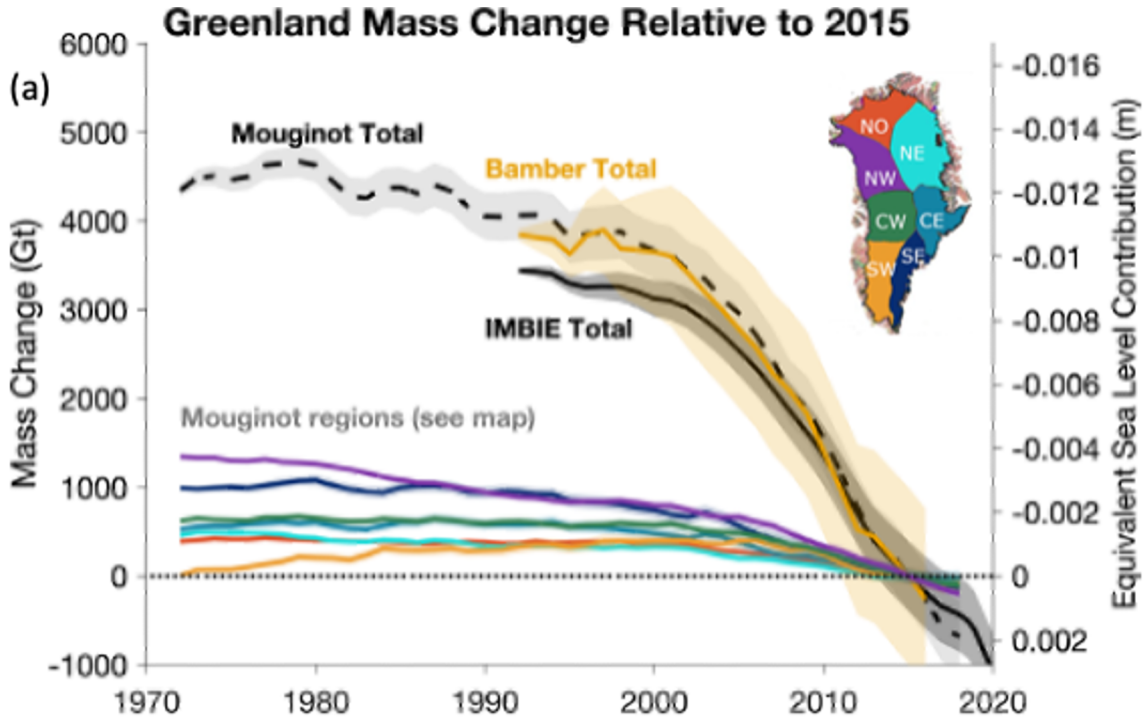
Projections from the Greenland ice sheet



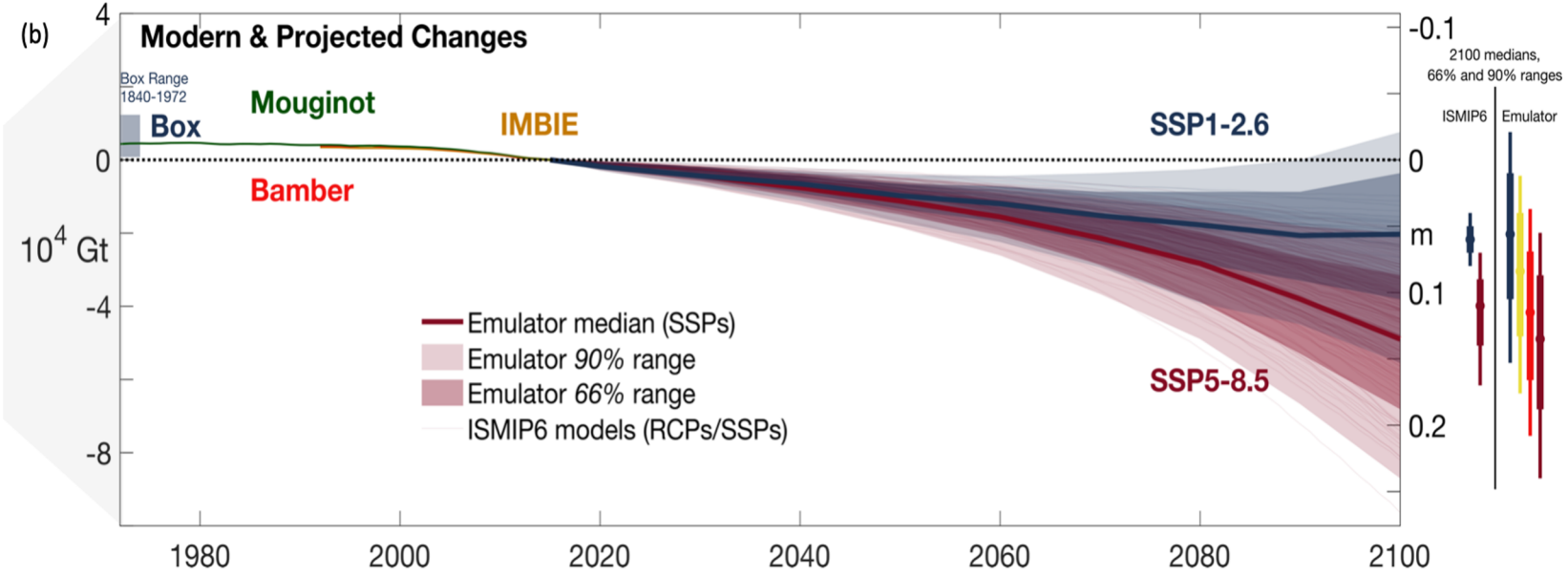
Sophie Nowicki

and many conversations with SeaRISE and ISMIP6 participants, and AR6 Chapter 9

09/20/2021

University at Buffalo
The State University of New York

The Greenland ice sheet will continue to lose mass throughout this century under all emissions scenarios *(virtually certain)*



The observed mass loss was driven by discharge and surface melt, with the latter becoming the dominating component with high interannual variability in the last decade.

The largest observed mass loss occurred in the Northwest and Southeast.

The contribution until 2100 will *likely* be:

0.01-0.10 m under SSP1-2.6,

(0.03-0.11 m under RCP2.6 in AR5 and SROCC)

up to

0.09-0.18 m under SSP5-8.5

(0.08-0.27 m under RCP8.5 in AR5 and SROCC).

Slightly narrower projected range cf AR5 and SROCC, but median ~same.

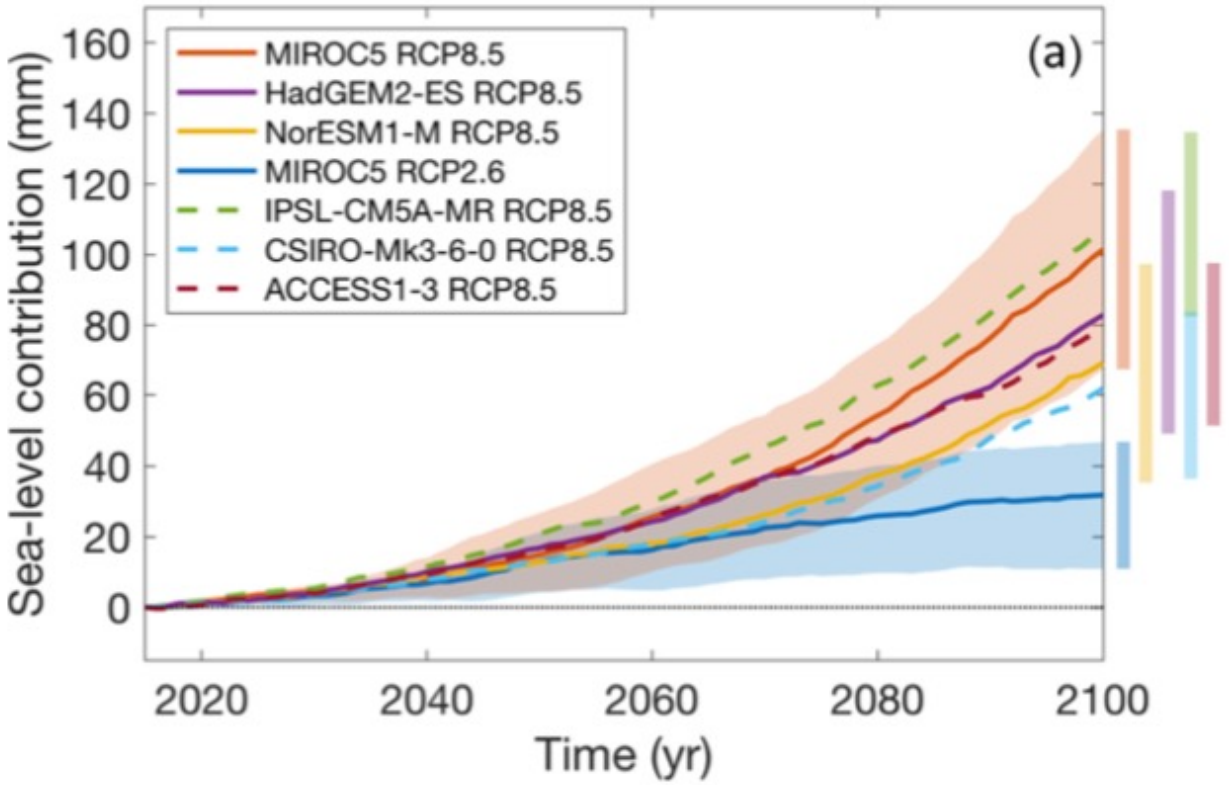
What is behind these AR6 projections? A zoo of ice sheet models…

Model ID	Numerics	Ice flow	Initialization	Initial year	Initial SMB	Velocity	Bed	Surface/ thickness	GHF	Res. min	Res. max
AWI-ISSM1	FE	HO	DAv	1990	RA3	J	M		G	1[1]	7.5
AWI-ISSM2	FE	HO	DAv	1990	RA3	J	M		G	1[1]	7.5
AWI-ISSM3	FE	HO	DAv	1990	RA3	J	M		G	0.75	7.5
BGC-BISICLES	FV	SSA	DAv	2000	HIR	RM	M			1.2	4.8
GSFC-ISSM	FE	SSA	DAv	2007	RA3	J	M		SR	0.5	25
ILTSPIK-SICOPOLIS1	FD	SIA	CYC/NDs	1990	ISMB	J	M	M	G	5	5
ILTSPIK-SICOPOLIS2	FD	HYB	CYC/NDs	1990	ISMB	J	M	M	G	5	5
IMAU-IMAUICE1	FD	SIA	SP/NDm	1990	RA3		M		SR	16	16
IMAU-IMAUICE2	FD	SIA	SP/NDm	1990	RA3		M		SR	8	8
JPL-ISSM	FE	HYB	DAv	1979	BOX/MAR[2]	RM	M		SR	0.25	15
JPL-ISSMPALEO	FE	SSA	SP/DAv[3]	1979	BOX/RA3[4]	RM	M		SR	3	30
LSCE-GRISLI	FD	HYB	SP/DAs[7]	1995	MAR		M	M	SR	5	5
MUN-GSM1	FD/FV[5]	HYB	CYC/NDm	1980	MAR		B		MIX	5	14[6]
MUN-GSM2	FD/FV[5]	HYB	CYC/NDm	1980	MAR		B		MIX	5	14[6]
NCAR-CISM	FE	HO	SP/DAi	1990	MAR		M	M	SR	4	4
UAF-PISM1	FD	HYB	CYC/NDs[7]	2008	RA1		M	M	SR	0.9	0.9
UAF-PISM2	FD	HYB	CYC/NDs[7]	2008	RA1		M	M	SR	0.9	0.9
UCIJPL-ISSM1	FE	HO	DAv	2007	RA1	RM	M		SR	0.5	30
UCIJPL-ISSM2	FE	HO	DAv	2007	RA1	RM	M		SR	0.2	20
VUB-GISM	FD	HO	CYC/DAi[7]	1990	MAR		M	M	SR	5	5
VUW-PISM	FD	HYB	SP/NDs[7]	2000	RA1		M		SR	2	2

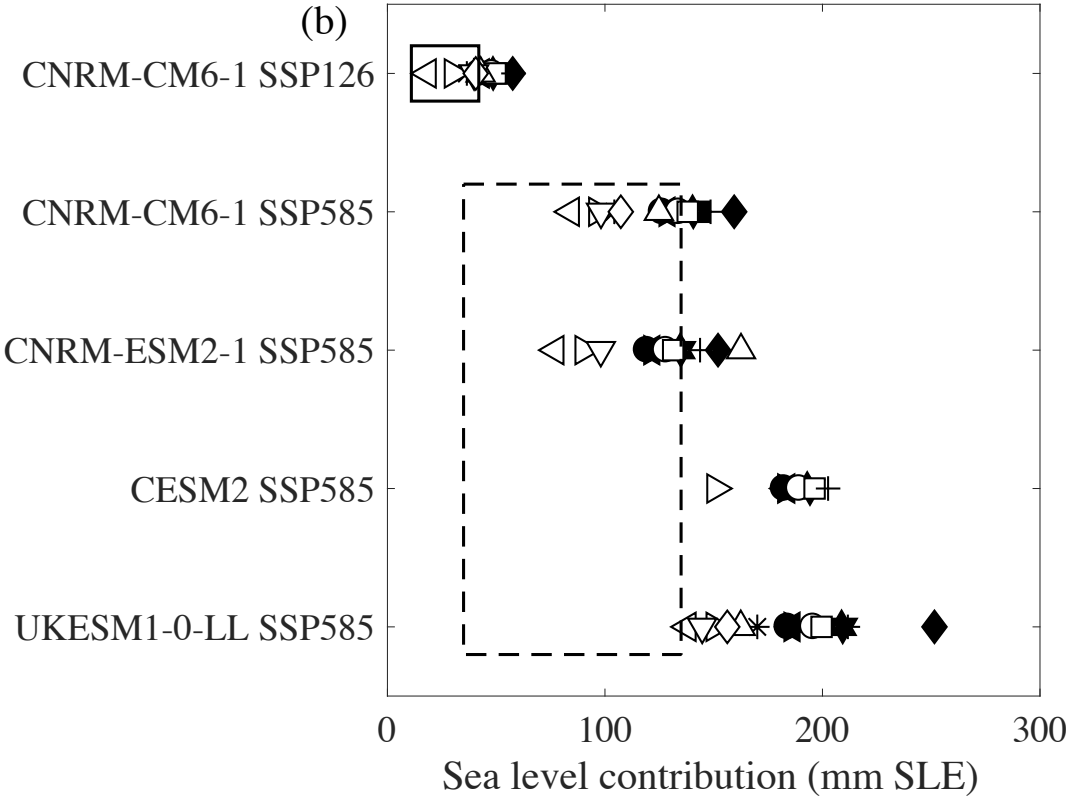
ISMIP6 Ice Sheet Model Intercomparison Project for CMIP6

Goelzer et al. (2020) Table A1

What is behind these AR6 projections? A zoo of ice sheet models **forced by selected CMIP models…**



Goelzer et al., 2020

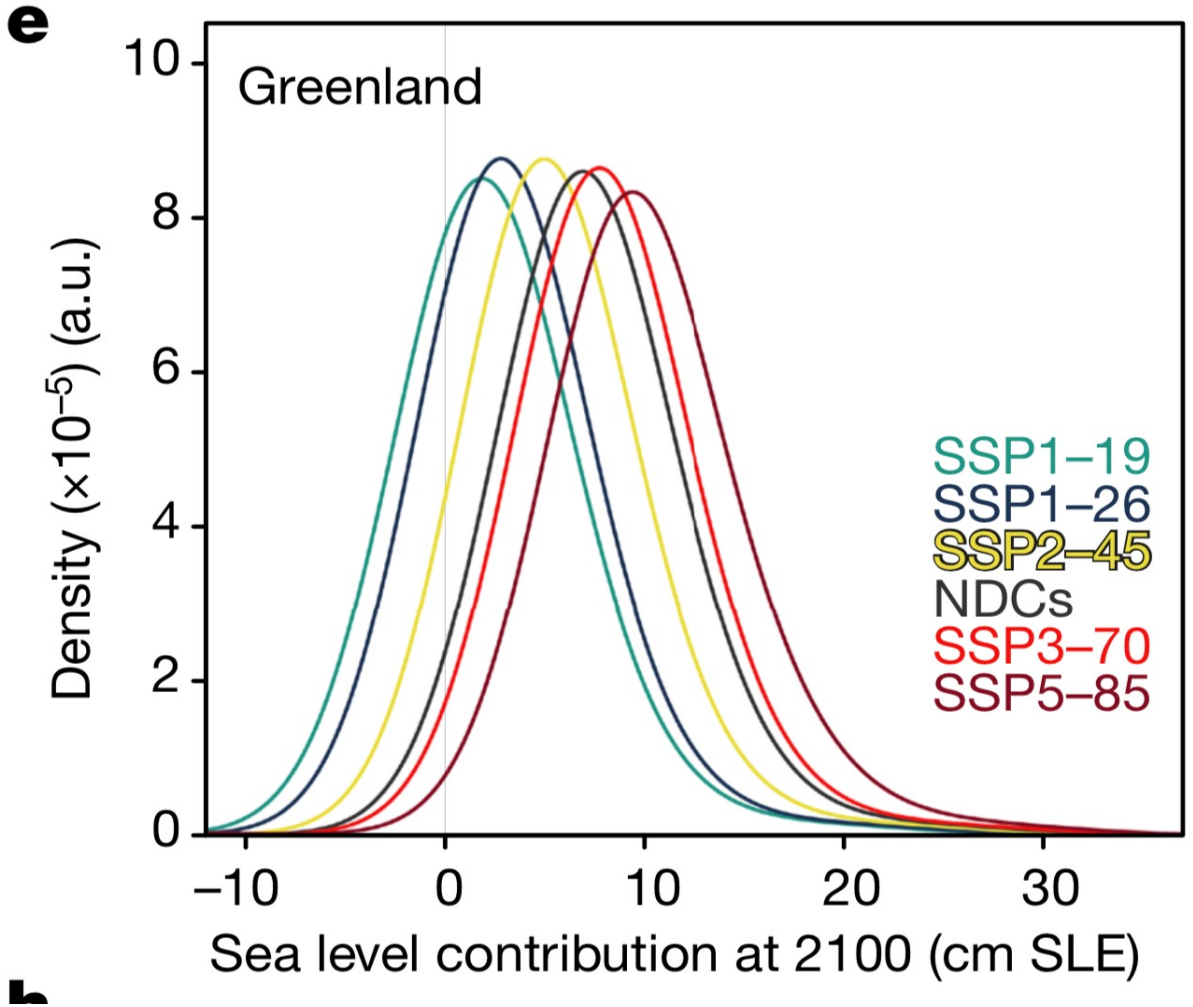


Payne et al., 2021

ISMIP6 Ice Sheet Model Intercomparison Project for CMIP6

*these projections are relative to control experiment with constant climate forcing.
ISMIP6 generated ~ 250 simulations for the Greenland ice sheet

What is behind these AR6 projections? A zoo of ice sheet models forced by CMIP models **and emulated**…



The numbers*:

3 cm under SSP1-26

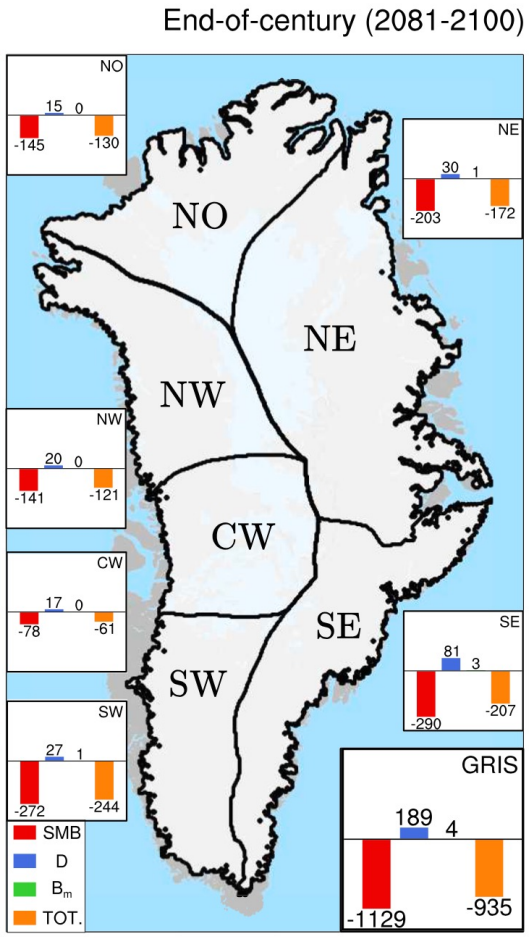
13 cm under SSP5-85

*Median projections for 2015-2100

ISMIP6
Ice Sheet Model Intercomparison Project for CMIP6

Edwards et al., 2021

What is behind these AR6 projections? Also coupled ice-sheet-climate model simulations and more…

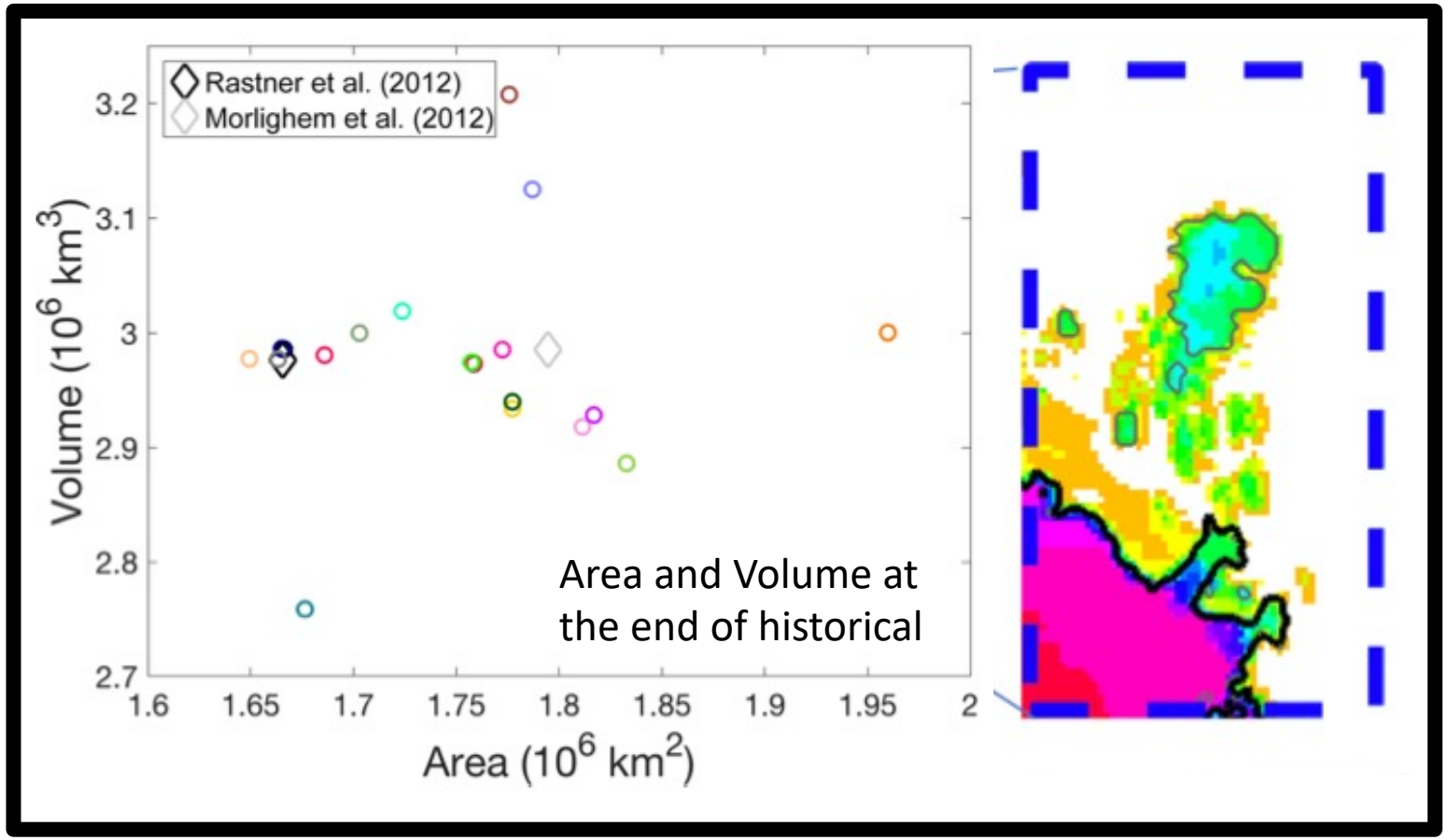


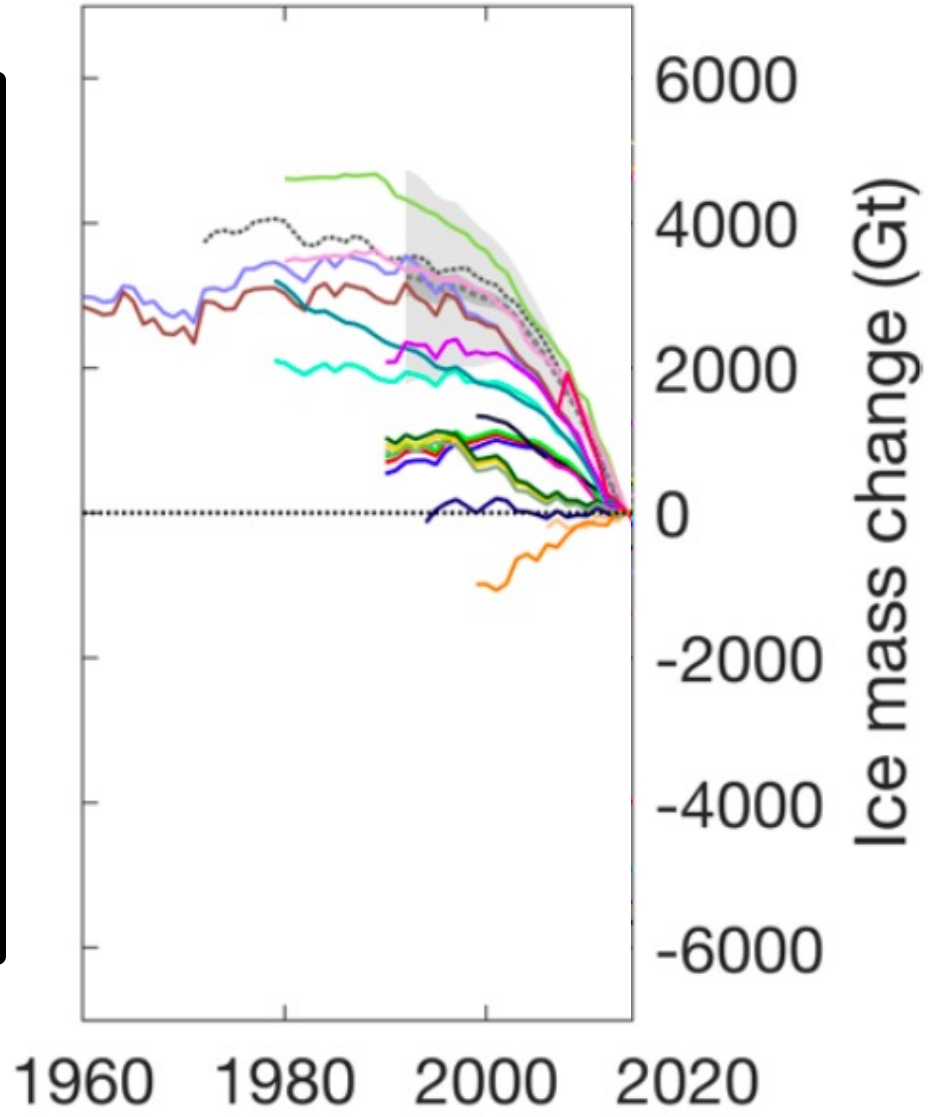
CESM2.1-CISM2.1 (Muntjewerf et al., 2020)

Study in AR6 Tables 9.2 and 9.8	Projected SL to 2100	Notes
Leclec'h et al., 2019	7.9cm RCP8.5	Coupled MAR-GRISLI
Van Breedam et al., 2020	7.3cm RCP8.5	Coupled LOVECLIM-AGISM
Muntjewerf et al., 2020	10.9cm SSP5-85	Coupled CESM2.1-CISM2.1
Chap 9	11cm SSP5-85	ISMIP6 CMIP5+CMIP6+ hist dynamic
Chap 9	14cm SSP5-85	ISMIP6 with AR5 parametric fit
Edwards et al., 2021	11cm SSP5-85	Emulated ISMIP6, no hist dynamic
AR6 Assessment for 2100	**13cm SSP5-85**	**Emulated ISMIP6, with hist dynamic**
Bamber et al., 2019	23cm SSP5-85	Expert Elicitation (SEJ)
AR5 & SROCC	*13cm SSP5-85*	*Median multiple studies*

"These projections (as well as those of AR5 and SROCC) are lower than the study of Aschwanden et al. (2019) … or the range from SEJ (Bamber et al., 2019) contributing to the deep uncertainty in projected sea level (Box 9.4)" AR6 Sect 9.4.1.3

What are the challenges? Reproducing historical…

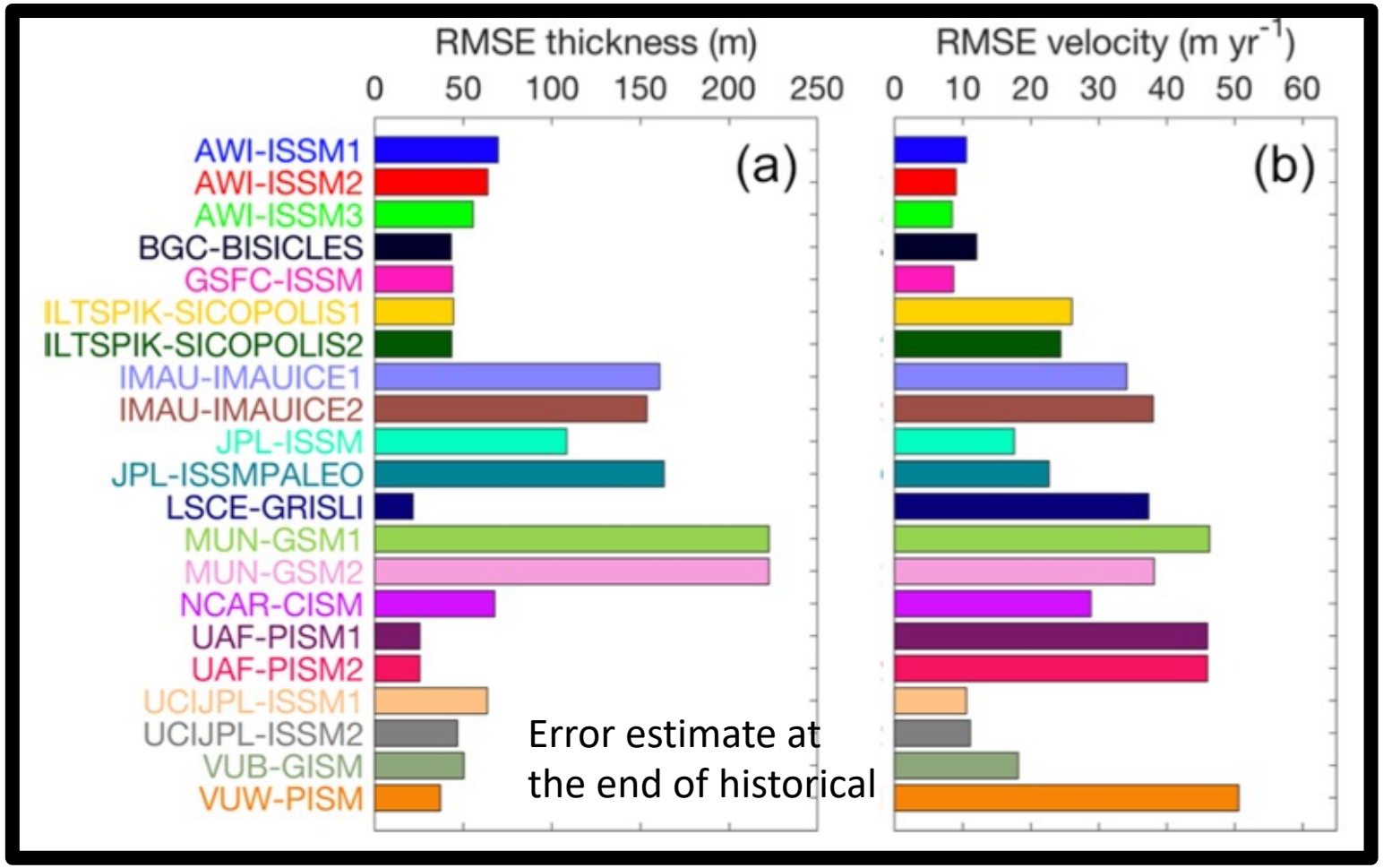


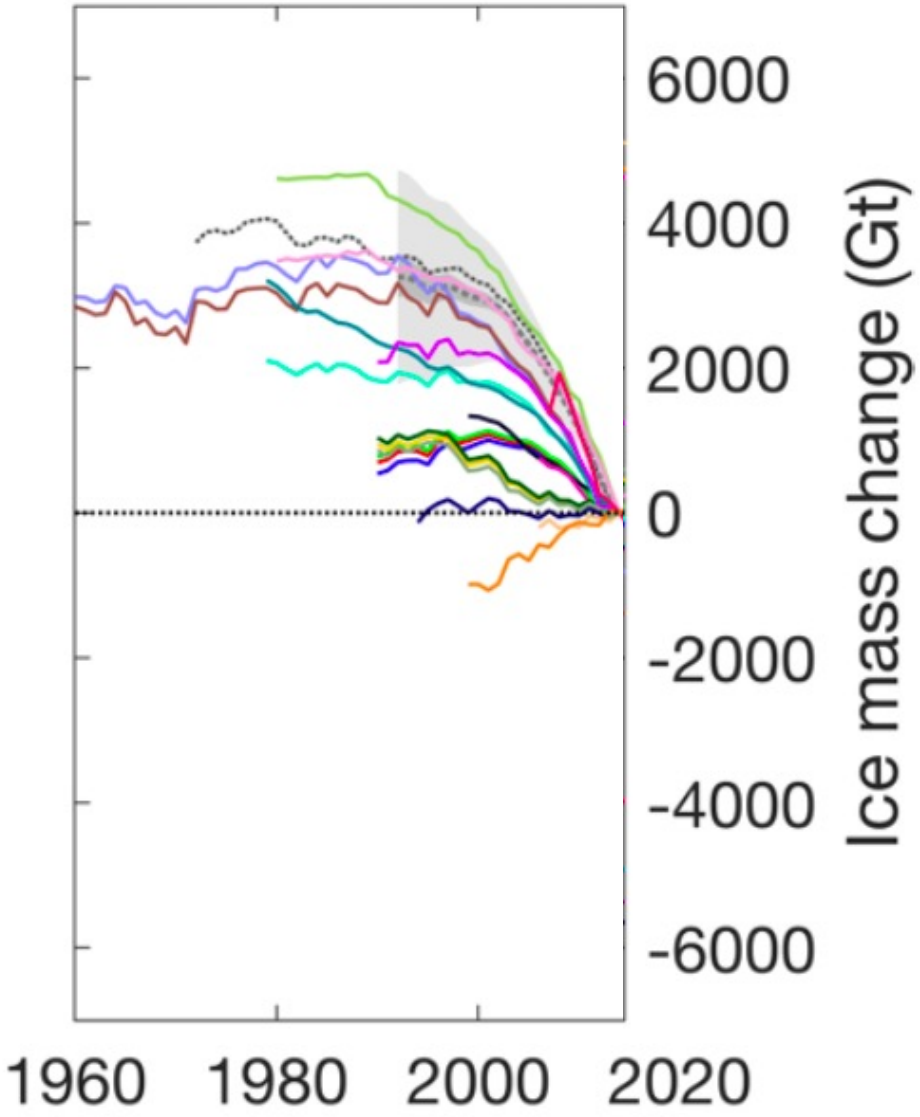


Goelzer et al., 2020

ISM are much better at capturing "present-day", but…

What are the challenges? Reproducing historical…



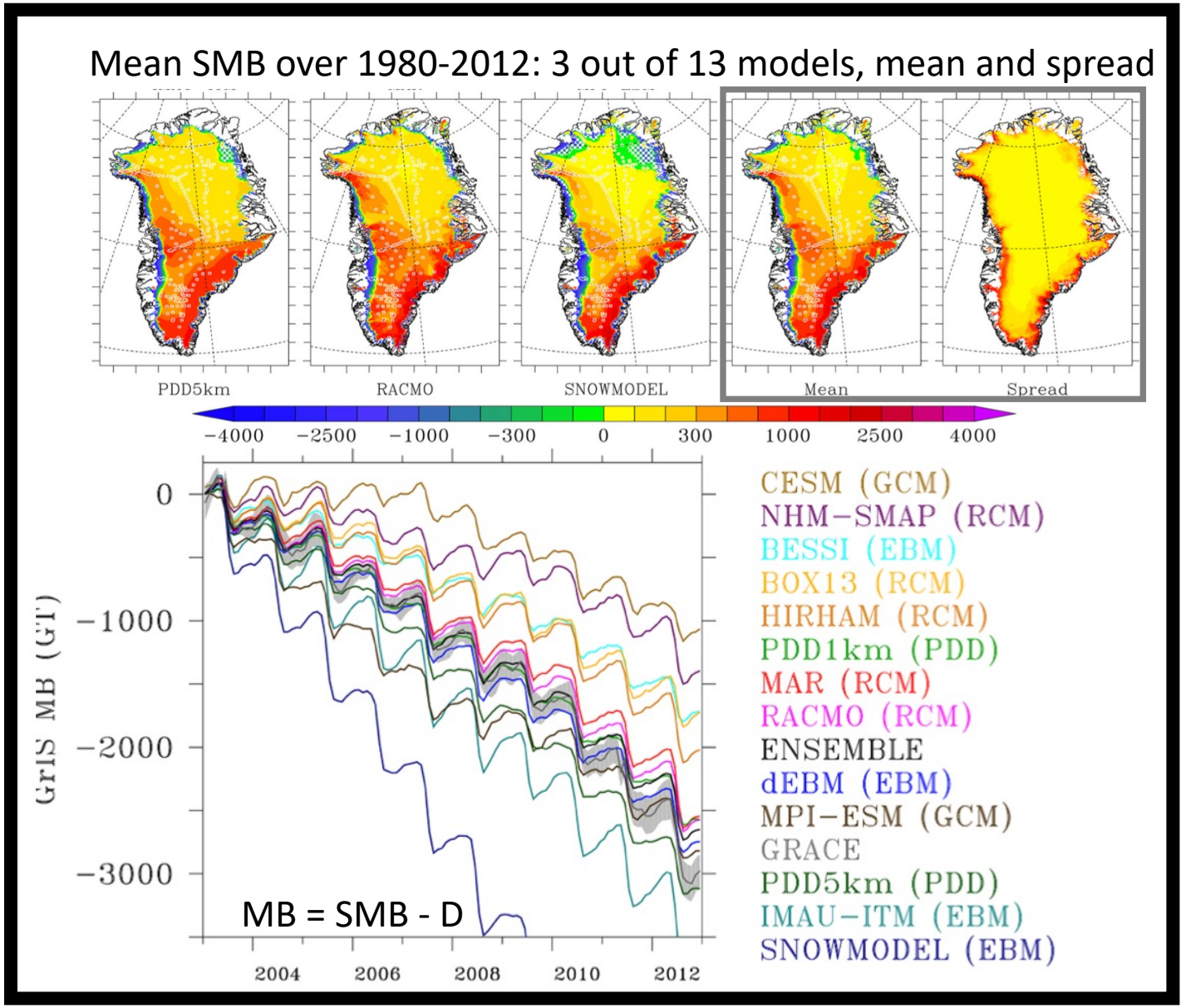


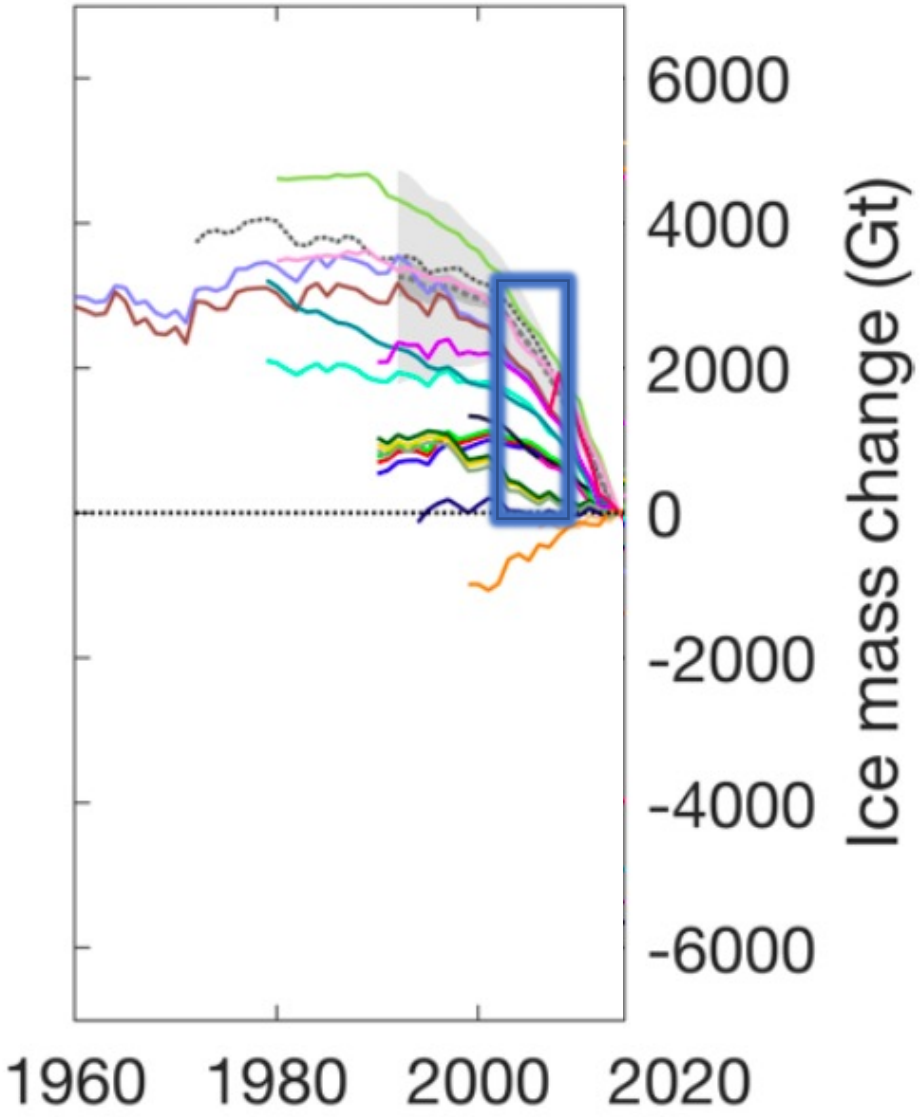
How would you assign weights?

Goelzer et al., 2020

What are the challenges? Historical climate forcing…

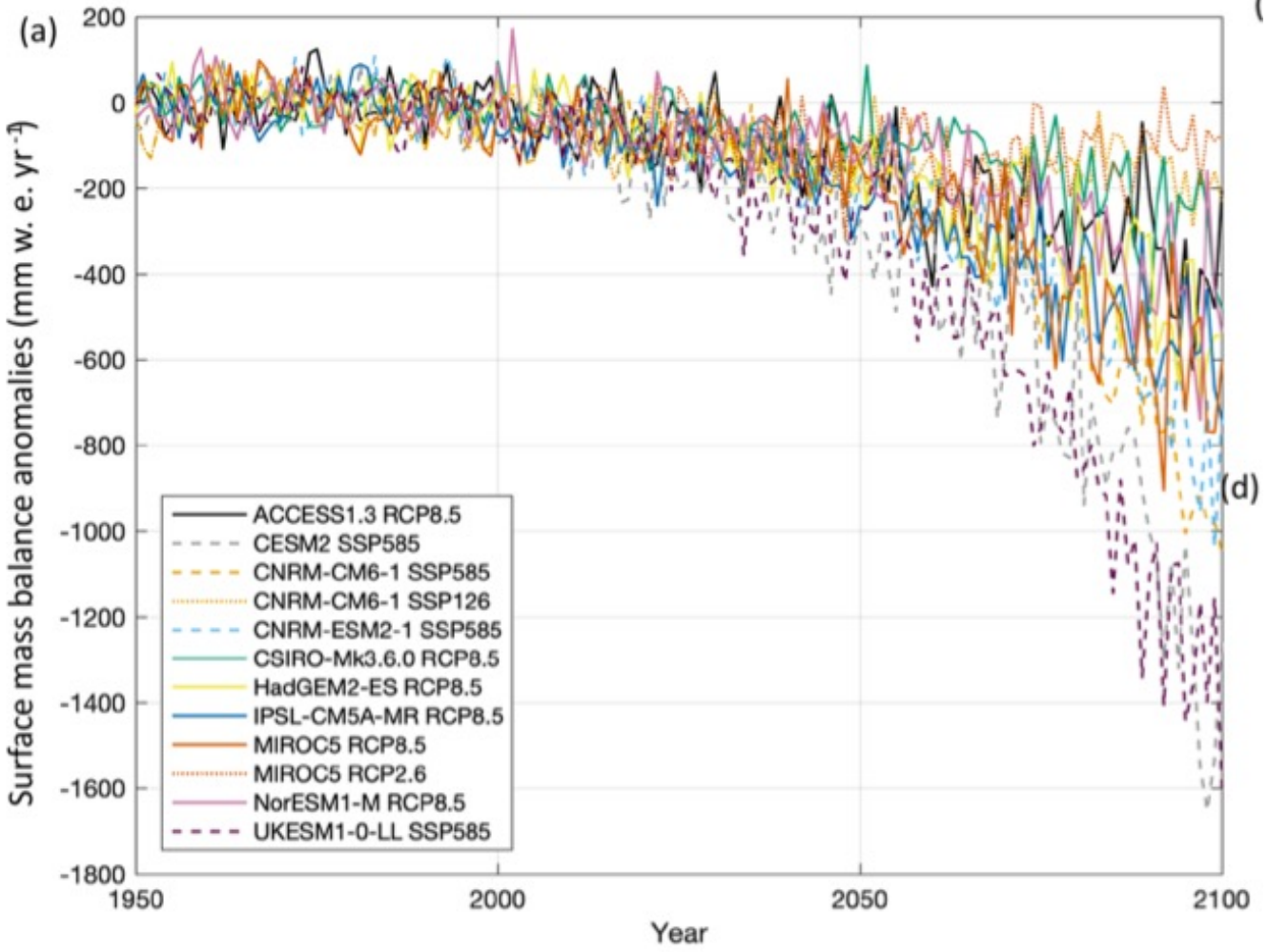
GrSMBMIP (Fettweis, 2020)

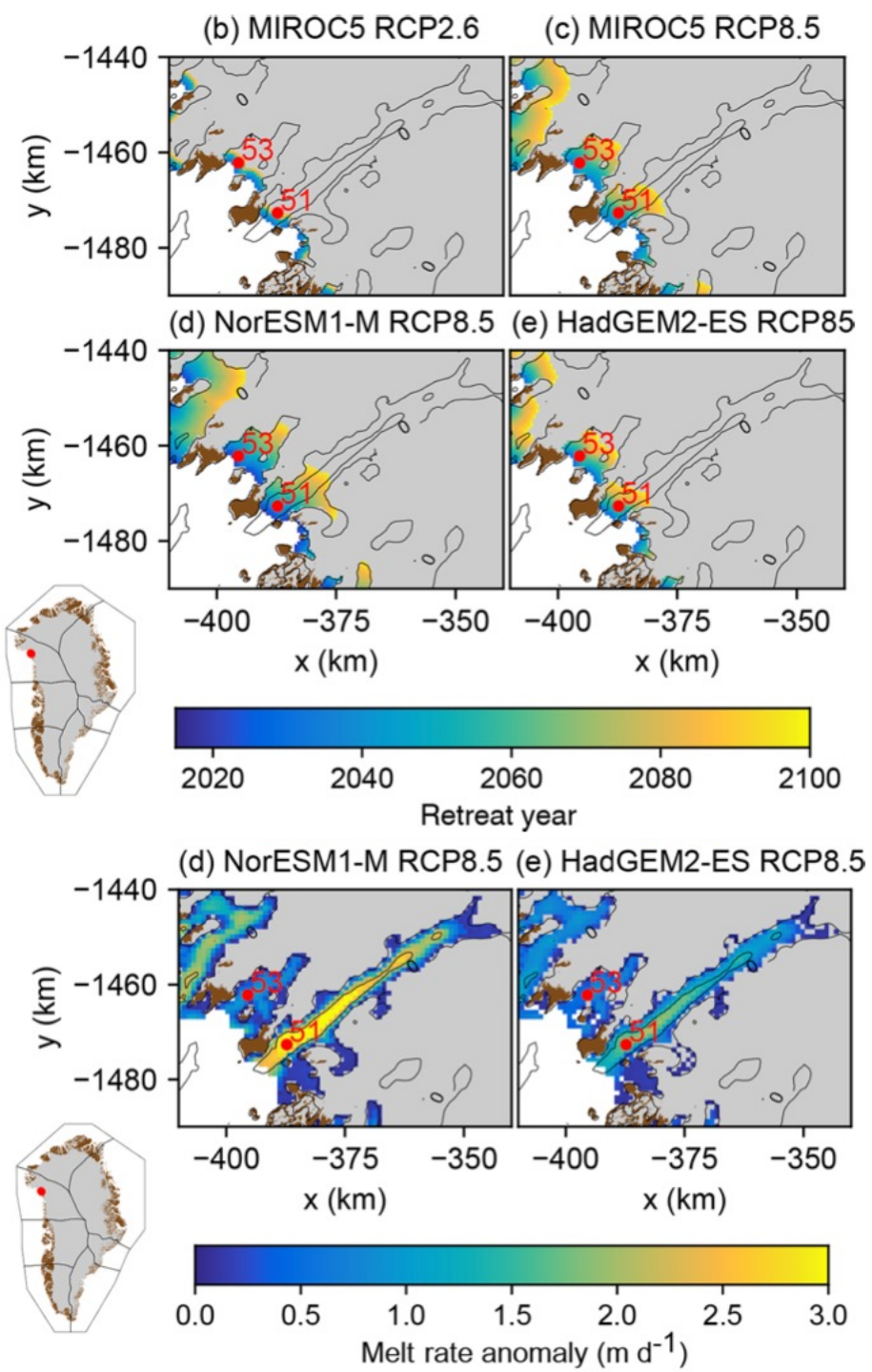




Goelzer et al., 2020

What are the challenges? Future atmospheric and ocean forcing, calving etc…



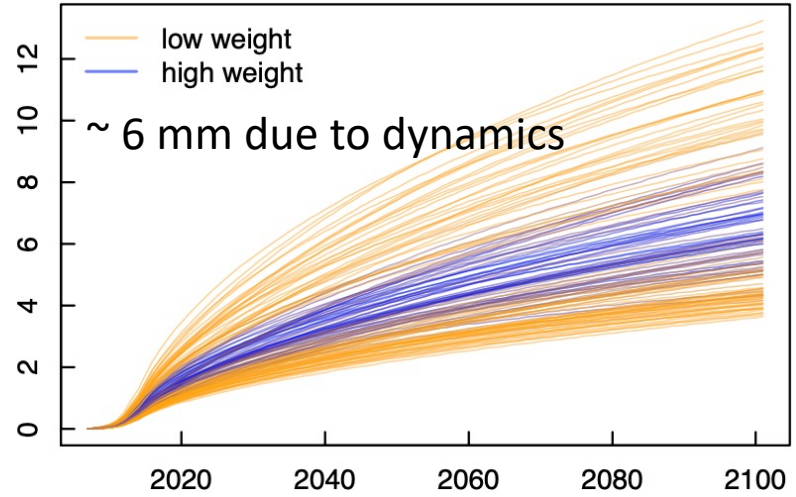


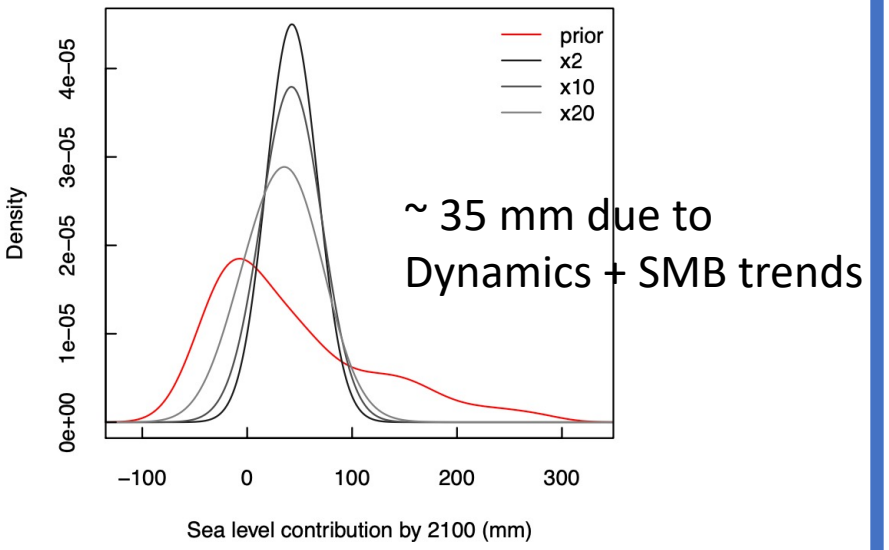
Nowicki et al. (2020), Barthel et al. (2020), Slater et al. (2019, 2020)

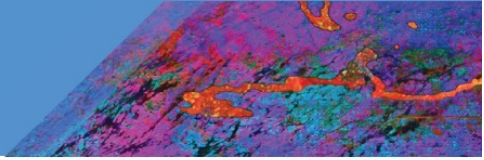
Challenges & research priorities

- Reproducing historical ISM:
  - Older observational datasets
  - Improved climatic forcing
- Assign weights or calibrated projections? How best to do that?
- Improving polar climate in ESM is key:
  - Inputs to RCMs, but beyond 2100, really need to have evolving ice sheets
  - RCMs include another layer of uncertainty, so can we by-pass RCMs?
- How to make progress with respect to “deep uncertainty”?
- …

How much is the committed sea level, that needs to be added back to ISMIP6 simulations? From large ensemble and GRACE calibration (Nias et al. in prep):







Methods (Table 9.7)

Driver of Global-Mean or Regional Sea-Level change	SROCC Projection Method	AR6 Projection method
Thermal expansion (Section 9.2.4.1)	CMIP5 ensemble drift-corrected zostoga, with surrogates derived from climate system heat content where not available	Two-layer emulator with climate sensitivity calibrated to the AR6 assessment (Appendix 7.A.2) and expansion coefficients calibrated to emulate CMIP6 models (Appendix 9.A.4.2, 9.A.4.3)
Greenland ice sheet (excluding peripheral glaciers) (Section 9.4.1.3; 9.4.1.4)	Surface mass balance: scaled cubic polynomial fit to GMST Dynamics: Quadratic function of time, calibrated based on multimodel assessment	Medium confidence processes up to 2100: Emulated ISMIP6 simulations (Box 9.3) (Edwards et al., 9998) Medium confidence processes after 2100: Parametric model fit to ISMIP6 simulations up to 2100, extrapolated based on either constant post-2100 rates or a quadratic interpolation to multimodel assessed 2300 range (Appendix 9.A.4.4) Low confidence processes: Structured expert judgement (Bamber et al., 2019)
Antarctic ice sheet (excluding peripheral glaciers[a]) (Section 9.4.2.5; 9.4.2.6)	Multimodel assessment	Medium confidence processes up to 2100: p-box including (1) Emulated ISMIP6 simulations (Edwards et al., 9998) and (2) LARMIP-2 simulations (Levermann et al., 2020a) augmented by AR5 surface mass balance model (Box 9.3) Medium confidence processes after 2100: p-box including (1) AR5 parametric AIS model and (2) LARMIP-2 simulations augmented by AR5 surface mass balance model, with both methods extrapolated based on either constant post-2100 rates or a quadratic interpolation to multimodel assessed 2300 range (Section 9.6.3.2) Low confidence processes: (1) Single ice-sheet-model ensemble simulations incorporating Marine Ice Cliff Instability (DeConto et al., 9998) and (2) structured expert judgement (Bamber et al., 2019)
Glaciers (including peripheral glaciers) (Section 9.5.1.3)	Power law function of integrated GMST fit to glacier models	Up to 2100: Emulated GlacierMIP (Marzeion et al., 2020; Edwards et al., 9998) simulations (Box 9.3) Beyond 2100: AR5 parametric model re-fit to GlacierMIP (Marzeion et al., 2020) (Appendix 9.A.4.5)
Land water storage (Section 9.6.3.2)	Groundwater depletion: combination of (1) continuation of early 21st century trends and (2) land-surface hydrology models (Wada et al., 2012) Water impoundment: combination of (1) continuation of historical rate and (2) assumption of no net impoundment after 2010	Groundwater depletion: Population/groundwater depletion relationship calibrated based on (Konikow, 2011; Wada et al., 2012, 2016) Water impoundment: Population/dam impoundment relationship calibrated based on (Chao et al., 2008), adjusted for new construction following (Hawley et al., 2020) for 2020 to 2040
Ocean dynamic sea level (Section 9.2.4.2)	CMIP5 ensemble zos field after polynomial drift removal	Distribution derived from CMIP6 ensemble zos field after linear drift removal (see Appendix 9.A.4.2, 9.A.4.3)
Gravitational, rotational, and deformational effects (Section 9.6.3.2)	Sea-level equation solver (Slangen et al., 2014a) driven by projections of ice sheet, glacier, and land water storage changes	
GIA and other drivers of VLM (Section 9.6.3.2)	GIA model, with ice history from mean of ANU and ICE-5G	Spatiotemporal statistical model of tide-gauge data (updated from (Kopp et al., 2014)) (Appendix 9.A.4.6)