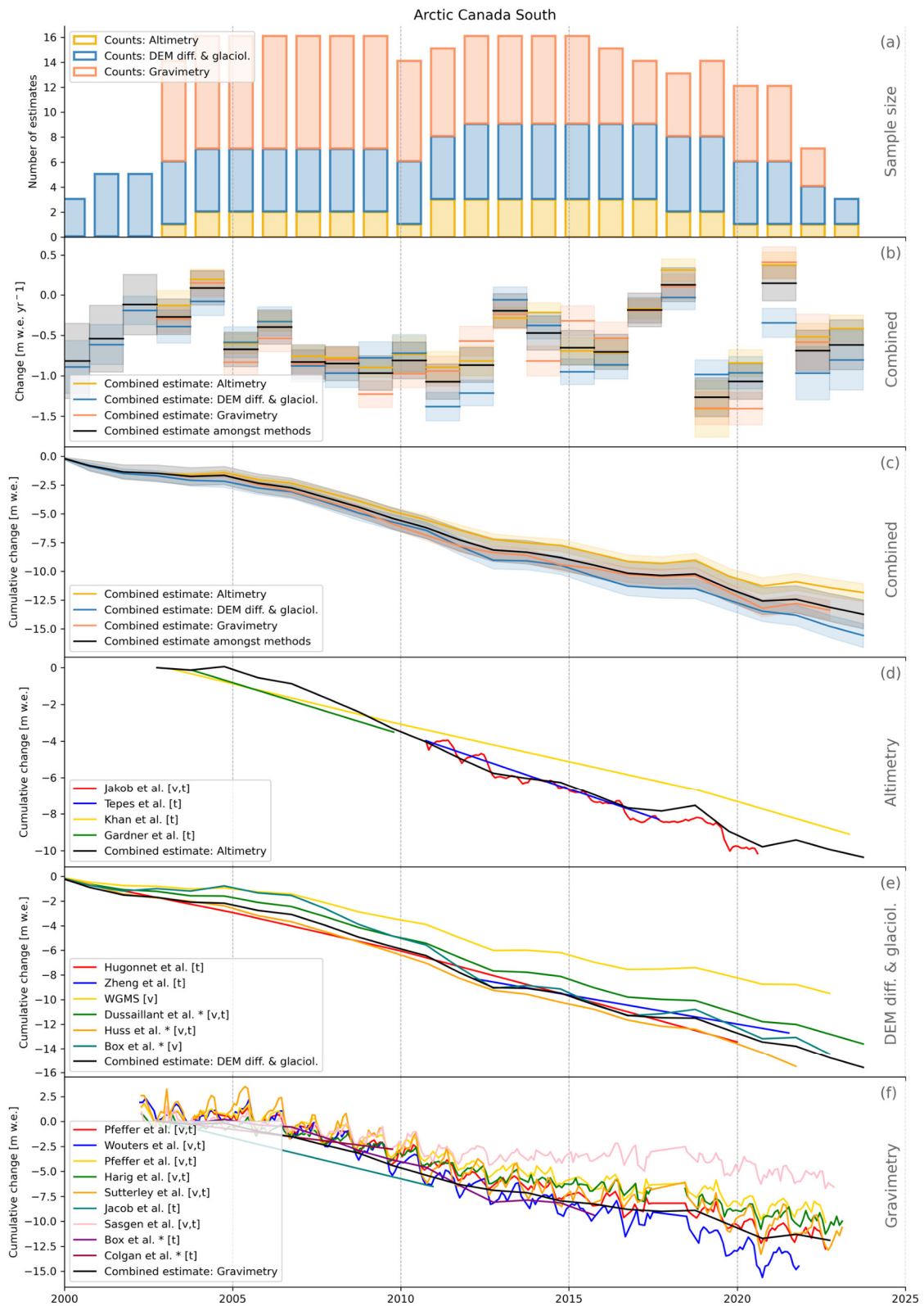
SI Figure 2 | Data submissions for Western Canada & USA



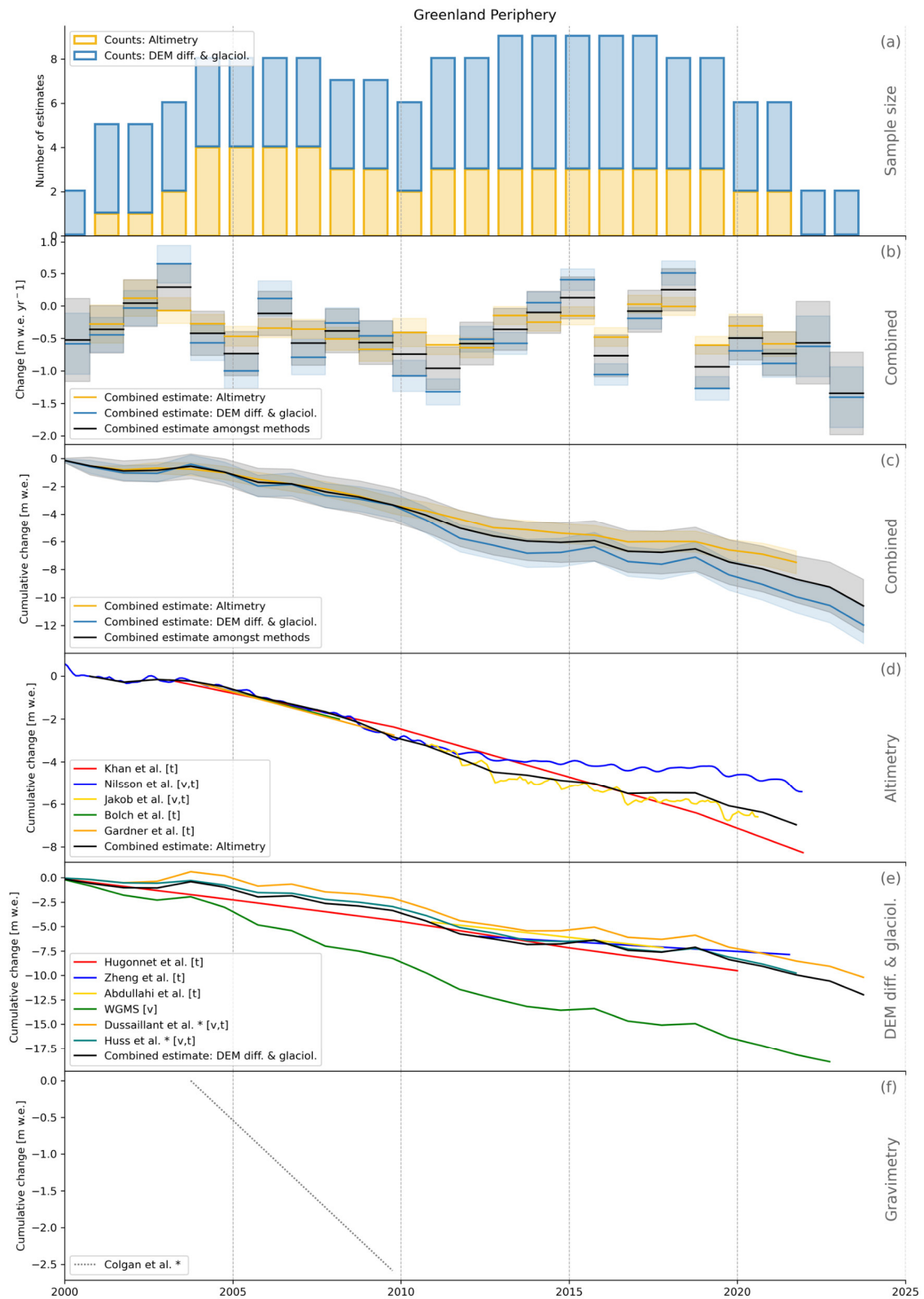
SI Figure 3 | Data submissions for Arctic Canada North



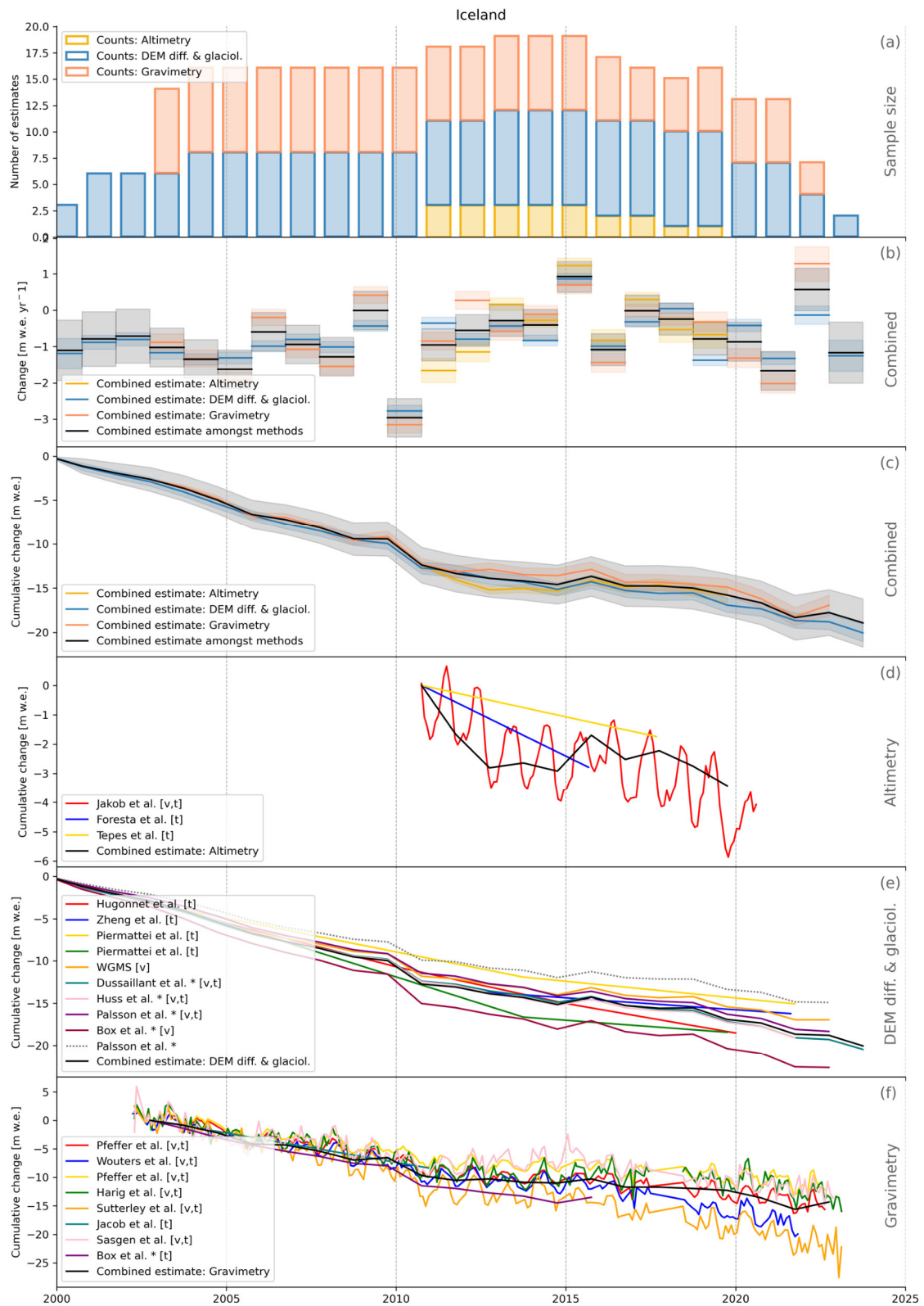
SI Figure 4 | Data submissions for Arctic Canada South



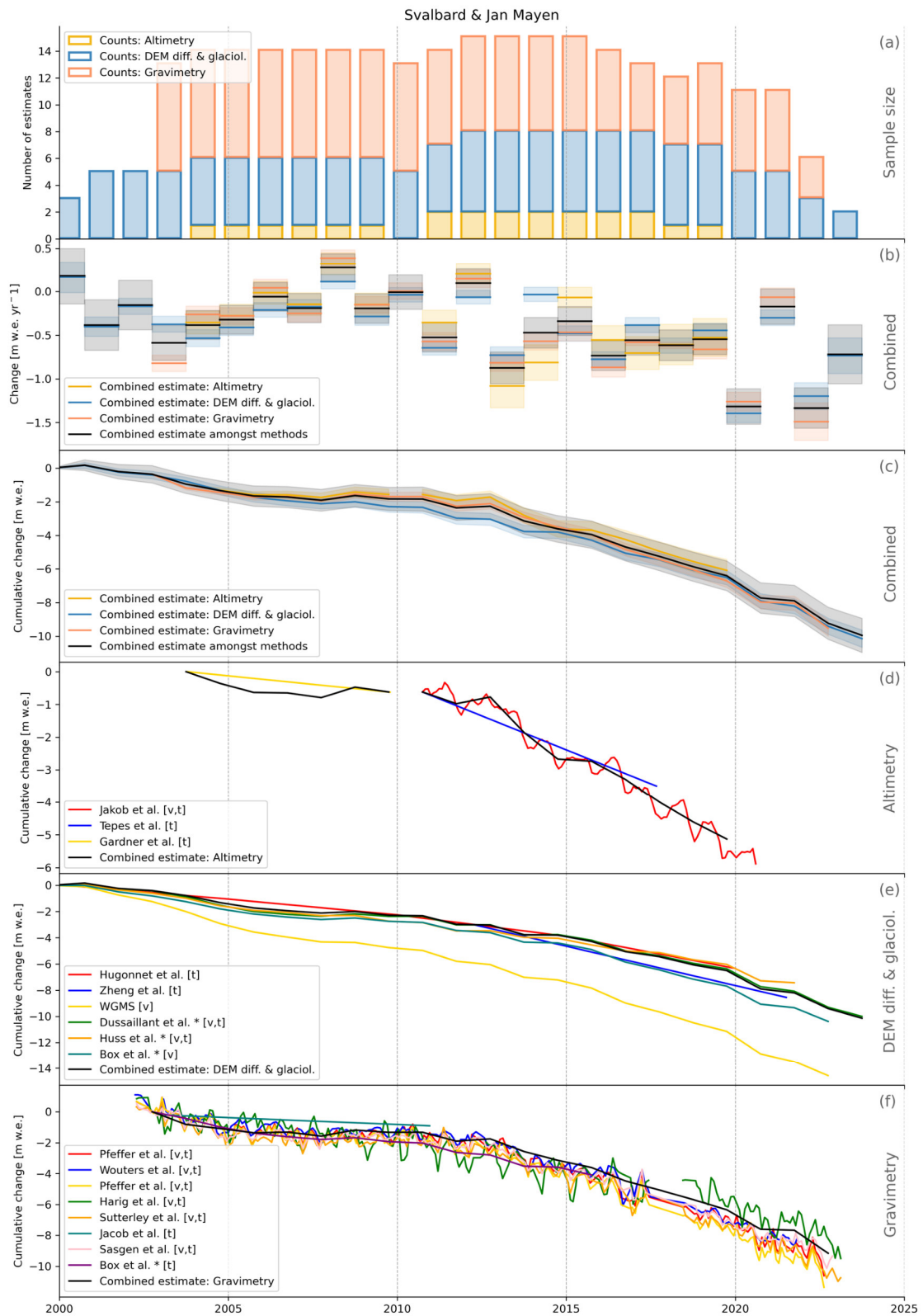
SI Figure 5 | Data submissions for Greenland Periphery



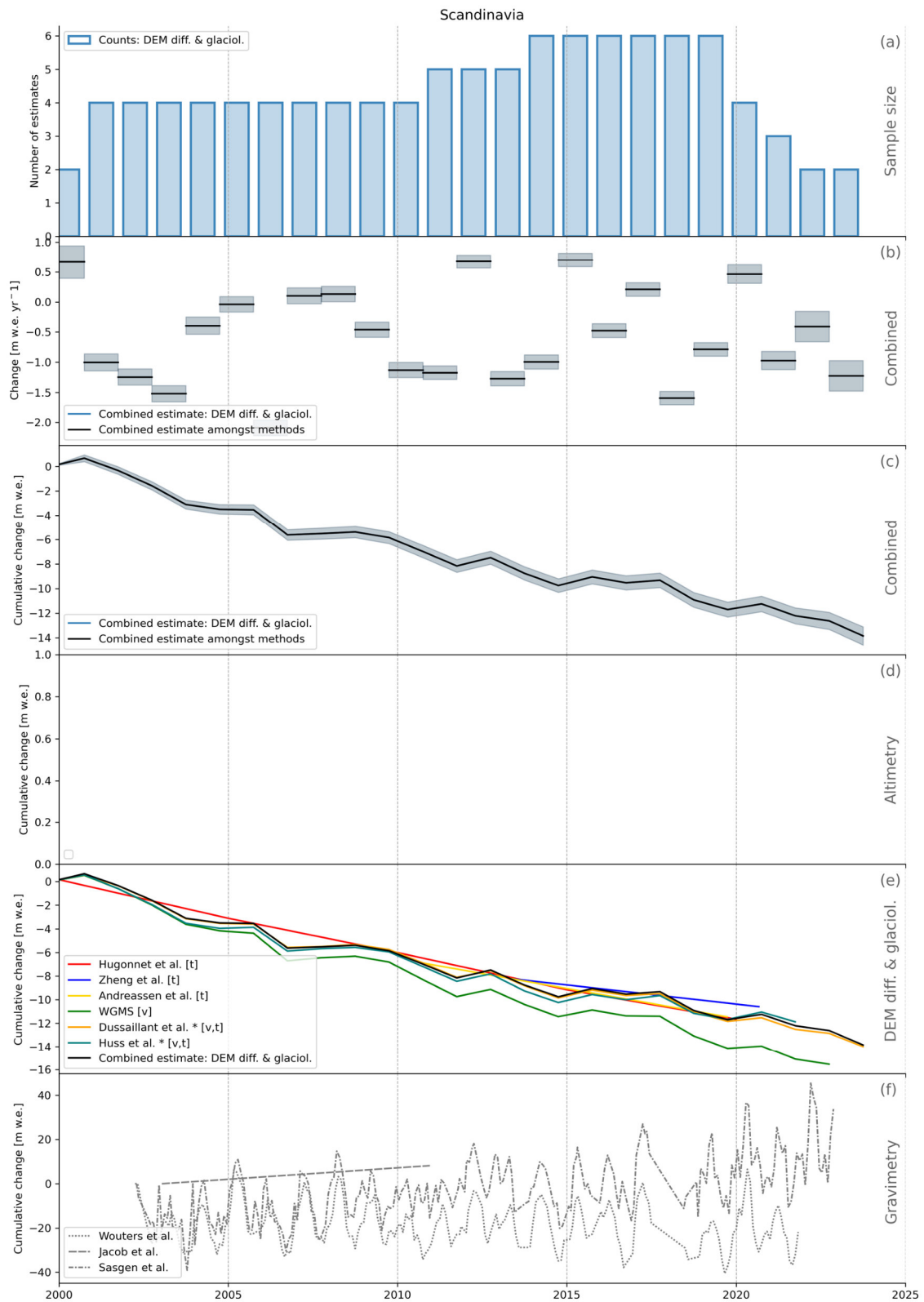
SI Figure 6 | Data submissions for Iceland



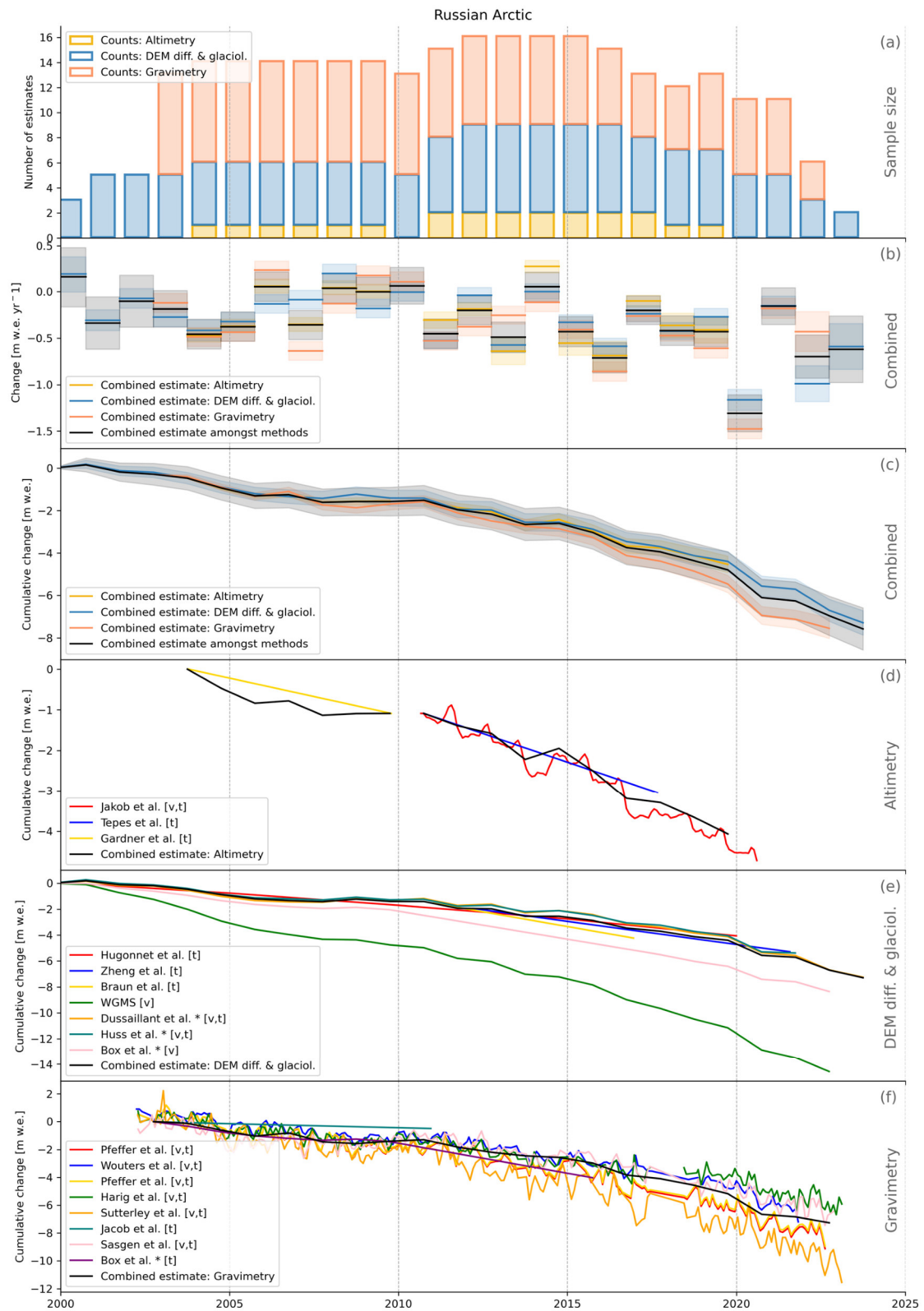
SI Figure 7 | Data submissions for Svalbard & Jan Mayen



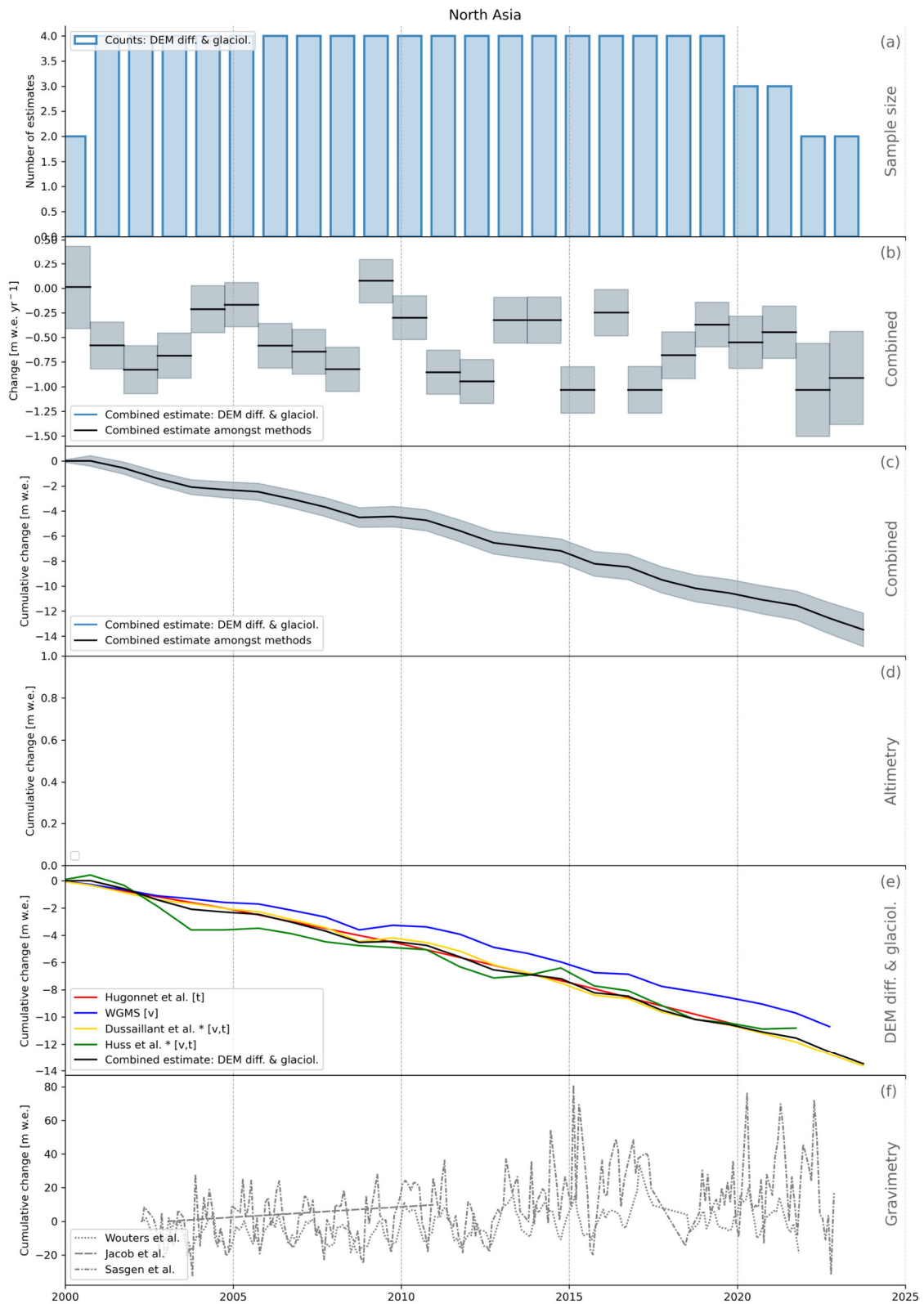
SI Figure 8 | Data submissions for Scandinavia



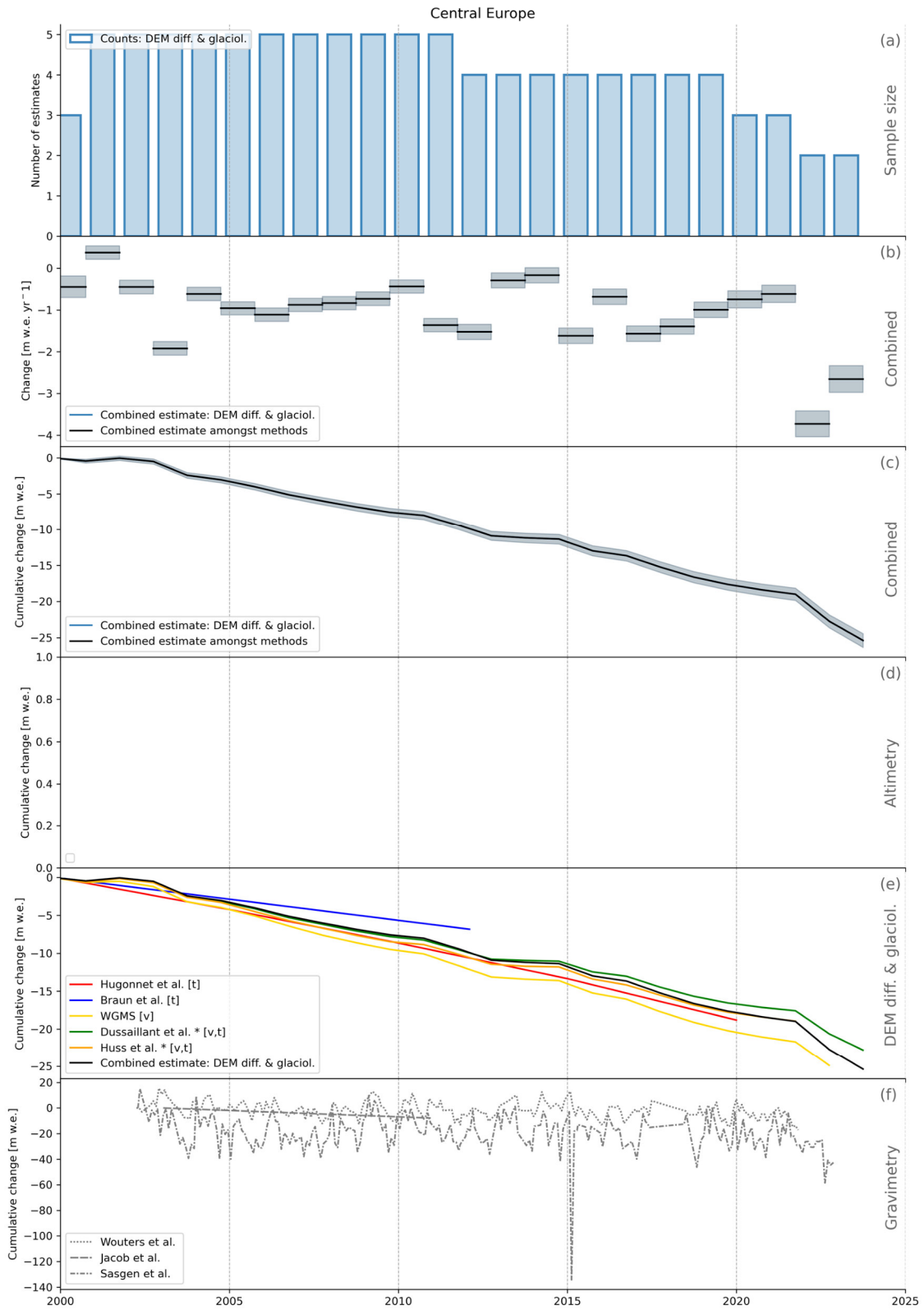
SI Figure 9 | Data submissions for Russian Arctic



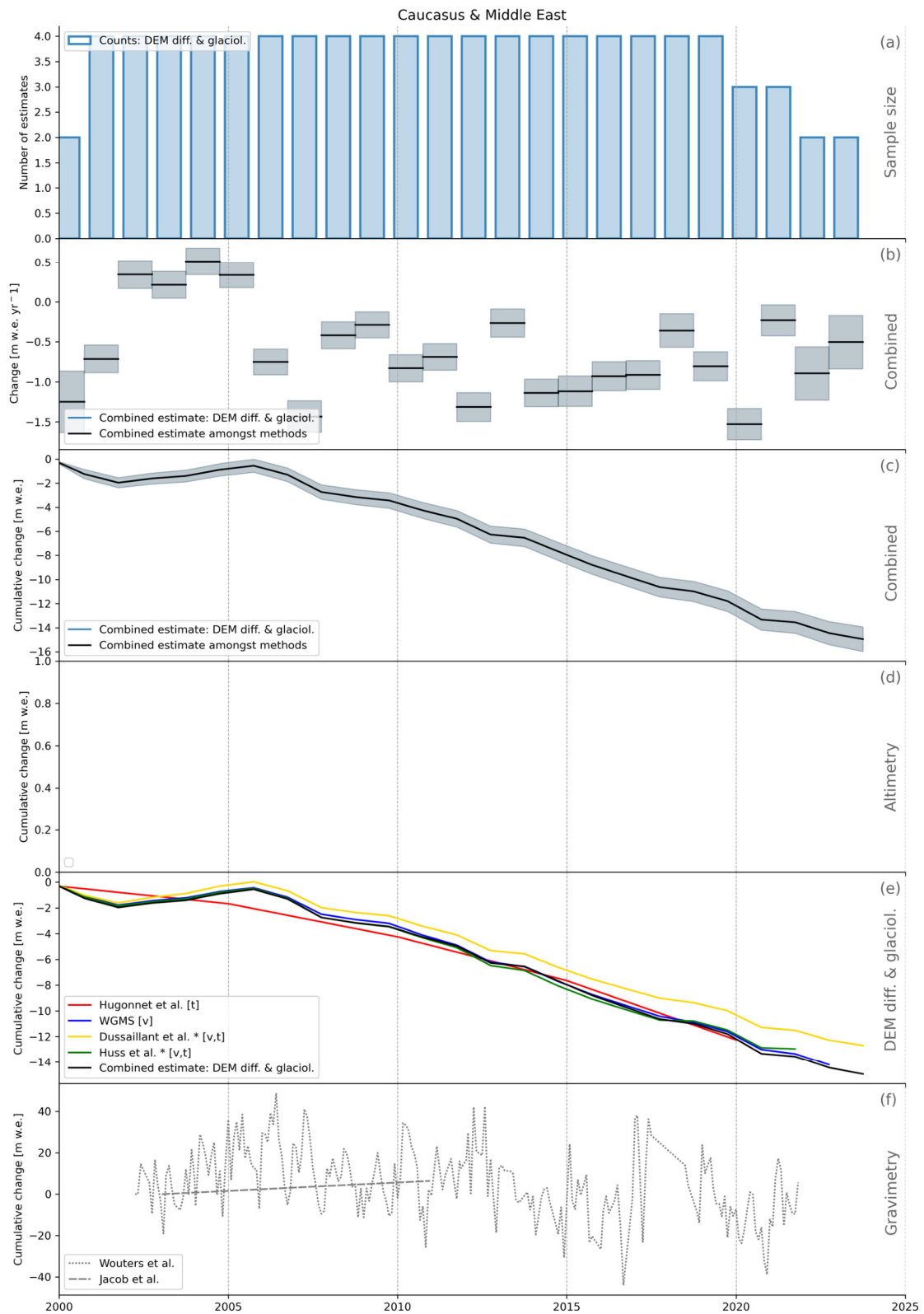
SI Figure 10 | Data submissions for North Asia



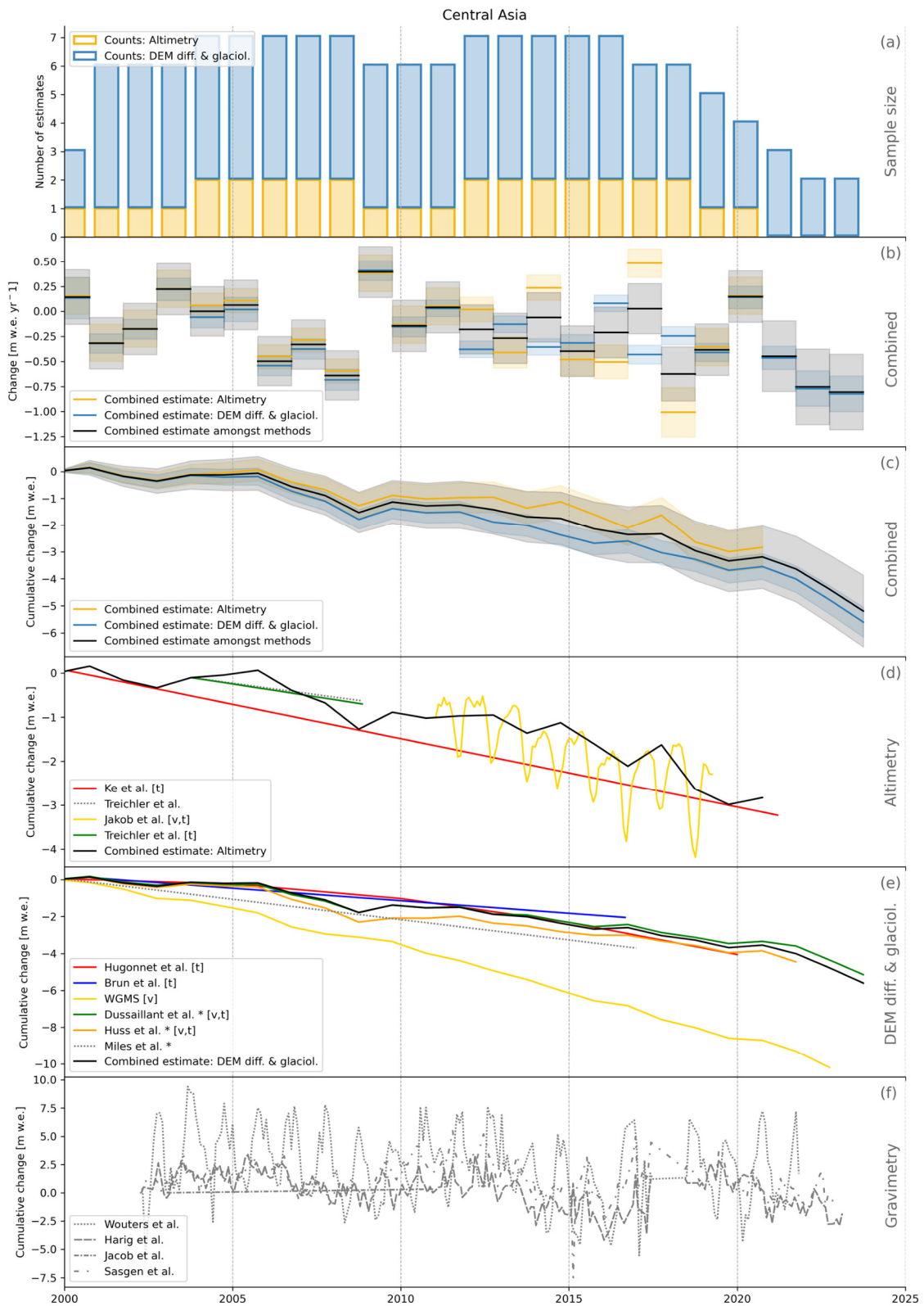
SI Figure 11 | Data submission for Central Europe



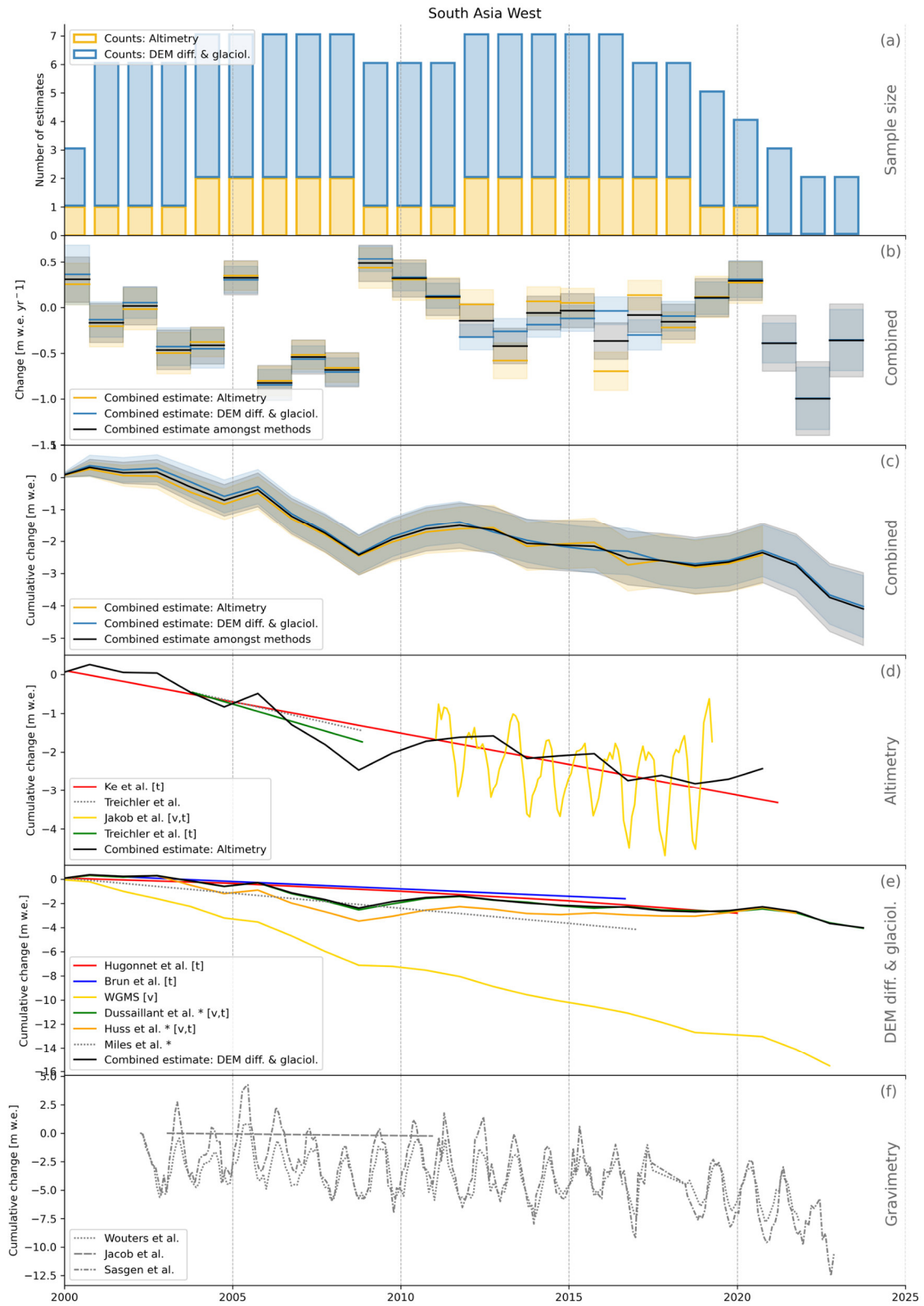
SI Figure 12 | Data submission for Caucasus & Middle East



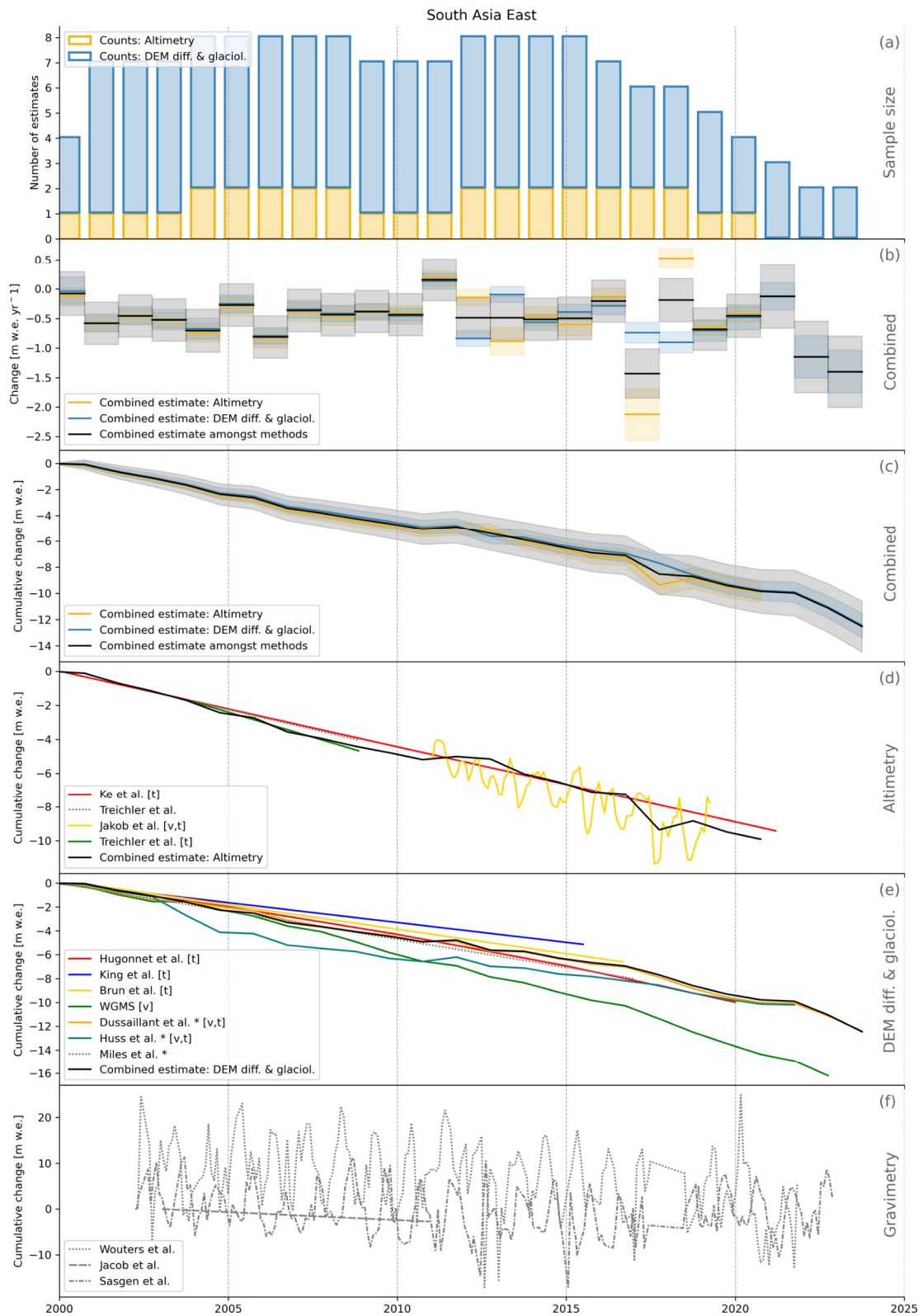
SI Figure 13 | Data submission for Central Asia



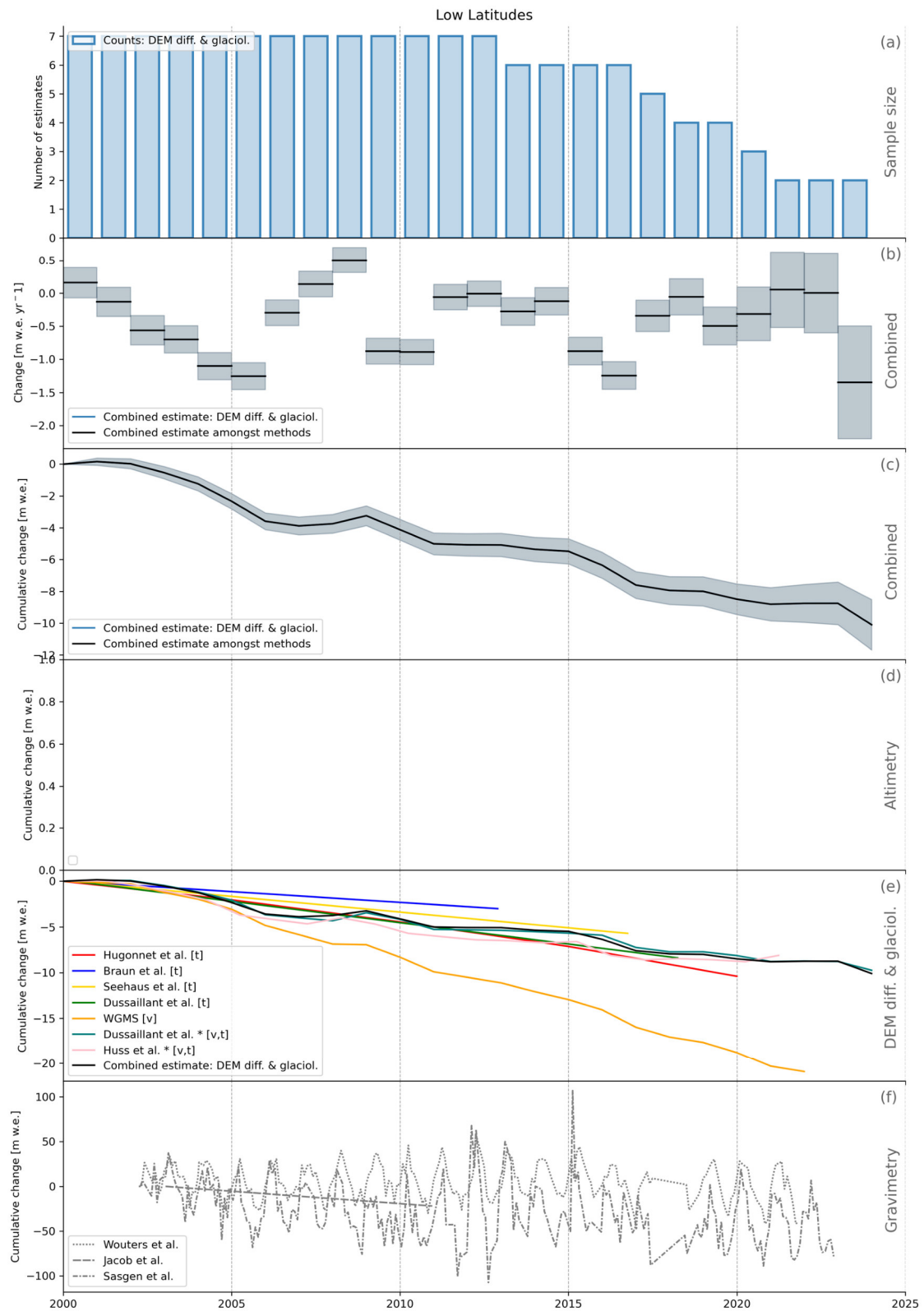
SI Figure 14 | Data submission for South Asia West



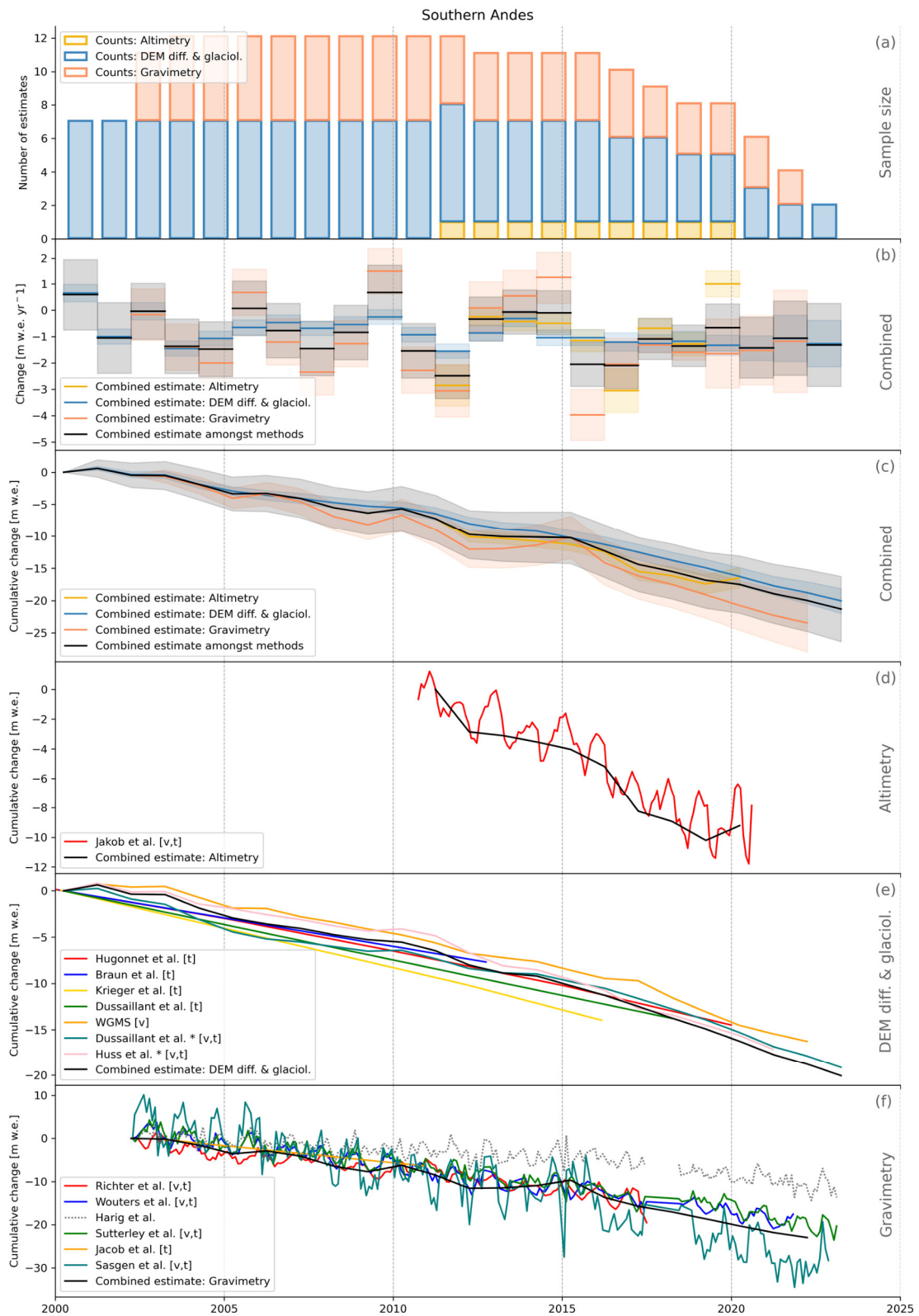
SI Figure 15 | Data submission for South Asia East



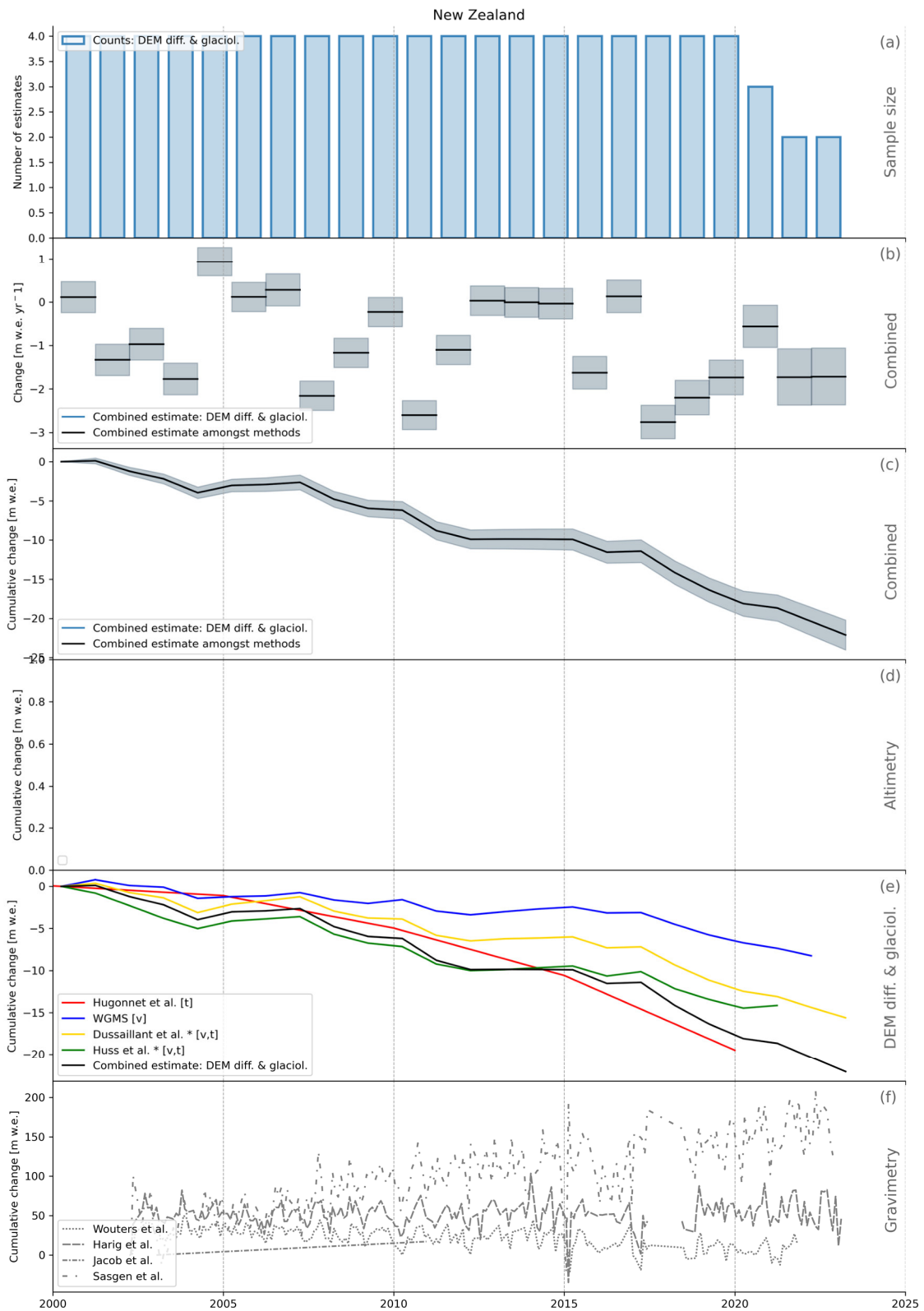
SI Figure 16 | Data submission for Low Latitudes



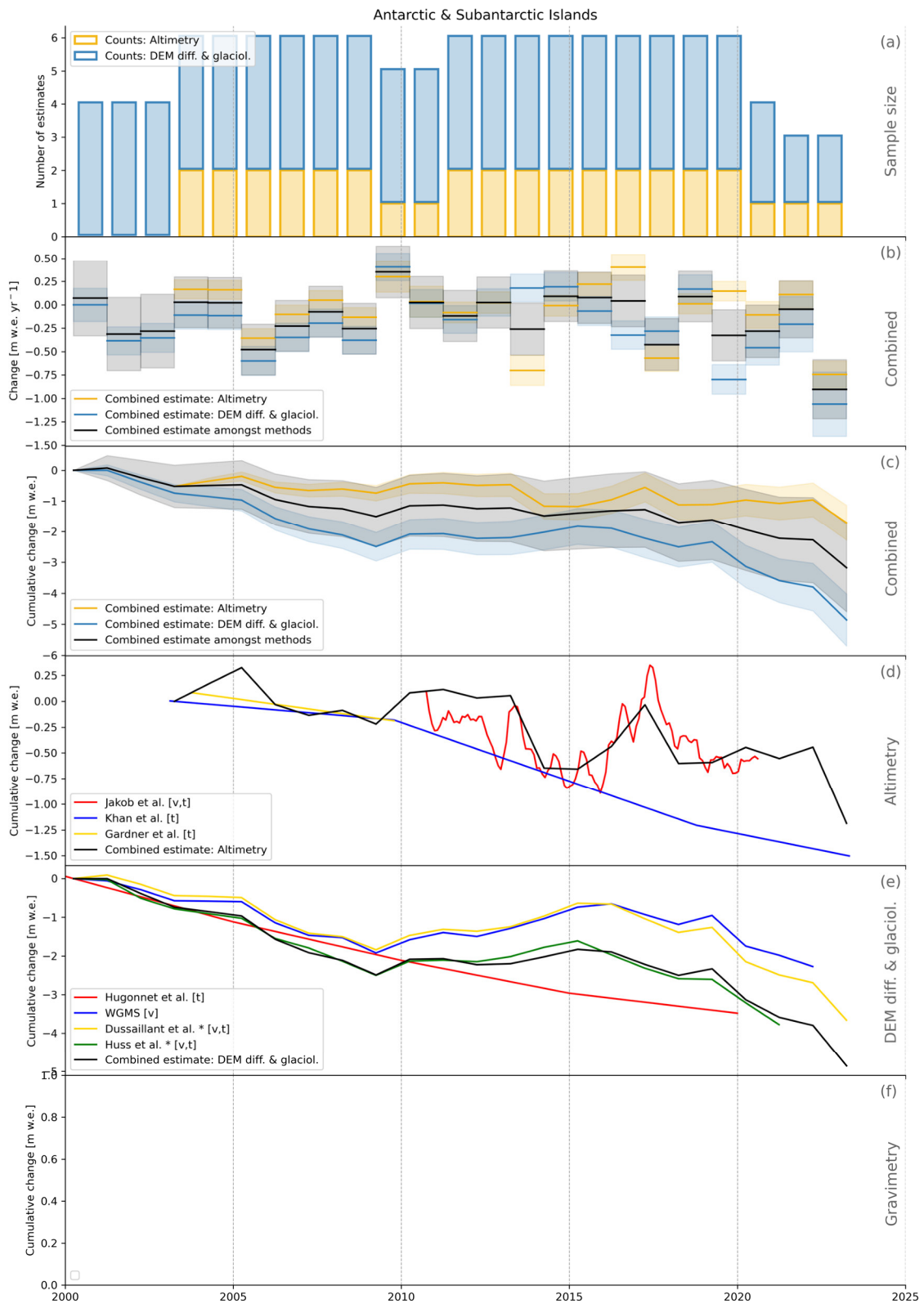
SI Figure 17 | Data submission for Southern Andes



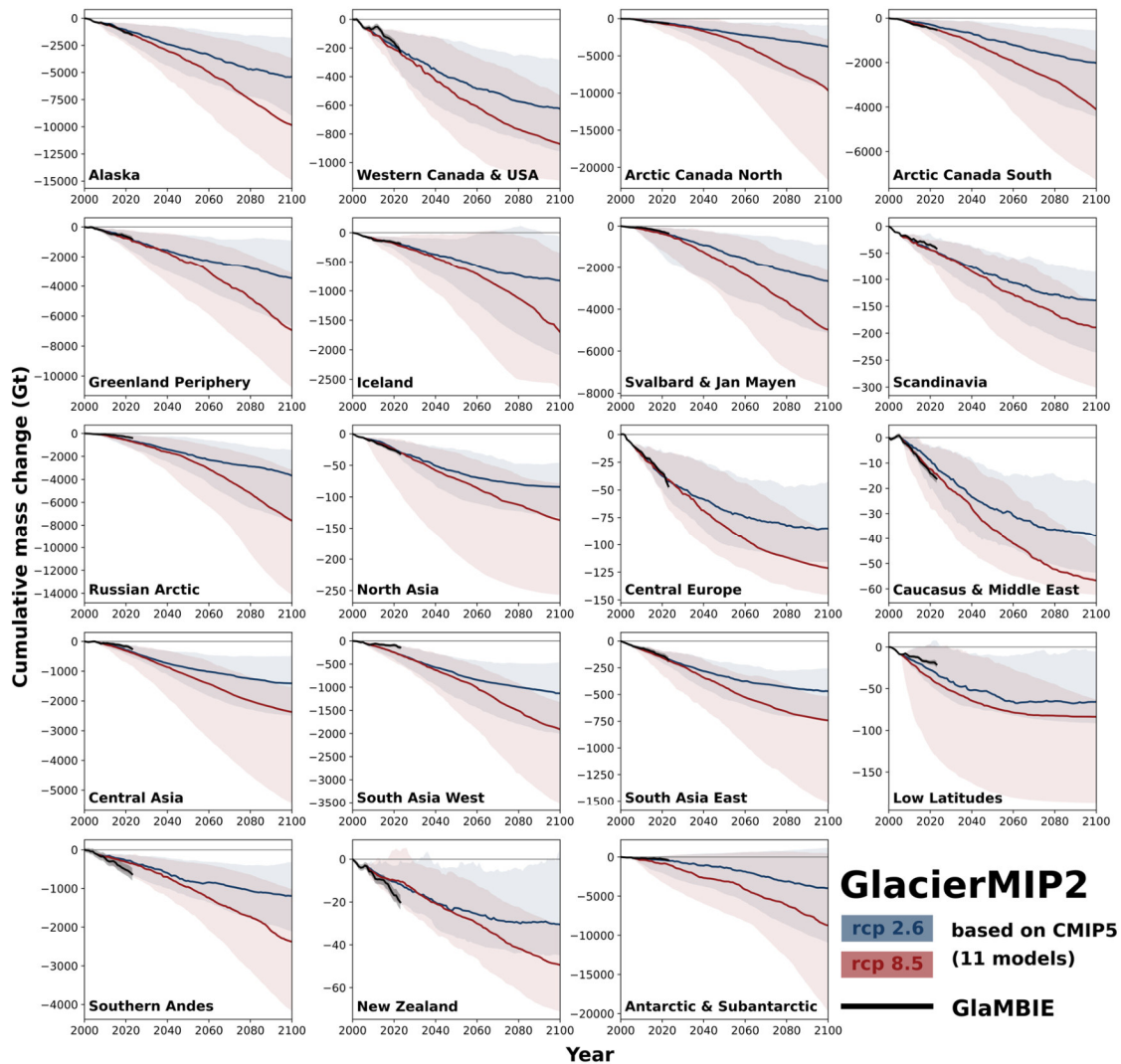
SI Figure 18 | Data submission for New Zealand



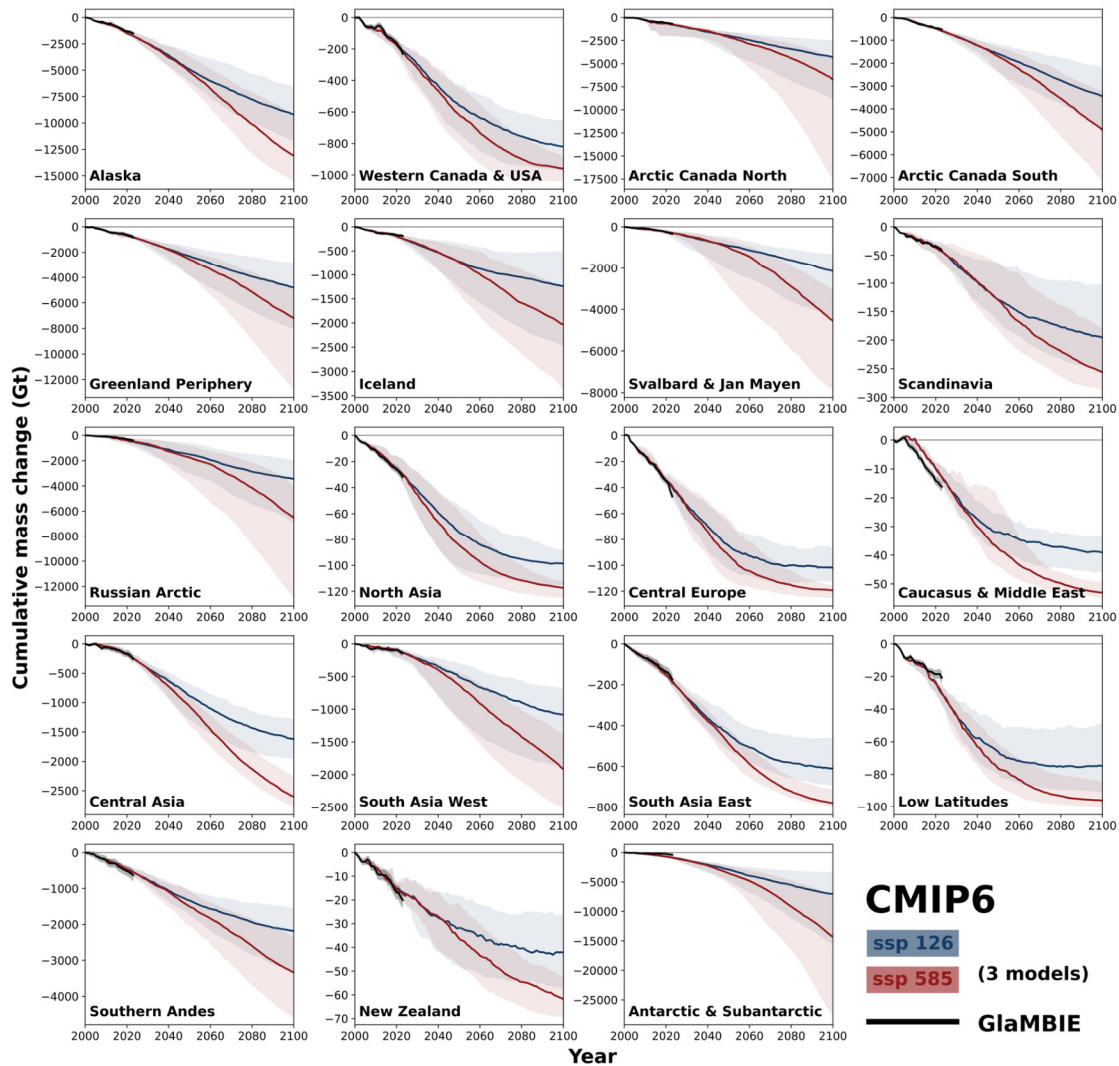
SI Figure 19 | Data submission for Antarctic and Subantarctic Islands



SI Figure 20 | Glacier mass-change observations and model projections (CMIP5). Regional comparison of observed cumulative glacier mass changes (in Gt) since 2000 with ensemble projections for 2007–2100 from the glacier model intercomparison project (GlacierMIP2, based on CMIP5) from Marzeion et al. (2020)⁴⁴, as used in IPCC AR6. Glacier mass-change observations (black line) are accompanied by their 95% confidence intervals (grey shading). For the projections, ensemble medians (blue and red lines) are shown with 95 percentile ranges (blue and red shadings) for low and high emission scenarios, respectively. Projections have been offset at their start date (2007) to fit the cumulative value of the observations.



SI Figure 21 | Glacier mass-change observations and model projections (CMIP6). Regional comparison of observed cumulative glacier mass changes (in Gt) since 2000 with ensemble projections for 2007–2100 from a more recent model study (based on CMIP6) from Zekollari et al. (2024)⁴⁵. Glacier mass-change observations (black line) are accompanied by their 95% confidence intervals (grey shading). For the projections, ensemble medians (blue and red lines) are shown with 90 percentile ranges (blue and red shadings) for low and high emission scenarios, respectively. Projections have been offset at their start date (2007) to fit the cumulative value of the observations.



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