Probabilistic sea-level rise projections for the Chesapeake Bay region

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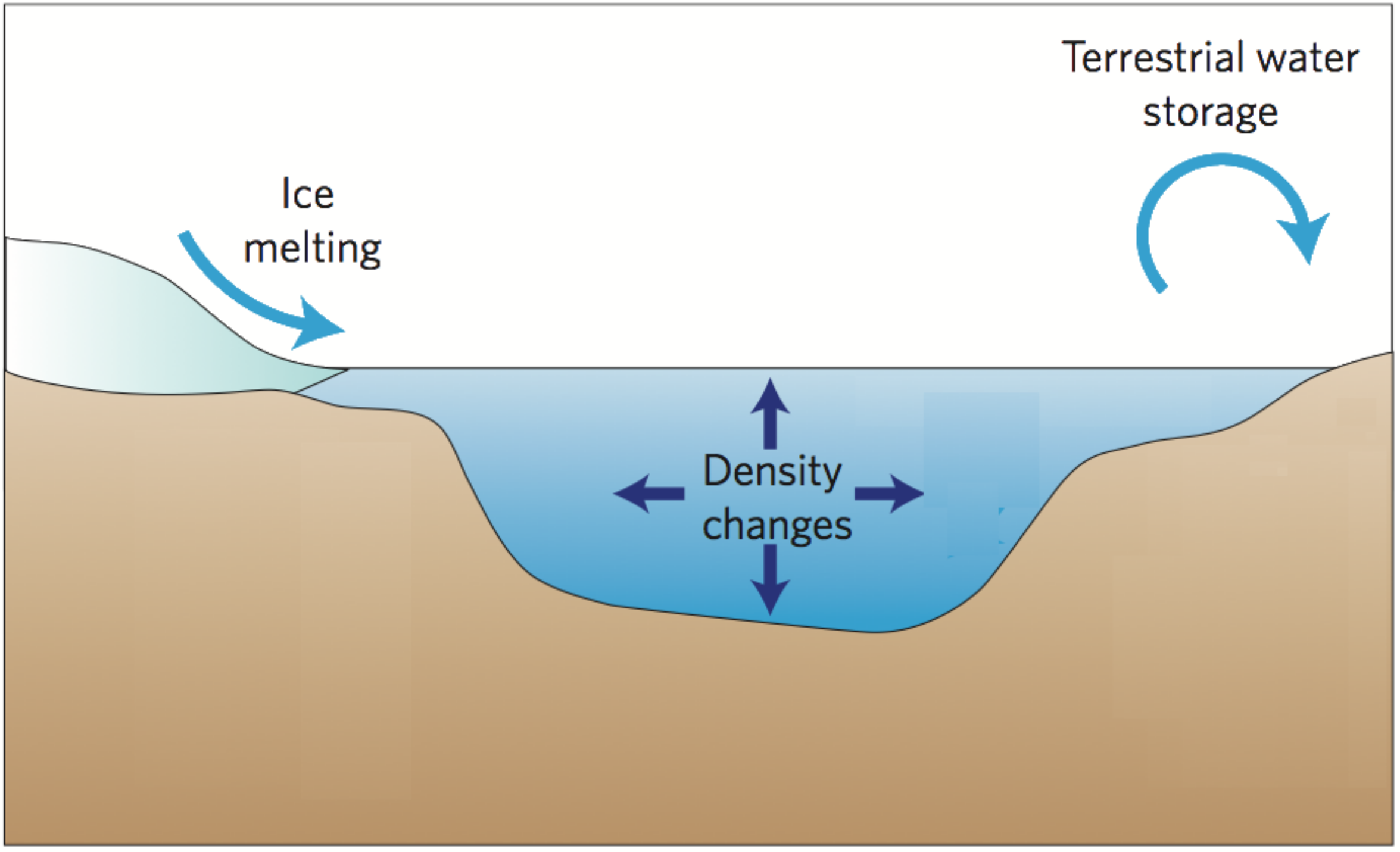
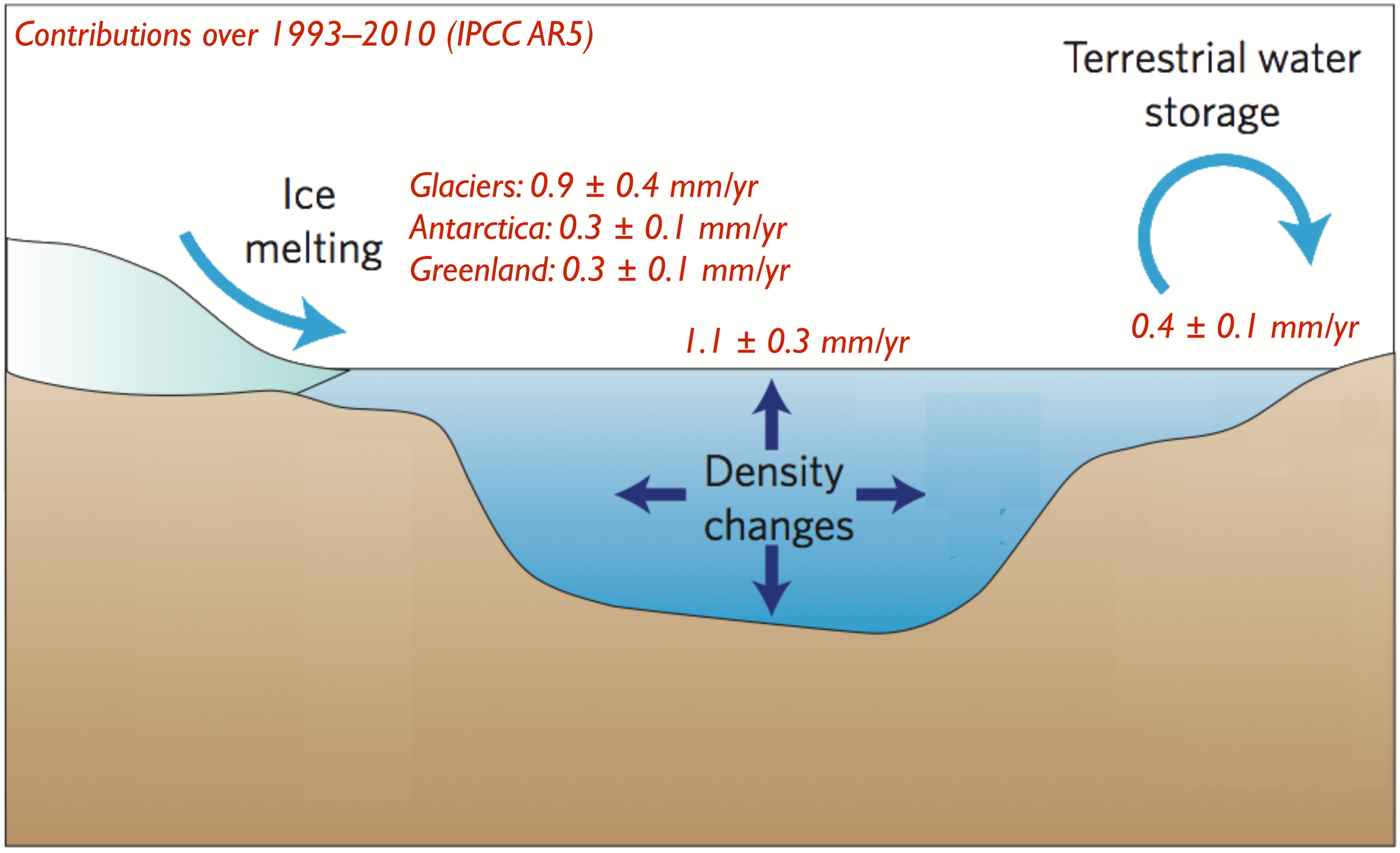
Chesapeake Bay Program Climate Resiliency Working Group
23 May 2016

Sources of global sea-level change (and uncertainty)



Milne et al. 2009

Sources of global sea-level change (and uncertainty)



Milne et al. 2009

Total Land Ice Hazard

Non-polar glaciers and ice caps	~26 cm [10”]
Greenland & Antarctic glaciers and ice caps	~46 cm [18”]
Greenland Ice Sheet	7 m [23’]
West Antarctic Ice Sheet	5 m [16’]
East Antarctic Ice Sheet	52 m [171’]

Lemke et al. (2007); Bamber et al. (2001); Lythe et al. (2001)
Harig & Simons (2012, 2015, polarice.princeton.edu)

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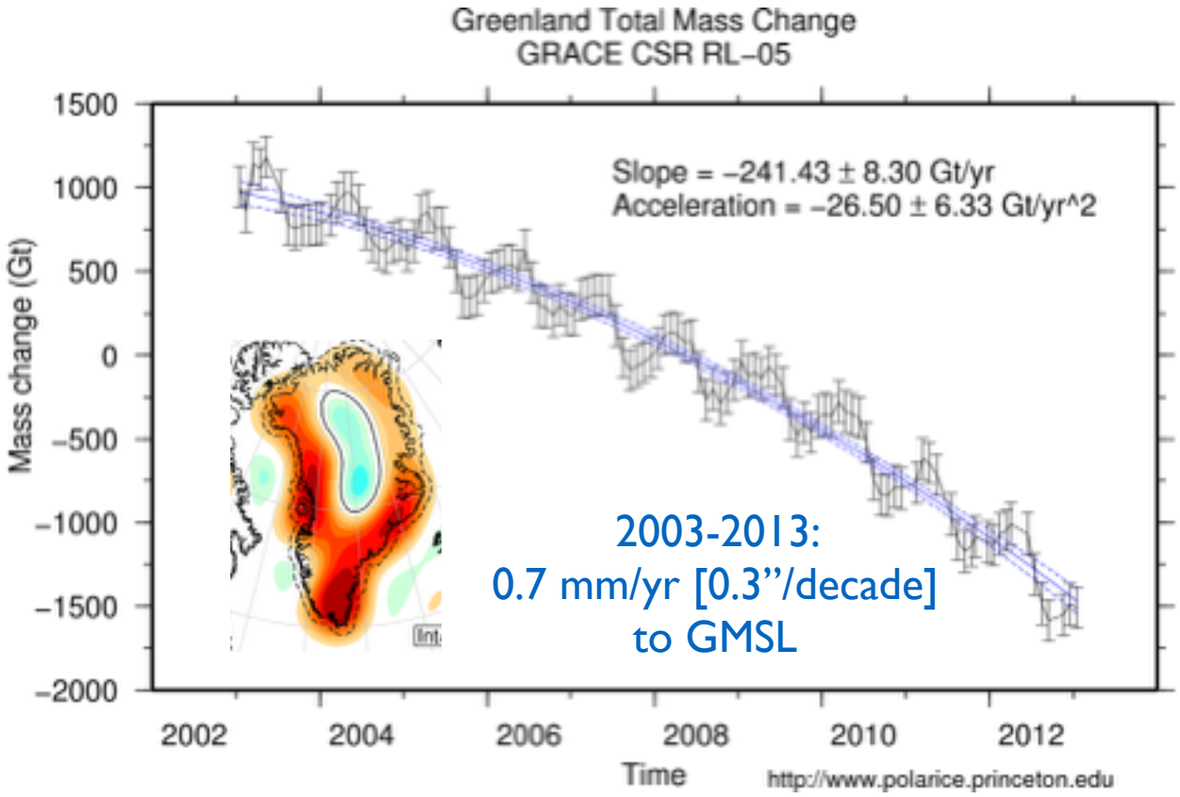

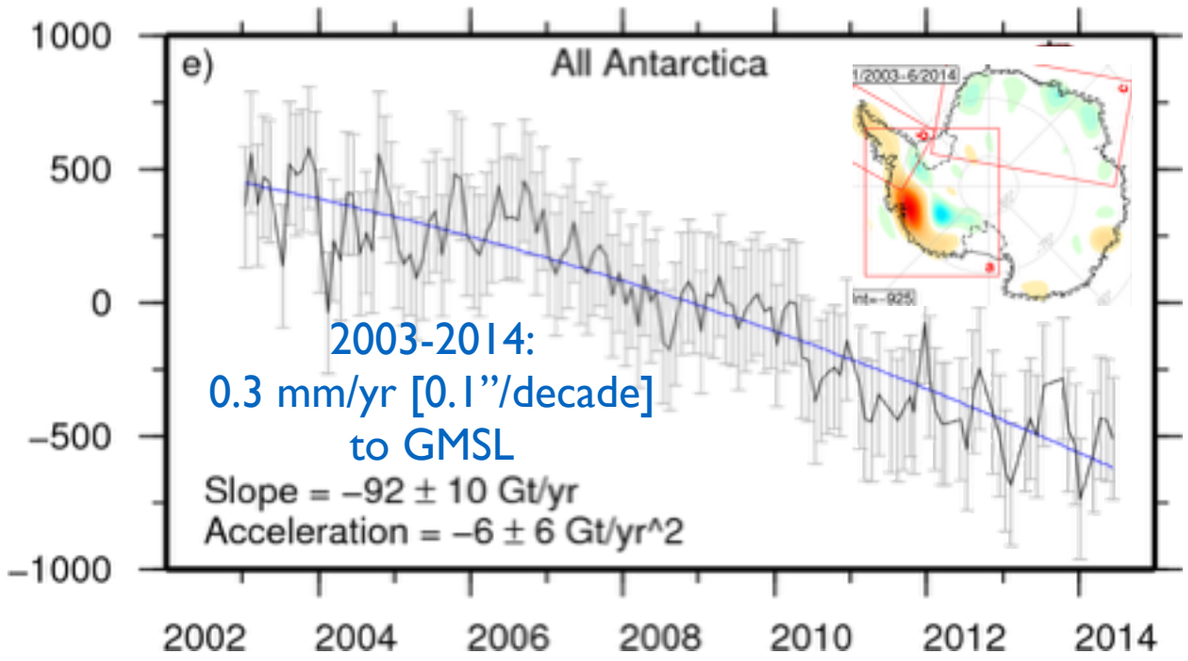

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Harig & Simons (2012, 2015, polarice.princeton.edu)

We need to synthesize multiple lines of knowledge to estimate future global sea-level rise

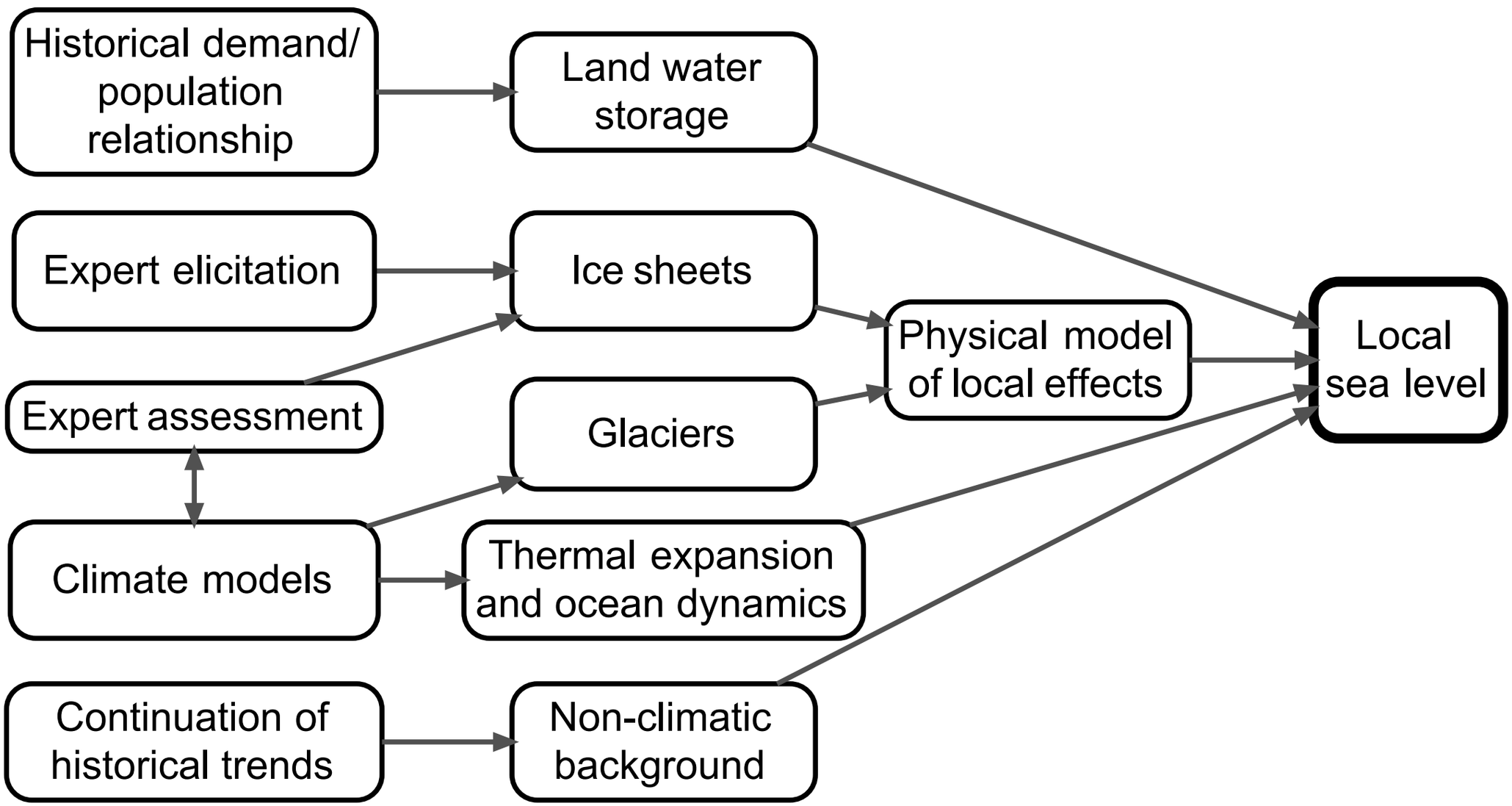
Earth's Future

RESEARCH ARTICLE
10.1002/2014EF000239

Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites

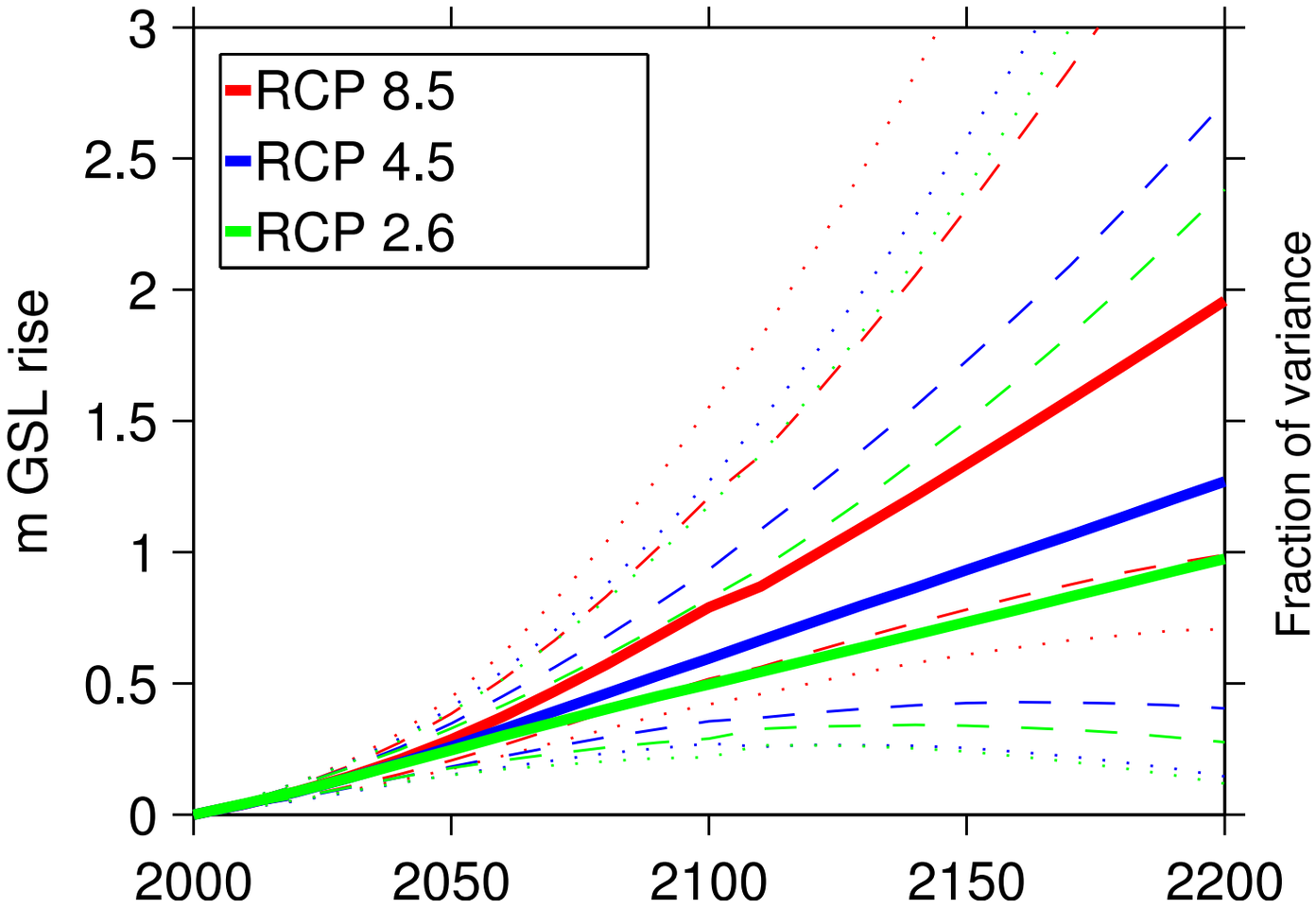
Robert E. Kopp[1], Radley M. Horton[2], Christopher M. Little[3], Jerry X. Mitrovica[4], Michael Oppenheimer[3], D. J. Rasmussen[5], Benjamin H. Strauss[6], and Claudia Tebaldi[6,7]

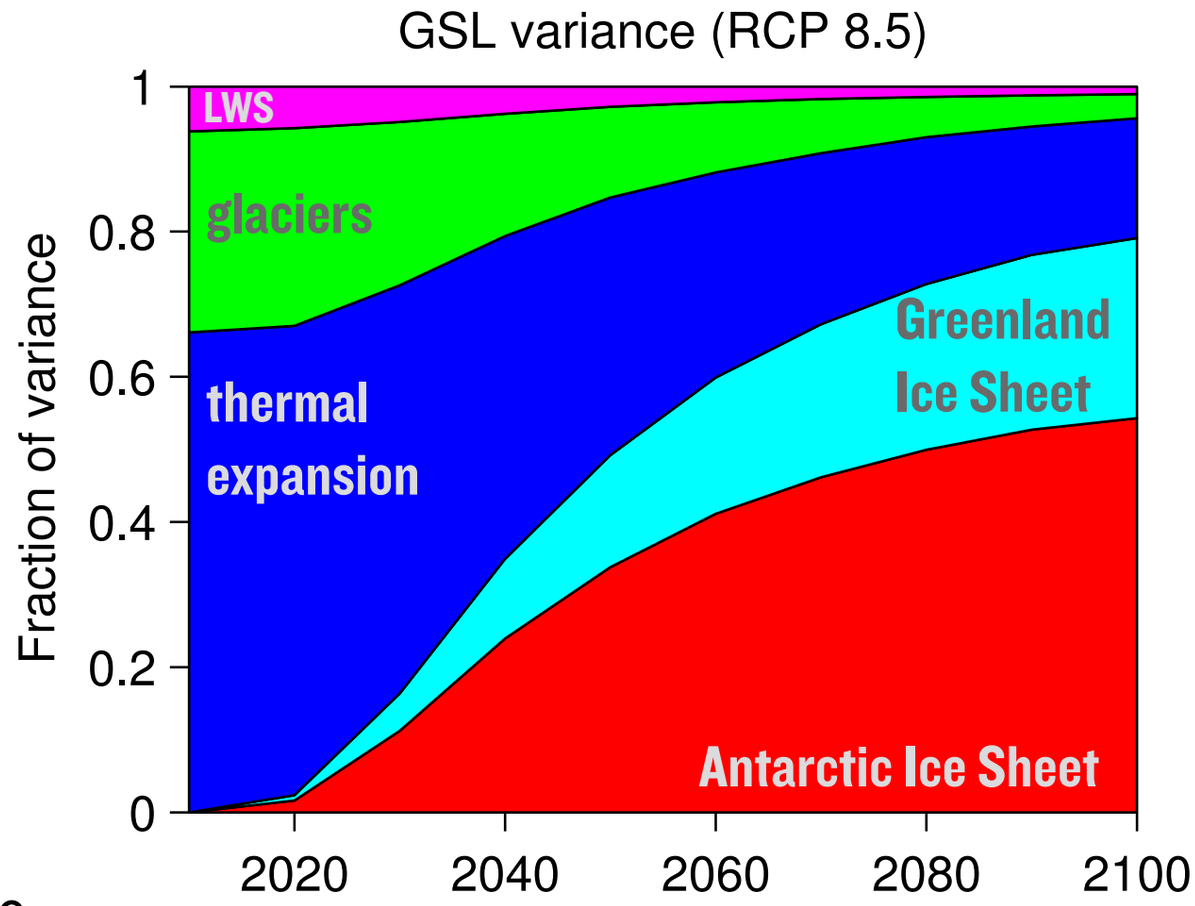
Key Points:
- Rates of local sea-level rise differs



Kopp et al. 2014

Projected GMSL rise and sources of uncertainty

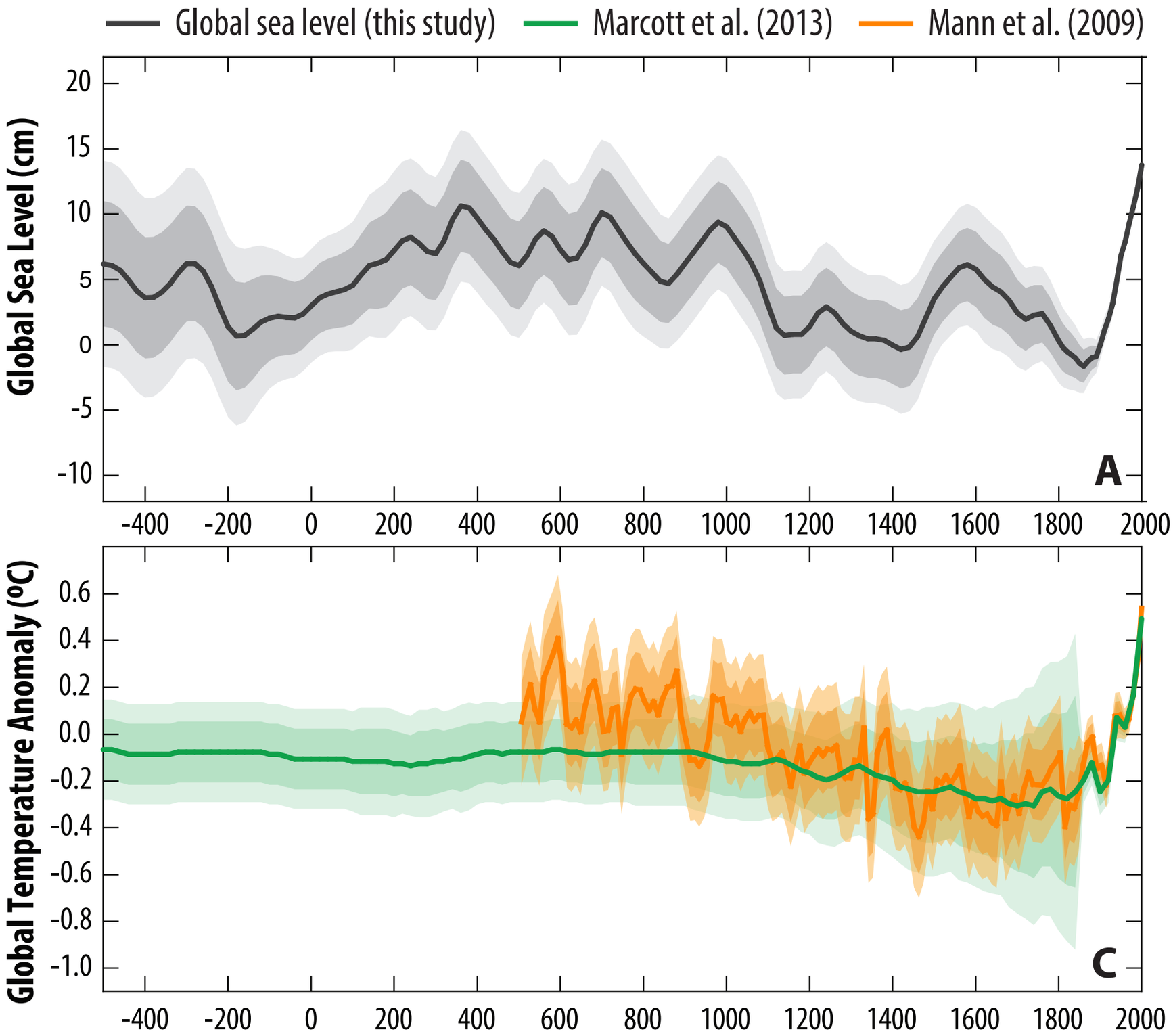




GMSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2100, RCP 8.5 (high emissions)	24”-39” (62-100 cm)	48” (121 cm)	69” (176 cm)	96” (245 cm)
2100, RCP 2.6 (low emissions)	14”-26” (37-65 cm)	32” (82 cm)	56” (141 cm)	83” (210 cm)

Kopp et al. 2014

One alternative approach: Semi-empirical models look at past relationship between temperature, GSL



Kopp et al. 2016

Broad agreement with semi-empirical estimates based on the Common Era record – which either increases confidence in projections or raises concern that expert PDFs are overly narrow

GMSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2100, RCP 8.5 (high emissions)	24”-39” (62-100 cm)	48” (121 cm)	69” (176 cm)	96” (245 cm)
semi-empirical	*23”-41” (59–105 cm)*	*52” (131 cm)*		
2100, RCP 2.6 (low emissions)	14”-26” (37-65 cm)	32” (82 cm)	56” (141 cm)	83” (210 cm)
semi-empirical	*11”-20” (28–51 cm)*	*24” (61 cm)*		

Kopp et al. 2014 and Kopp et al., 2016

But this is an area of deep uncertainty – our knowledge is still evolving!

Preliminary updates based on DeConto & Pollard (2016) projections of Antarctic contribution (interim product – final expected 2017)

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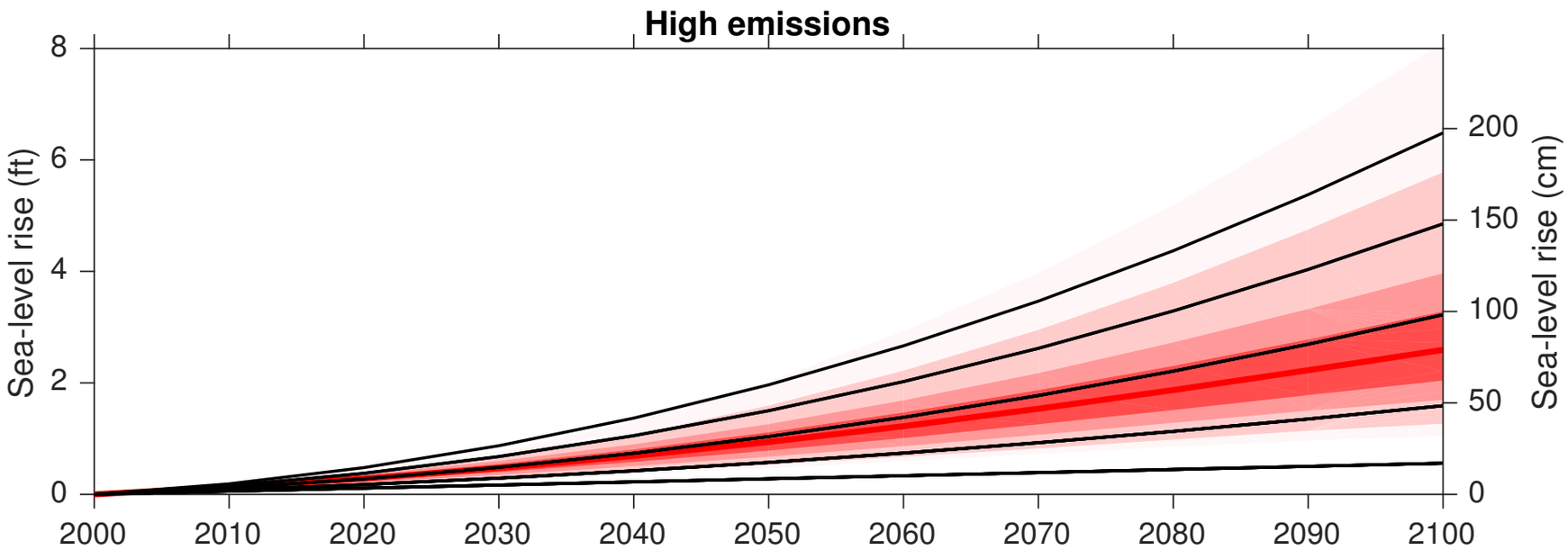
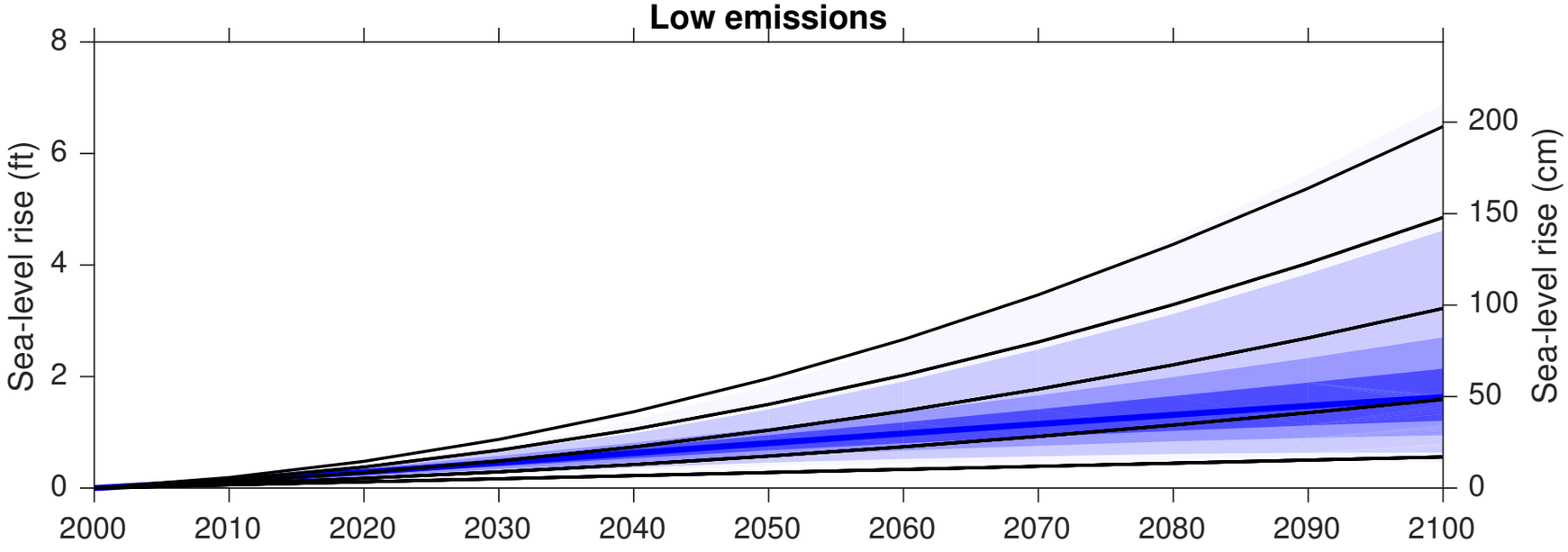
2100, RCP 8.5 (high emissions)	24”-39” (62-100 cm)	48” (121 cm)	69” (176 cm)	96” (245 cm)
interim DeConto & Pollard update	*35”-78” (90–200 cm)*			
2100, RCP 2.6 (low emissions)	14”-26” (37-65 cm)	32” (82 cm)	56” (141 cm)	83” (210 cm)
interim DeConto & Pollard update	*12”-24” (31–62 cm)*			

Kopp et al. 2014 and Kopp and DeConto, in prep.

Comparison to CARSWG global mean projections





Dark = likely (17th-83rd percentile range)
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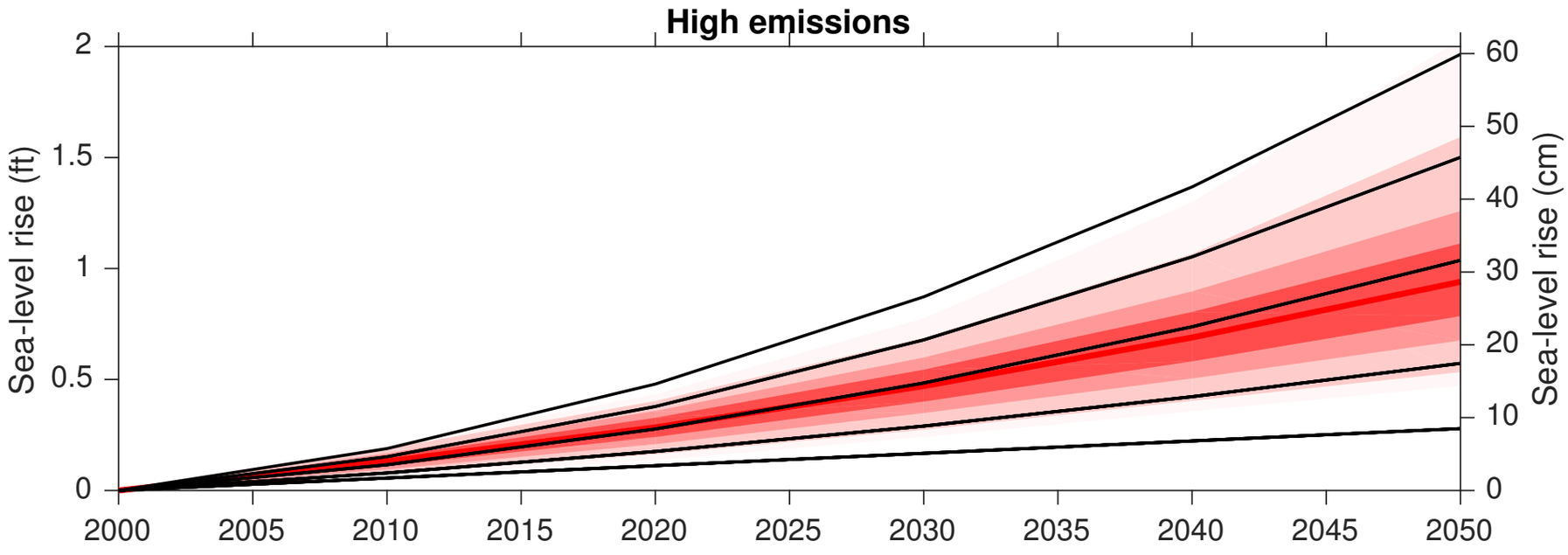
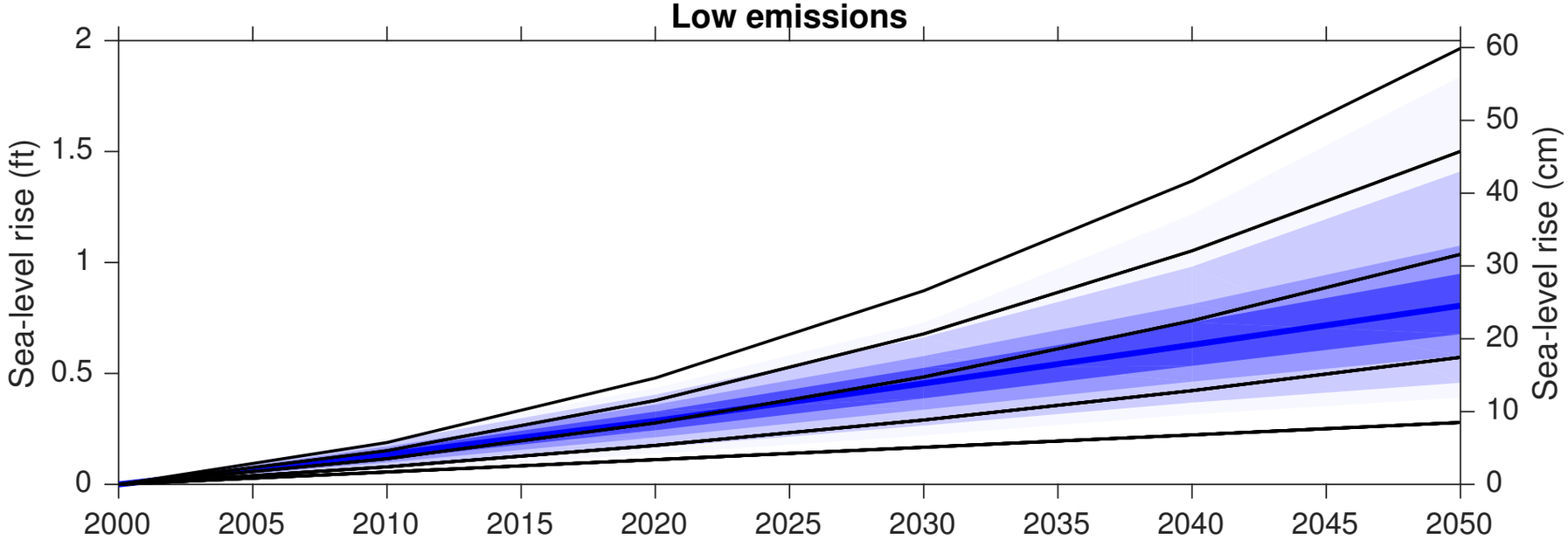
Comparison to CARSWG global mean projections





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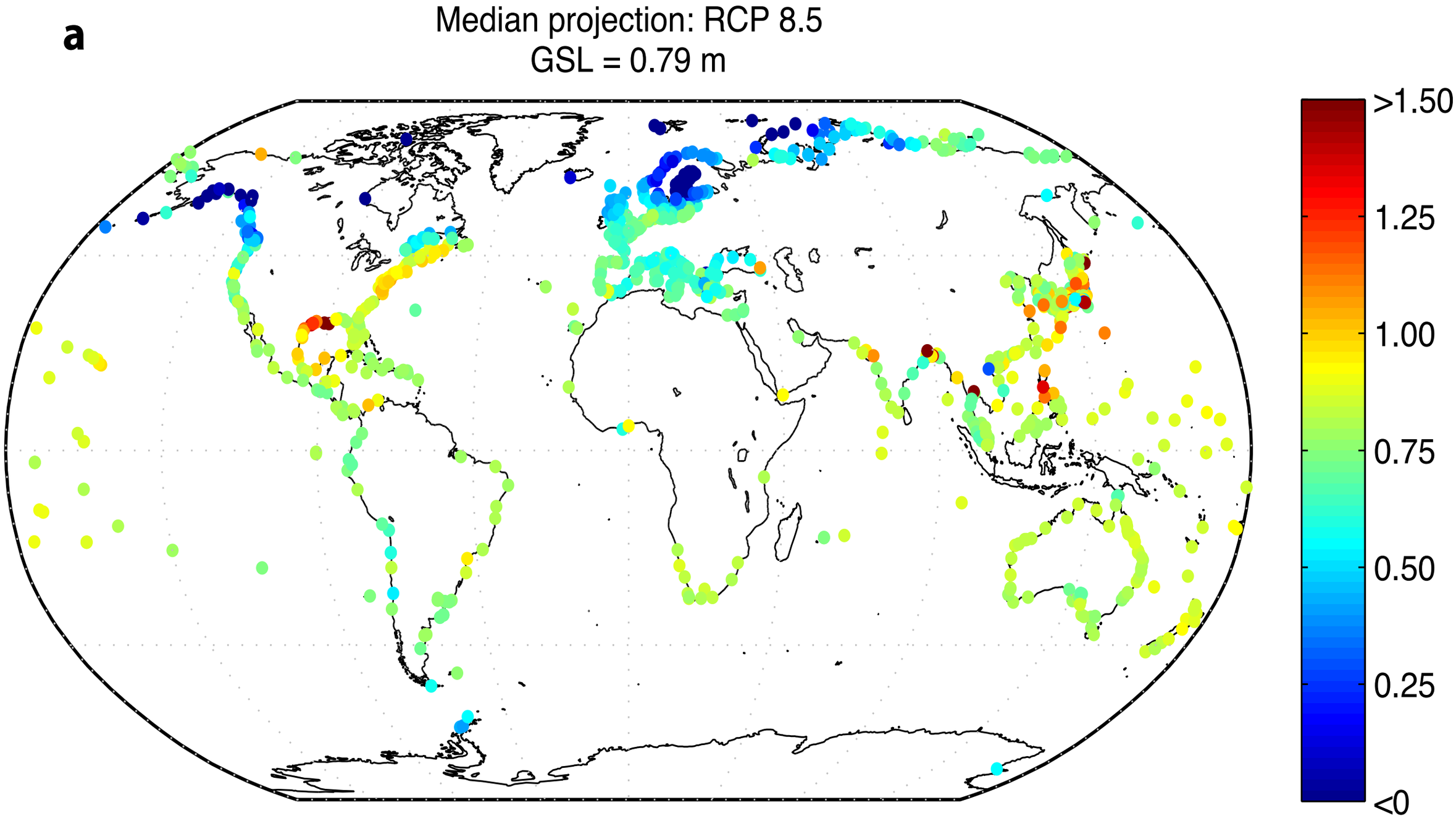
Localizing projections

Local sea-level rise projections show significant spatial variability

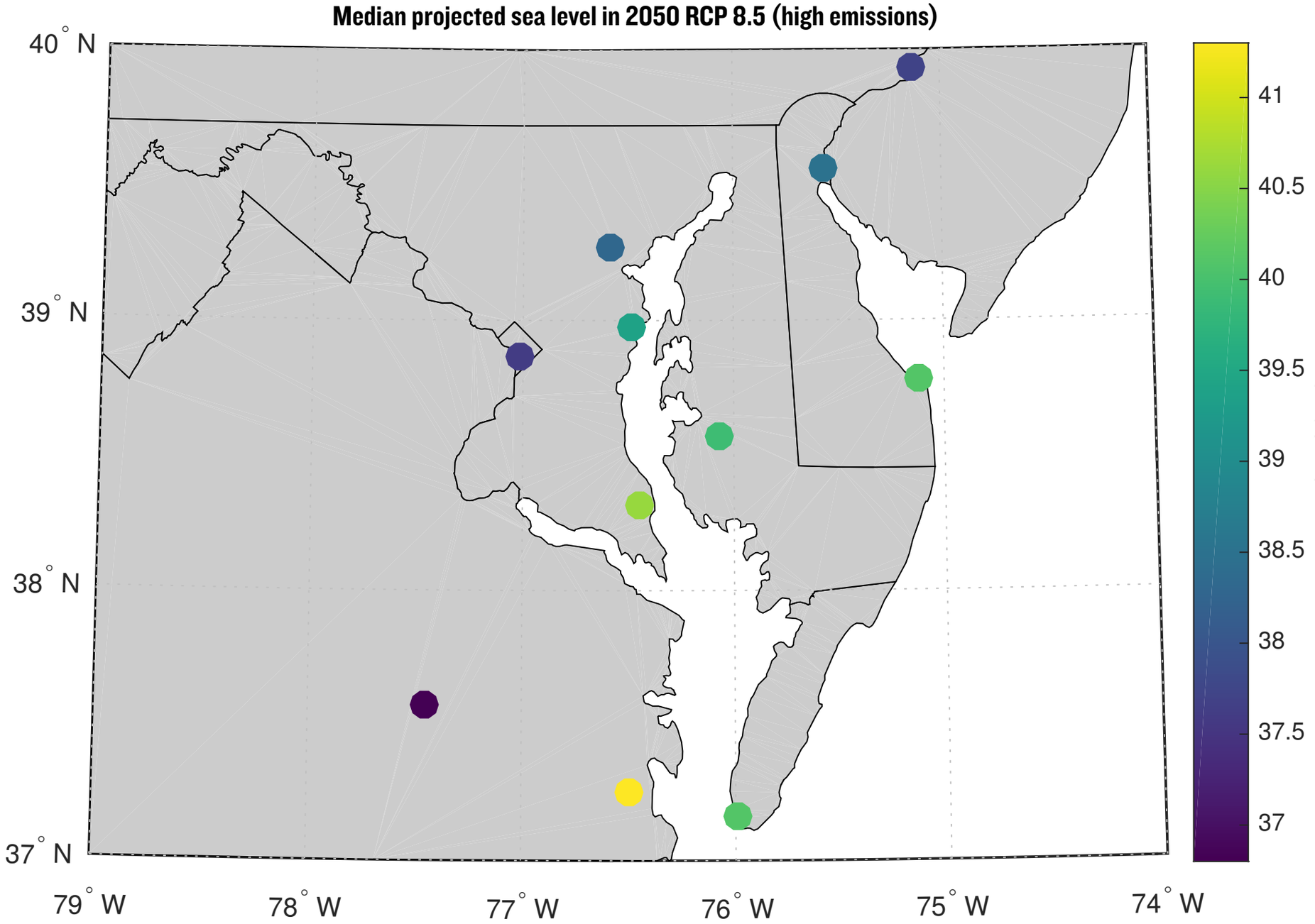


Kopp et al. 2014

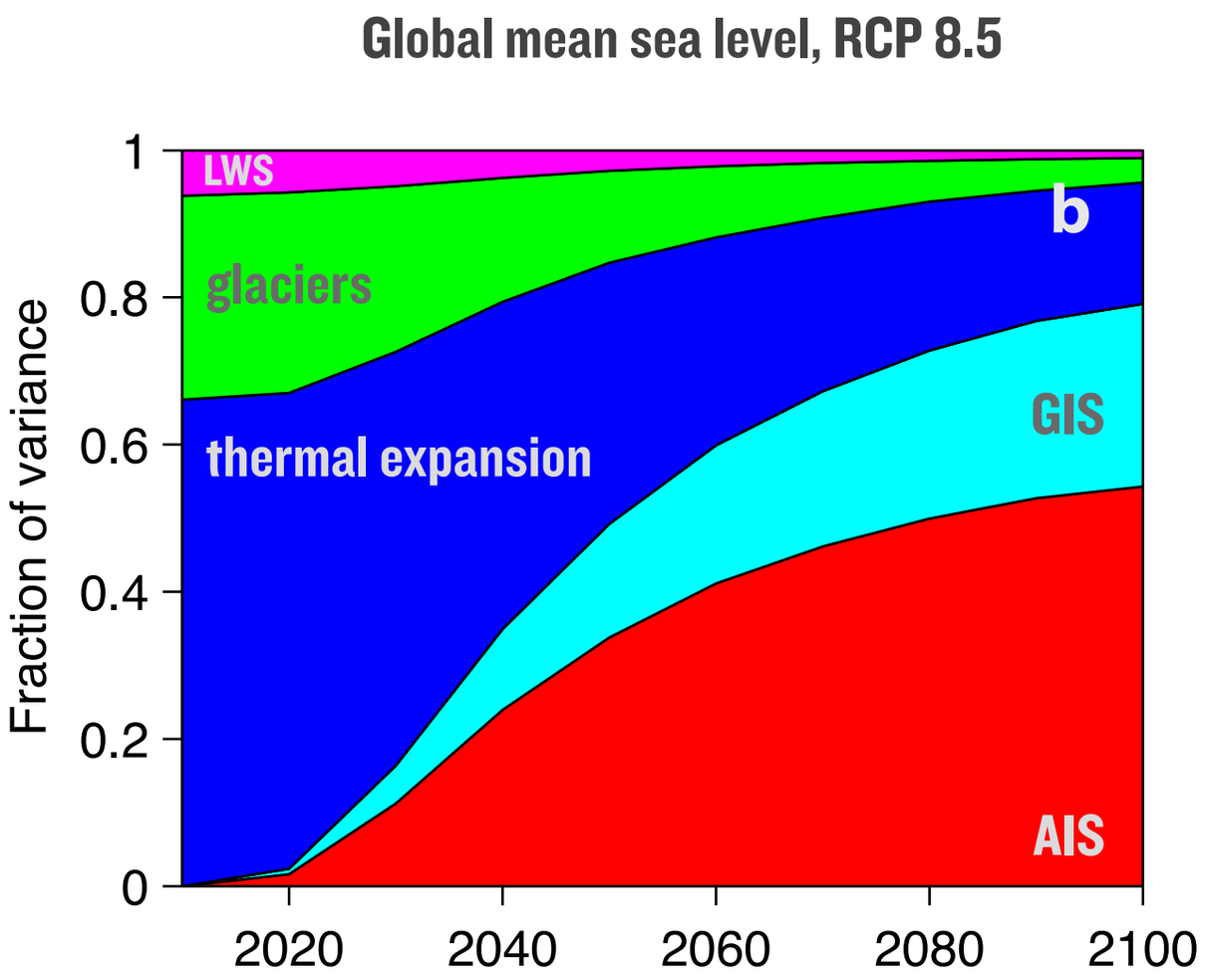
Spatial variability in Chesapeake Bay projections

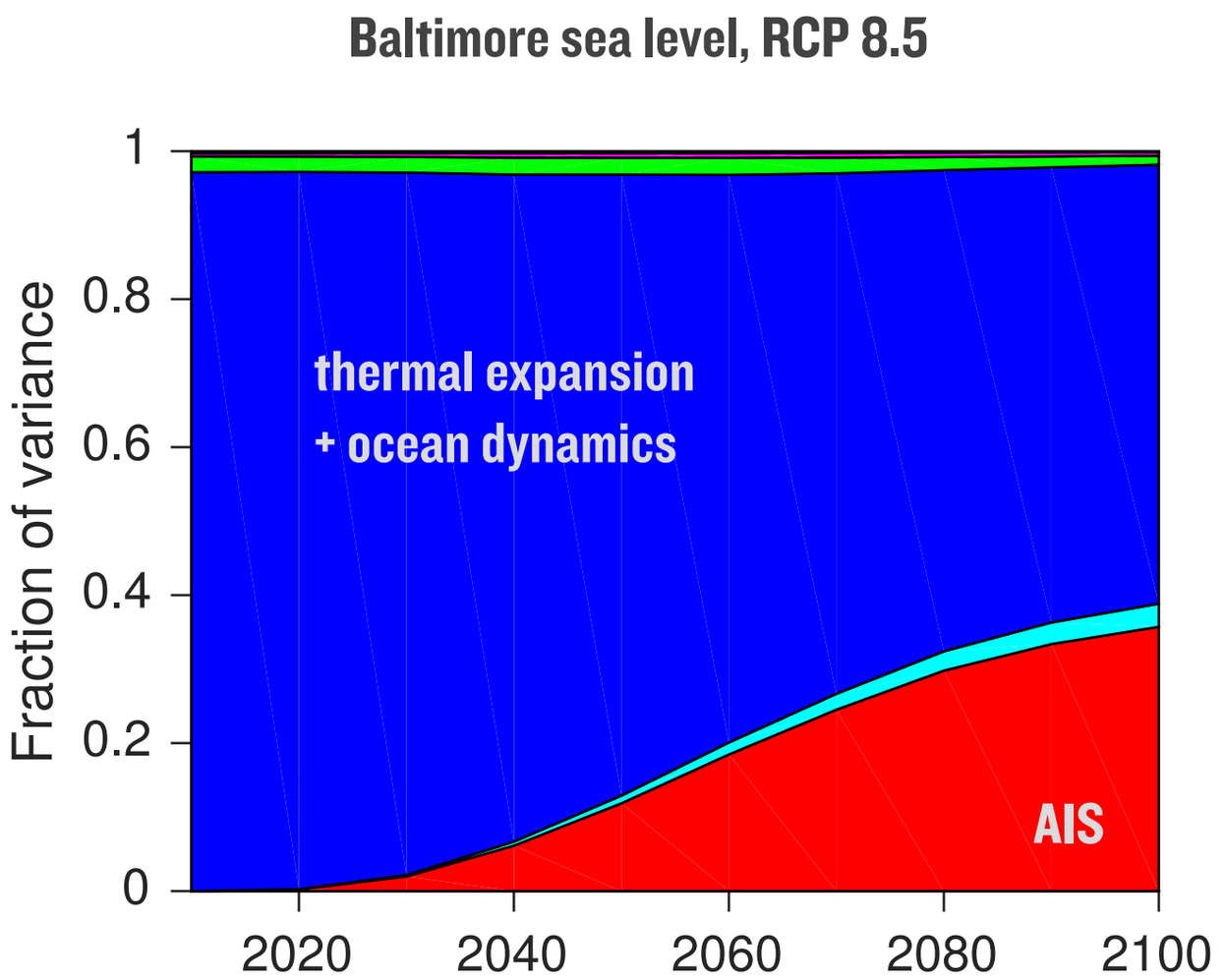
Uniformly higher than global mean due primarily to glacial-isostatic adjustment, and secondarily to ocean dynamics and ice-sheet fingerprints

Variability within region fairly small (~1 mm/yr), dominated by effects of groundwater withdrawal



Dominant sources of uncertainty can differ globally and regionally





In the Chesapeake Bay area, sea-level uncertainty is dominated by the contributions of the Antarctic ice sheet and ocean dynamics.

Kopp et al. 2014

Projections for 2020

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	5	6	7	9	10	11	12	12	13
PHILADELPHIA	1	5	8	13	18	21	25	26	29
REEDY POINT	2	6	9	13	18	21	24	26	28
BALTIMORE	4	6	9	13	17	20	23	24	26
ANNAPOLIS	4	7	10	14	18	21	24	25	26
WASHINGTON	4	7	9	13	17	19	22	23	25
LEWES	3	6	9	14	18	22	25	26	28
CAMBRIDGE II	5	8	10	14	18	20	23	24	26
SOLOMON'S ISLAND	5	8	11	14	18	21	23	24	26
RICHMOND	3	6	9	13	16	19	22	23	25
GLOUCESTER POINT	5	8	11	15	18	21	24	25	27
KIPTOPEKE BEACH	5	8	10	14	18	20	23	24	26
CHESAPEAKE BAY BR. TUN.	6	8	11	15	18	21	24	25	27
SEWELLS POINT	6	9	12	15	19	22	24	25	27
PORTSMOUTH	6	8	11	15	19	21	24	25	27
DUCK PIER OUTSIDE	5	8	11	15	18	21	24	25	27
WILMINGTON	2	5	8	11	15	17	20	21	22

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Projections for 2030

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	9	11	12	14	17	18	20	21	24
PHILADELPHIA	4	9	14	21	27	32	38	39	43
REEDY POINT	6	10	15	21	27	32	37	38	42
BALTIMORE	6	11	15	21	27	31	36	37	41
ANNAPOLIS	7	11	15	21	27	32	37	38	41
WASHINGTON	7	11	15	21	26	30	35	36	39
LEWES	7	11	16	22	28	33	38	39	43
CAMBRIDGE II	8	12	16	22	27	31	36	37	41
SOLOMON'S ISLAND	9	13	17	22	28	32	36	37	41
RICHMOND	6	10	14	20	26	30	35	36	40
GLOUCESTER POINT	9	13	17	23	28	33	37	38	42
KIPTOPEKE BEACH	8	12	16	22	28	32	36	38	41
CHESAPEAKE BAY BR. TUN.	9	13	17	23	29	33	38	39	42
SEWELLS POINT	10	14	18	24	30	34	38	40	43
PORTSMOUTH	9	13	17	23	29	34	38	39	43
DUCK PIER OUTSIDE	8	12	17	23	29	33	38	39	44
WILMINGTON	4	8	12	18	23	27	31	33	36

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Projections for 2050, high emissions (RCP 8.5)

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	17	21	24	29	34	38	45	49	62
PHILADELPHIA	11	19	27	38	49	57	67	71	80
REEDY POINT	14	21	28	39	49	56	66	70	80
BALTIMORE	14	21	28	38	48	56	65	69	80
ANNAPOLIS	15	22	29	39	49	57	66	70	81
WASHINGTON	16	22	28	38	47	54	63	67	79
LEWES	15	22	30	40	50	58	68	72	82
CAMBRIDGE II	18	24	31	40	49	56	65	69	82
SOLOMON'S ISLAND	19	25	31	41	50	57	65	69	82
RICHMOND	13	20	27	37	47	54	63	67	78
GLOUCESTER POINT	19	25	32	41	51	58	67	71	83
KIPTOPEKE BEACH	17	23	30	40	50	57	66	70	82
CHESAPEAKE BAY BR. TUN.	19	26	33	42	52	59	68	72	84
SEWELLS POINT	20	27	34	43	53	60	69	73	85
PORTSMOUTH	19	26	33	42	52	60	69	73	84
DUCK PIER OUTSIDE	18	24	31	41	51	59	68	72	83
WILMINGTON	12	18	24	33	42	48	57	61	75

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Projections for 2050, low emissions (RCP 2.6)

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	15	18	21	25	29	33	39	43	56
PHILADELPHIA	8	16	23	34	44	52	62	66	76
REEDY POINT	13	19	26	35	44	51	60	63	76
BALTIMORE	12	19	25	34	44	51	60	64	76
ANNAPOLIS	13	20	26	36	45	52	61	65	77
WASHINGTON	12	19	25	34	43	50	58	62	75
LEWES	13	20	27	36	45	53	62	66	78
CAMBRIDGE II	15	21	27	36	45	52	60	64	78
SOLOMON'S ISLAND	16	22	28	37	46	53	61	65	78
RICHMOND	10	16	23	33	43	50	59	63	74
GLOUCESTER POINT	16	22	29	38	47	54	62	66	79
KIPTOPEKE BEACH	14	21	27	36	46	53	61	66	78
CHESAPEAKE BAY BR. TUN.	17	23	30	38	47	54	63	67	80
SEWELLS POINT	18	24	31	40	48	55	64	68	81
PORTSMOUTH	17	23	30	39	48	54	63	67	80
DUCK PIER OUTSIDE	16	22	28	37	46	53	62	66	79
WILMINGTON	11	16	21	29	36	42	50	55	69

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Projections for 2100, high emissions (RCP 8.5)

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	42	52	62	79	100	121	155	176	247
PHILADELPHIA	21	43	64	93	126	151	190	209	300
REEDY POINT	28	48	67	95	125	150	190	208	295
BALTIMORE	28	48	67	94	124	148	188	207	294
ANNAPOLIS	30	50	69	97	127	151	190	210	297
WASHINGTON	28	48	66	93	122	146	186	205	292
LEWES	31	52	71	99	129	153	193	213	301
CAMBRIDGE II	34	53	71	98	127	150	190	210	296
SOLOMON'S ISLAND	35	54	72	99	128	152	192	212	298
RICHMOND	25	44	63	91	121	146	187	203	292
GLOUCESTER POINT	35	54	73	101	130	155	195	214	303
KIPTOPEKE BEACH	33	52	71	98	128	152	193	212	302
CHESAPEAKE BAY BR. TUN.	37	57	75	102	132	156	196	216	305
SEWELLS POINT	40	59	77	105	134	158	198	219	307
PORTSMOUTH	38	57	75	103	132	156	196	216	305
DUCK PIER OUTSIDE	35	54	73	100	130	154	195	214	304
WILMINGTON	26	42	58	82	109	132	170	194	281

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Projections for 2100, low emissions (RCP 2.6)

cm relative to 1991-2009 mean sea level, by percentile of projection

Site	1	5	16.7	50	83.3	95	99	99.5	99.9
Global	22	29	37	50	65	82	118	141	210
PHILADELPHIA	12	27	41	62	85	106	145	170	242
REEDY POINT	17	30	44	63	85	105	143	171	244
BALTIMORE	17	31	44	63	85	106	144	171	242
ANNAPOLIS	20	33	46	66	88	108	146	174	245
WASHINGTON	18	31	43	62	84	104	142	170	241
LEWES	20	33	47	66	89	109	148	176	248
CAMBRIDGE II	22	34	47	66	88	108	146	175	248
SOLOMON'S ISLAND	23	36	49	68	90	110	148	176	248
RICHMOND	15	28	42	61	83	103	141	169	242
GLOUCESTER POINT	24	37	50	70	92	112	150	178	251
KIPTOPEKE BEACH	21	34	47	67	90	110	149	177	250
CHESAPEAKE BAY BR. TUN.	26	39	52	71	94	114	152	181	254
SEWELLS POINT	29	42	55	74	96	116	155	183	255
PORTSMOUTH	27	40	53	72	94	114	153	181	254
DUCK PIER OUTSIDE	23	36	50	70	93	113	152	181	256
WILMINGTON	13	24	36	54	74	94	134	162	237

likely range (2-in-3 chance)

very likely range (9-in-10 chance)

worst case

Kopp et al. 2014

Summary projections: Baltimore, MD

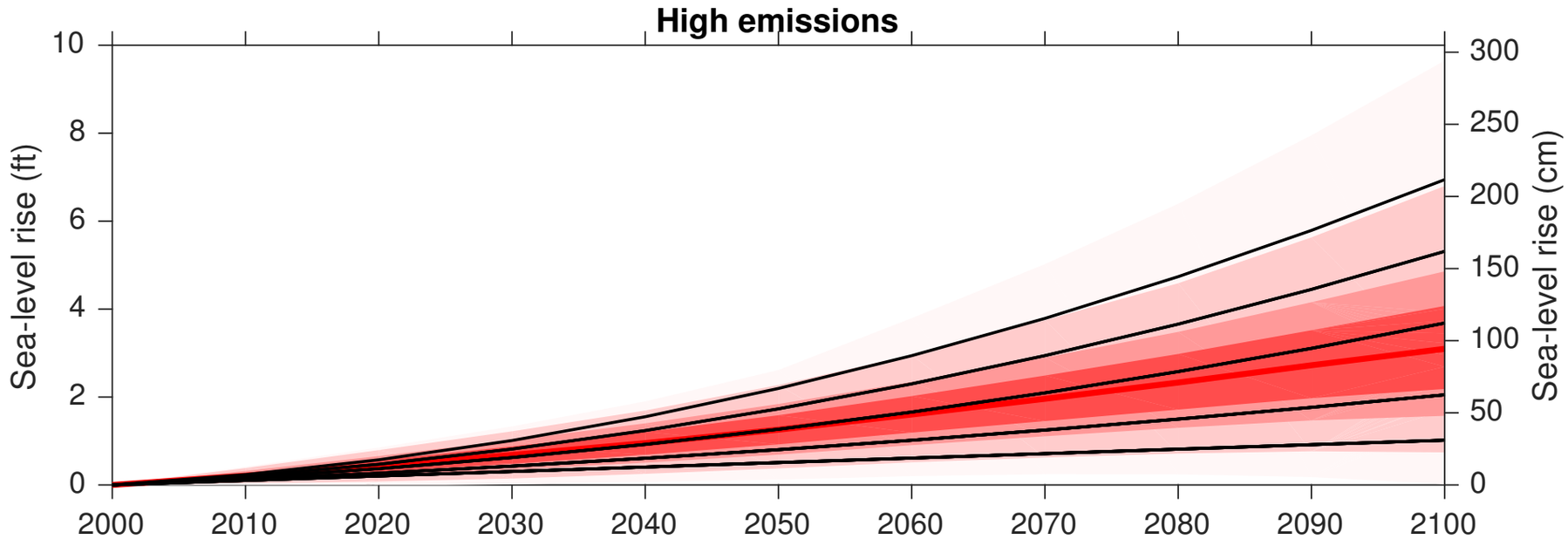
RSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2020	4”-7” (9-17 cm)	8” (20 cm)	9” (24 cm)	10” (26 cm)
2030	6”-11” (15-27 cm)	12” (31 cm)	15” (37 cm)	16” (41 cm)
2050	11”-19” (28-48 cm)	22” (56 cm)	27” (69 cm)	31” (80 cm)
2100, RCP 8.5	26”-49” (67-124 cm)	58” (148 cm)	82” (207 cm)	116” (294 cm)
2100, RCP 2.6	17”-34” (44-85 cm)	42” (106 cm)	67” (171 cm)	95” (242 cm)

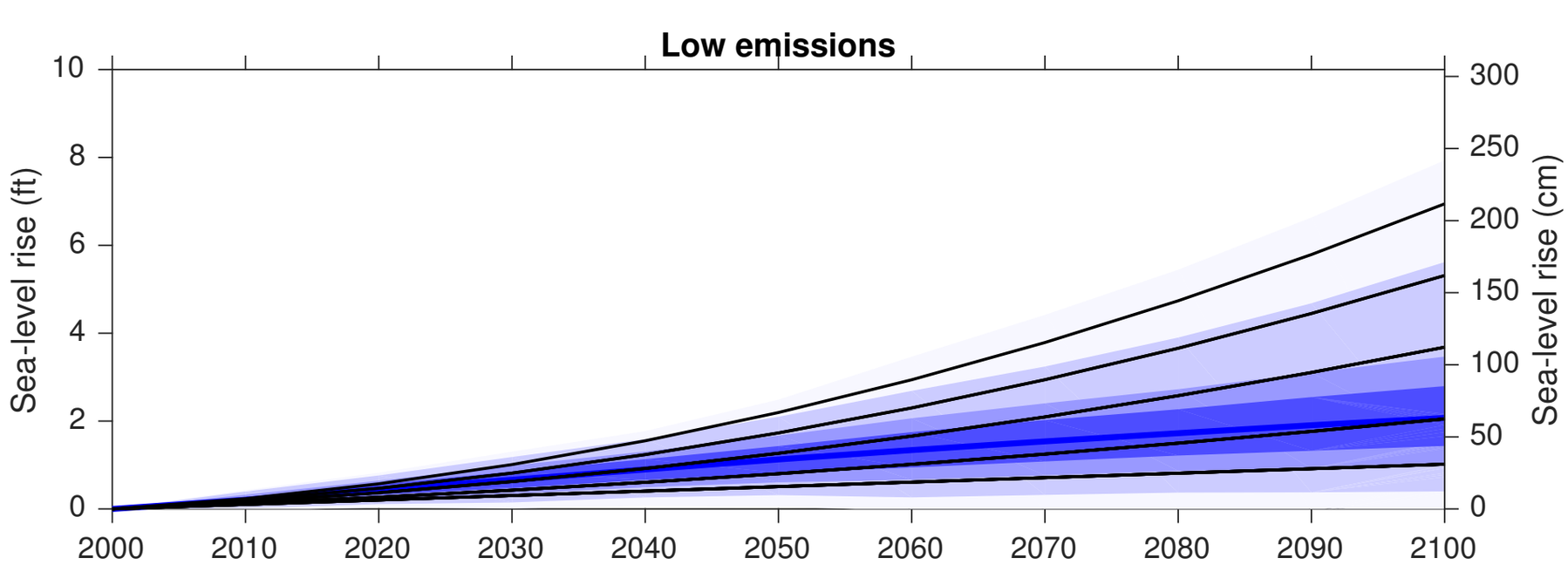
Summary projections: Sewells Point, VA

RSL rise from 2000 to:	Likely (17-83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. poss. (99.9%)
2020	5”-7” (12-19 cm)	9” (19 cm)	10” (24 cm)	11” (27 cm)
2030	7”-12” (18-30 cm)	13” (34 cm)	16” (40 cm)	17” (43 cm)
2050	13”-21” (34-53 cm)	24” (60 cm)	29” (73 cm)	33” (85 cm)
2100, RCP 8.5	30”-53” (77-134 cm)	62” (158 cm)	86” (219 cm)	121” (307 cm)
2100, RCP 2.6	21”-38” (55-96 cm)	46” (116 cm)	72” (183 cm)	101” (255 cm)

Projections through to 2050 use RCP 8.5, since difference between emissions pathways is minimal (<2”) until second half of the century.

Baltimore, MD – comparison to VLM-adjusted CARSWG





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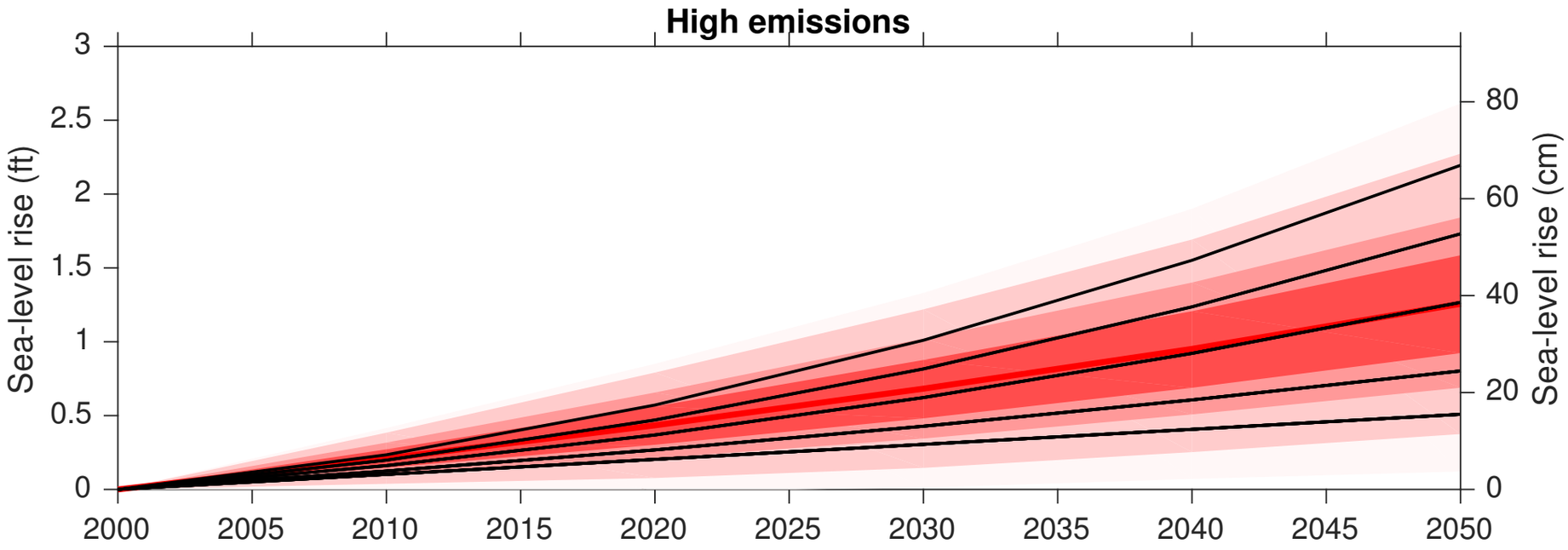

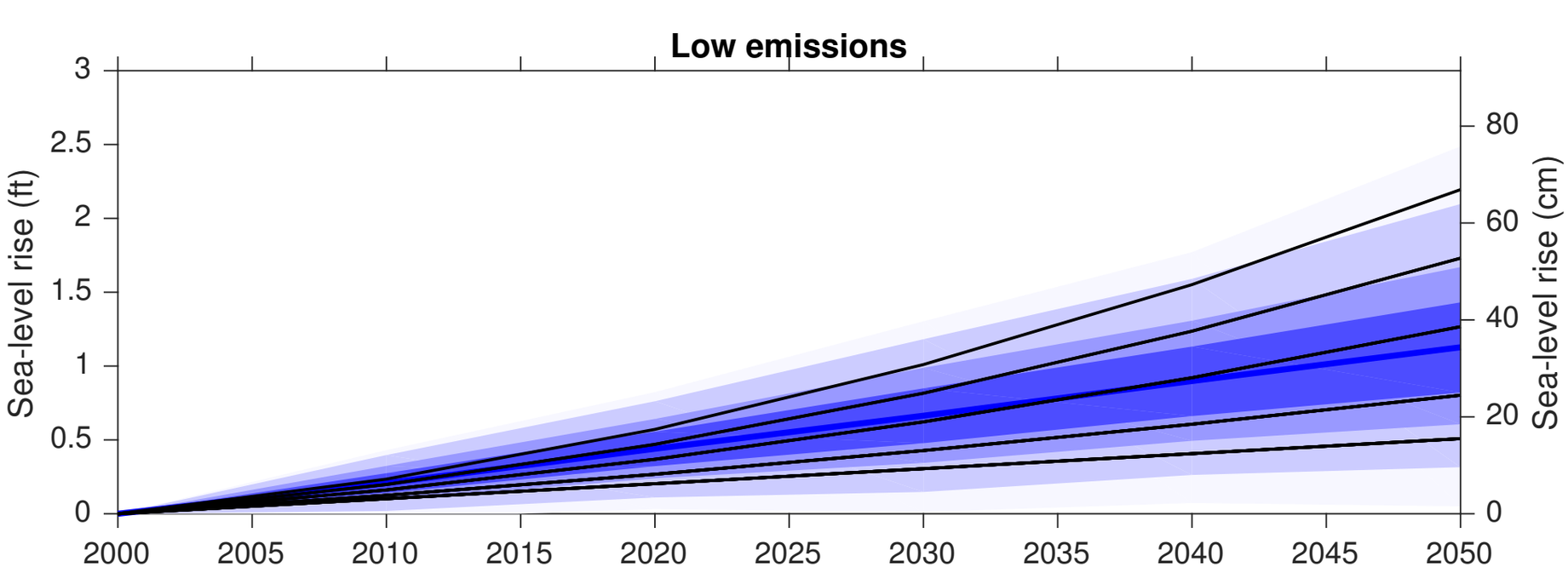

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