nature portfolio

https://doi.org/10.1038/s41558-021-01127-1

Supplementary information

Extreme sea levels at different global warming levels

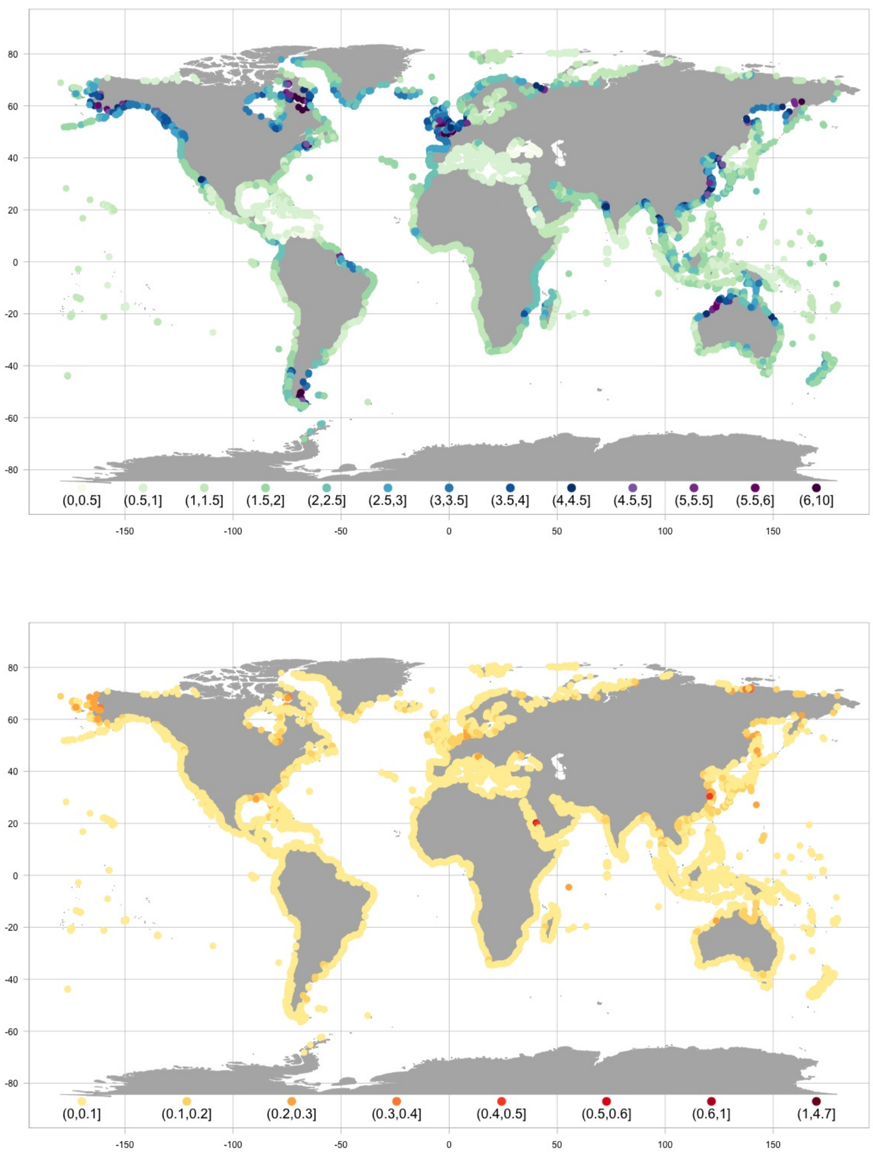
In the format provided by the authors and unedited

Extreme Sea Levels at Different Global Warming Levels
Supplementary Information

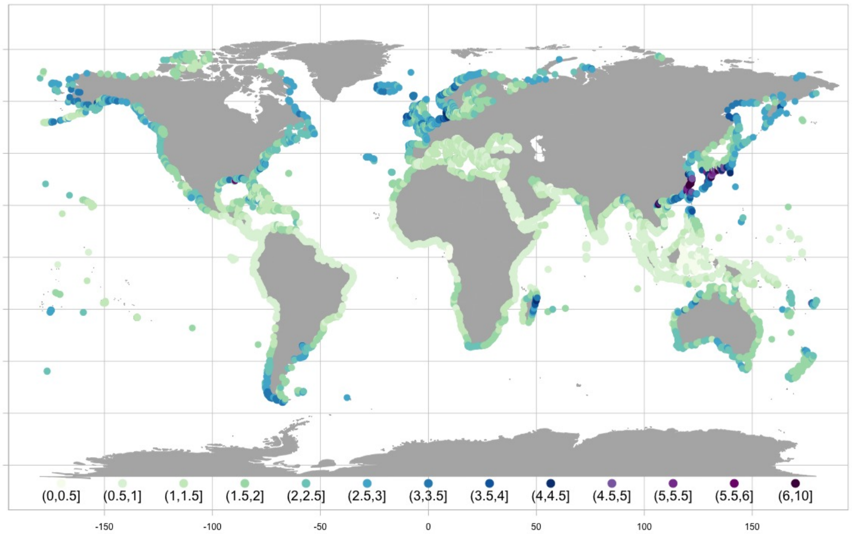
Claudia Tebaldi*[1], Roshanka Ranasinghe[2], Michalis Vousdoukas[3], DJ Rasmussen[4], Ben Vega-Westhoff[5], Ebru Kirezci[6], Robert E. Kopp[7], Ryan Sriver[5], and Lorenzo Mentaschi[3,8]

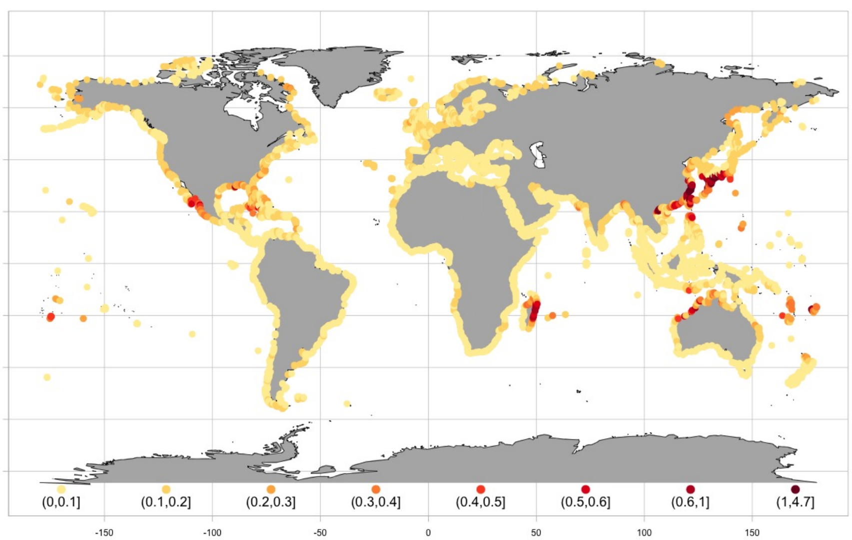
[1] Joint Global Change Research Institute, College Park, MD, USA
claudia.tebaldi@pnnl.gov
[2] Dept. of Coastal and Urban Risk & Resilience, IHE Delft institute for Water Education, Delft, The Netherlands; Harbour, Coastal and Offshore Engineering, Deltares, Delft, The Netherlands; Water Engineering and Management, Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands
[3] European Commission, Joint Research Centre (JRC), Ispra, Italy
[4] Princeton School of Public and International Affairs, Princeton University, Princeton, NJ, USA
[5] University of Illinois, Urbana-Champaign, IL, USA
[6] University of Melbourne, Melbourne, AU
[7] Rutgers Institute of Earth, Ocean, and Atmospheric Sciences and Department of Earth and Planetary Sciences, Rutgers University, New Brunswick, NJ, USA
[8] now at Department of Physics and Astronomy Augusto Righi, University of Bologna, Bologna, Italy

Supplementary Figures

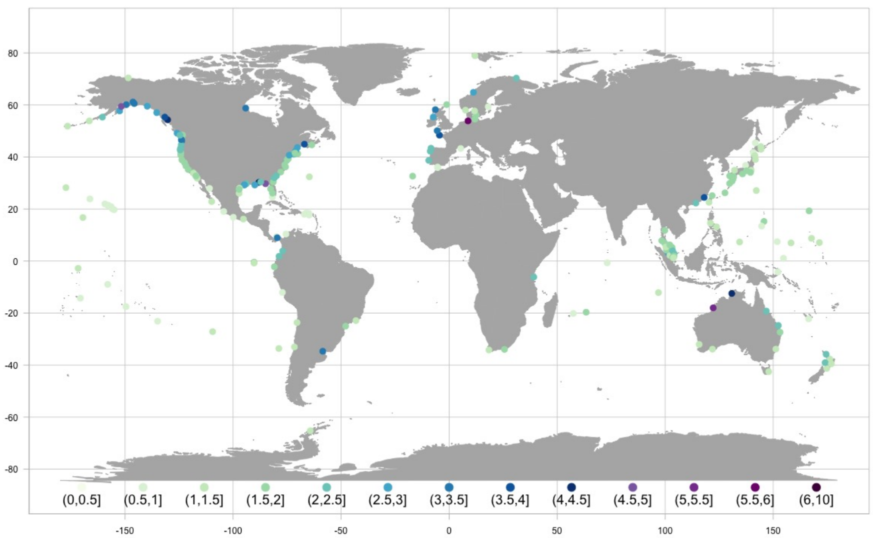


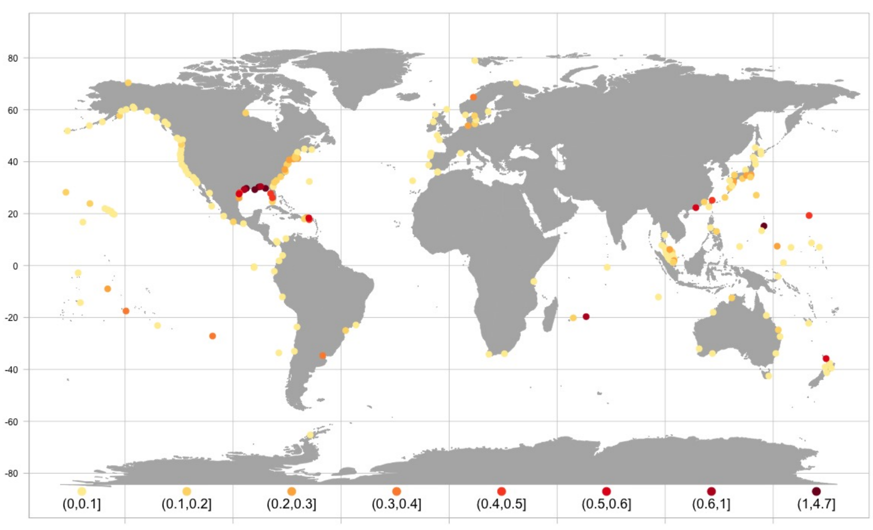
Supplementary Figure 1. ESLs from Kirezci et al.(2020). Estimates of the 100-yr ESL events (top) and their standard error (bottom) from Kirezci et al.(2020). Units for the events are meters above mean sea level; units for the standard errors are meters.



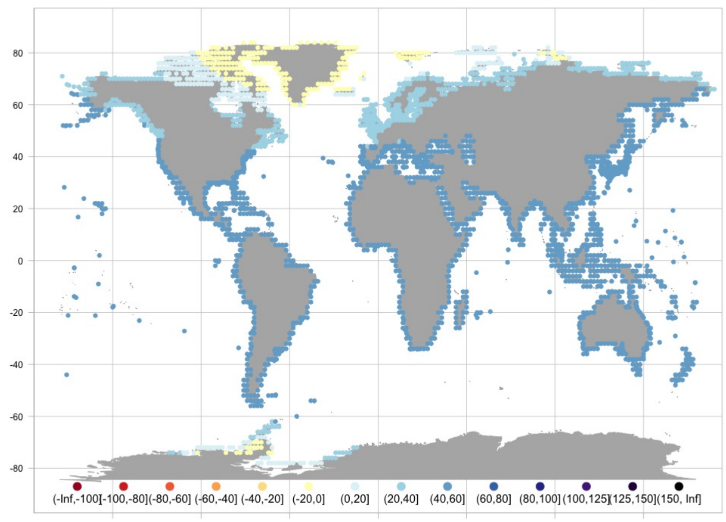


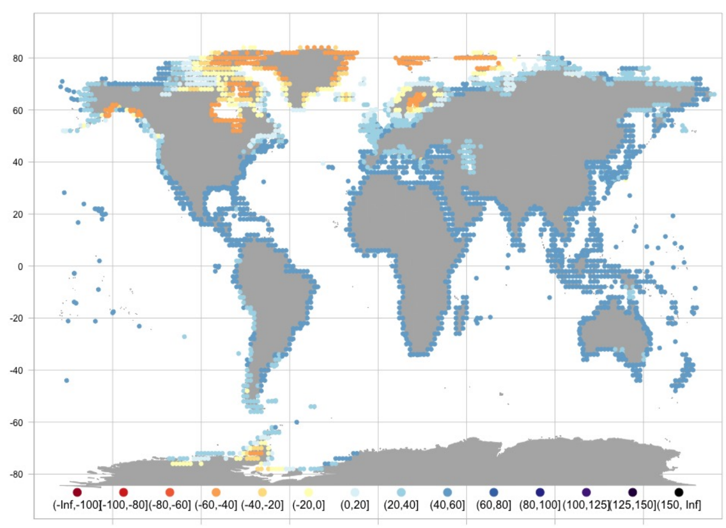
Supplementary Figure 2. ESLs from Vousdoukas et al. (2018). Estimates of the 100-yr ESL events (top) and their standard error (bottom) from Vousdoukas et al.(2018). Units for the events are meters above mean sea level; units for the standard errors are meters.Note that higher errors are observed at the locations with cyclonic activity, expressing the higher uncertainty in GPD fitting when peaks also from tropical cyclones are considered.



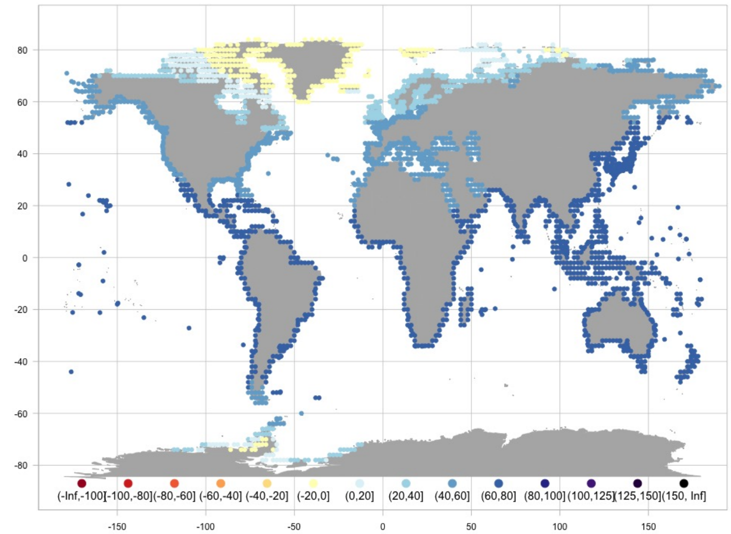


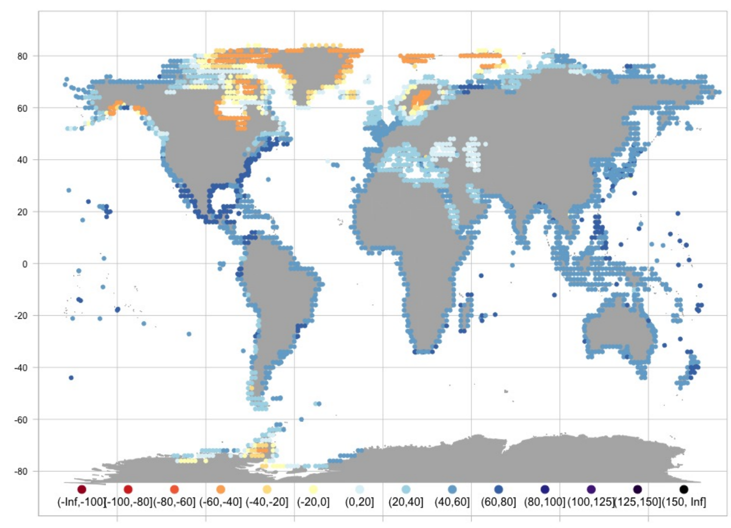
Supplementary Figure 3. ESLs from Rasmussen et al. (2018). Estimates of the 100-yr ESL events (top) and their standard error (bottom) from Rasmussen et al. (2018). Units for the events are meters above mean sea level; units for the standard errors are meters.



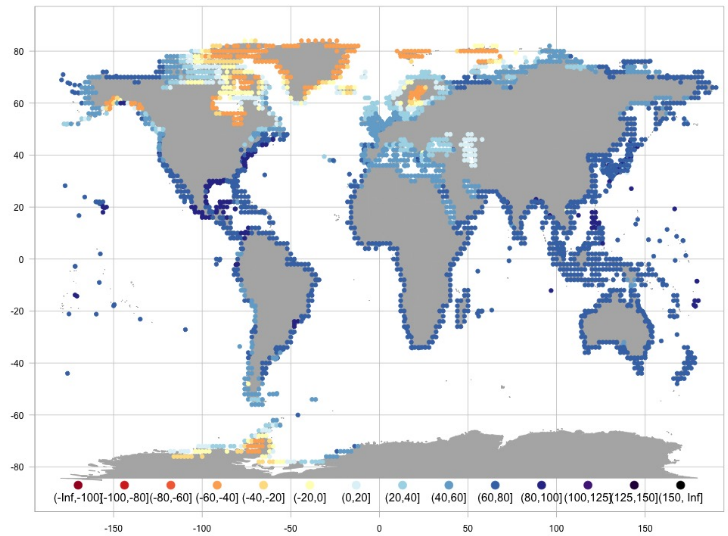


Supplementary Figure 4. RSLC by 2100 for 1.5 °C. Median projections of relative sea level change by 2100 for 1.5 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.

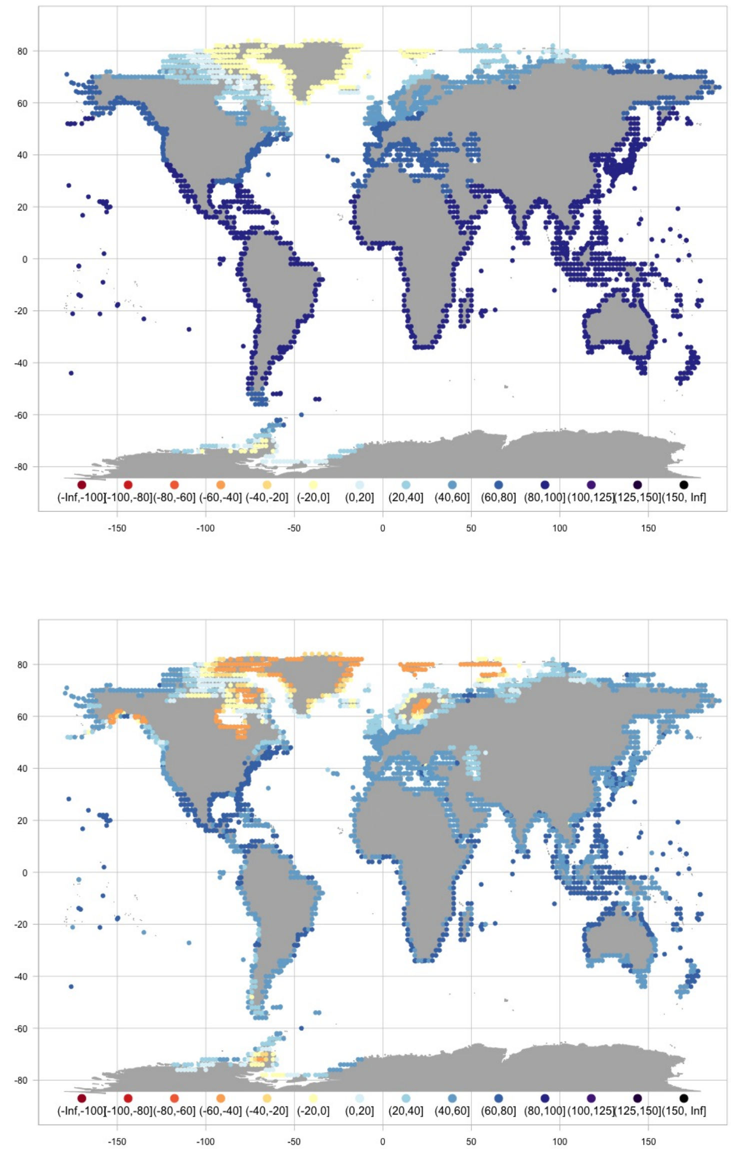




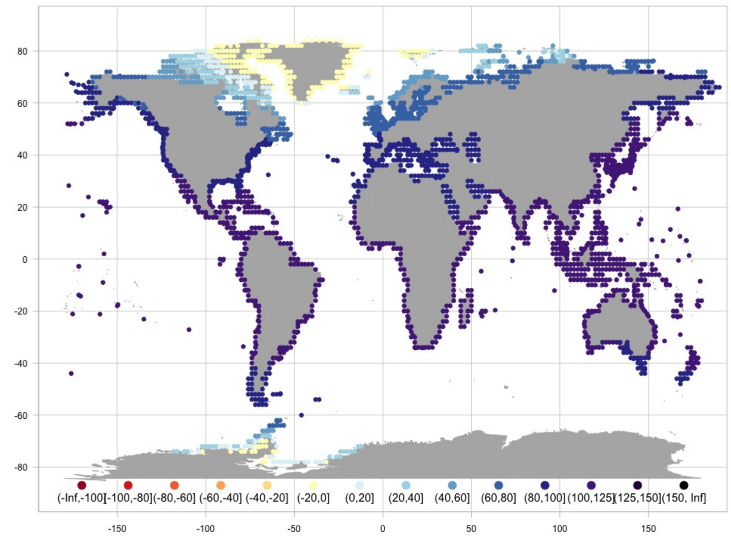
Supplementary Figure 5. RSLC by 2100 for 2.0 °C. Median projections of relative sea level change by 2100 for 2.0 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.

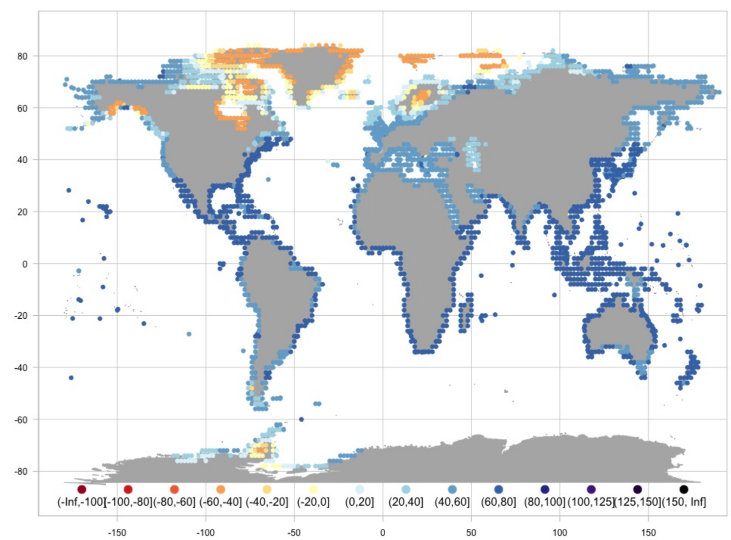


Supplementary Figure 6. RSLC by 2100 for 2.0 °C+. Median projections of relative sea level change by 2100 for 2.0 °C including the contribution of ice-sheet melt estimated according to SEJ. These are available only for the method from Rasmussen et al. (2018). Units are cm. referenced to 2000.

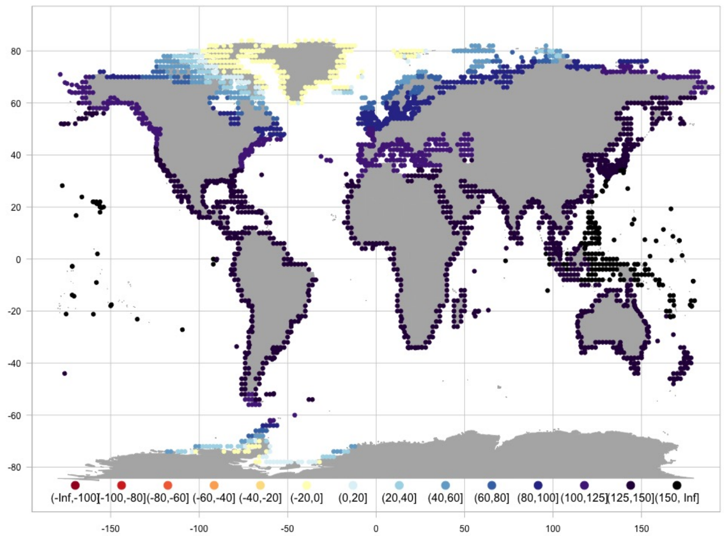


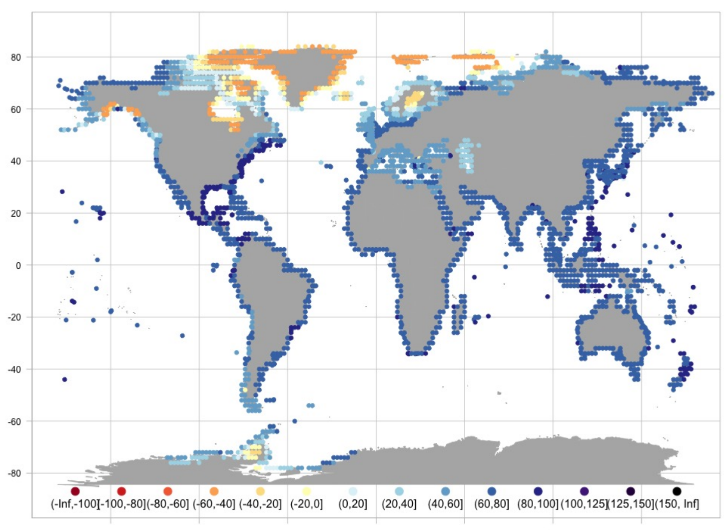
Supplementary Figure 7. RSLC by 2100 for 2.5 °C. Median projections of relative sea level change by 2100 for 2.5 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.



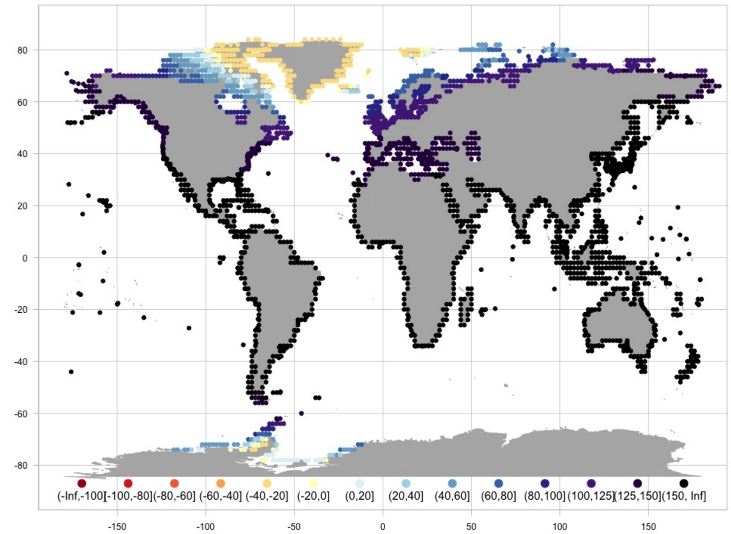


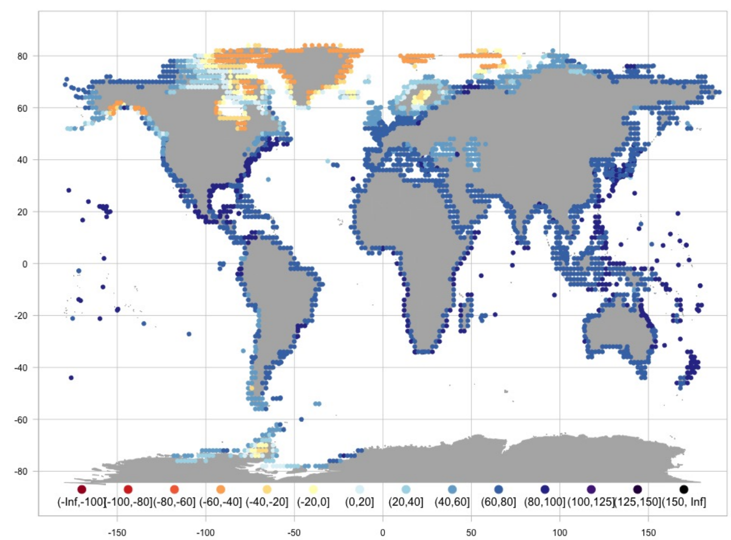
Supplementary Figure 8. RSLC by 2100 for 3.0 °C.Median projections of relative sea level change by 2100 for 3.0 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.



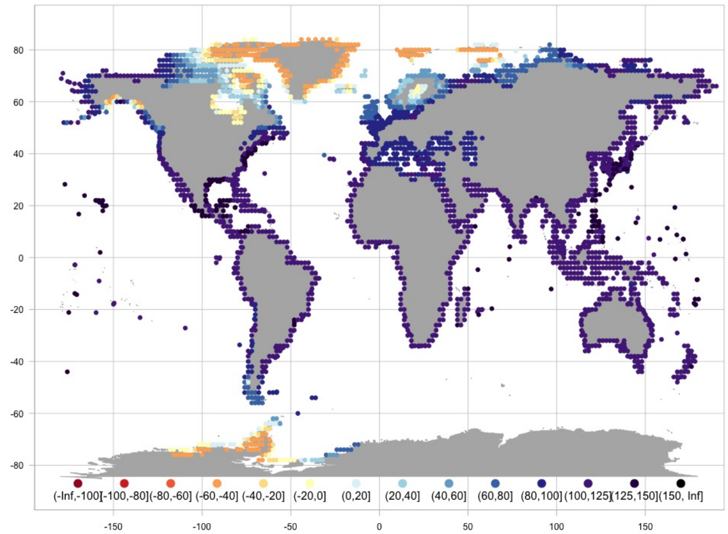


Supplementary Figure 9. RSLC by 2100 for 4.0 °C. Median projections of relative sea level change by 2100 for 4.0 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.

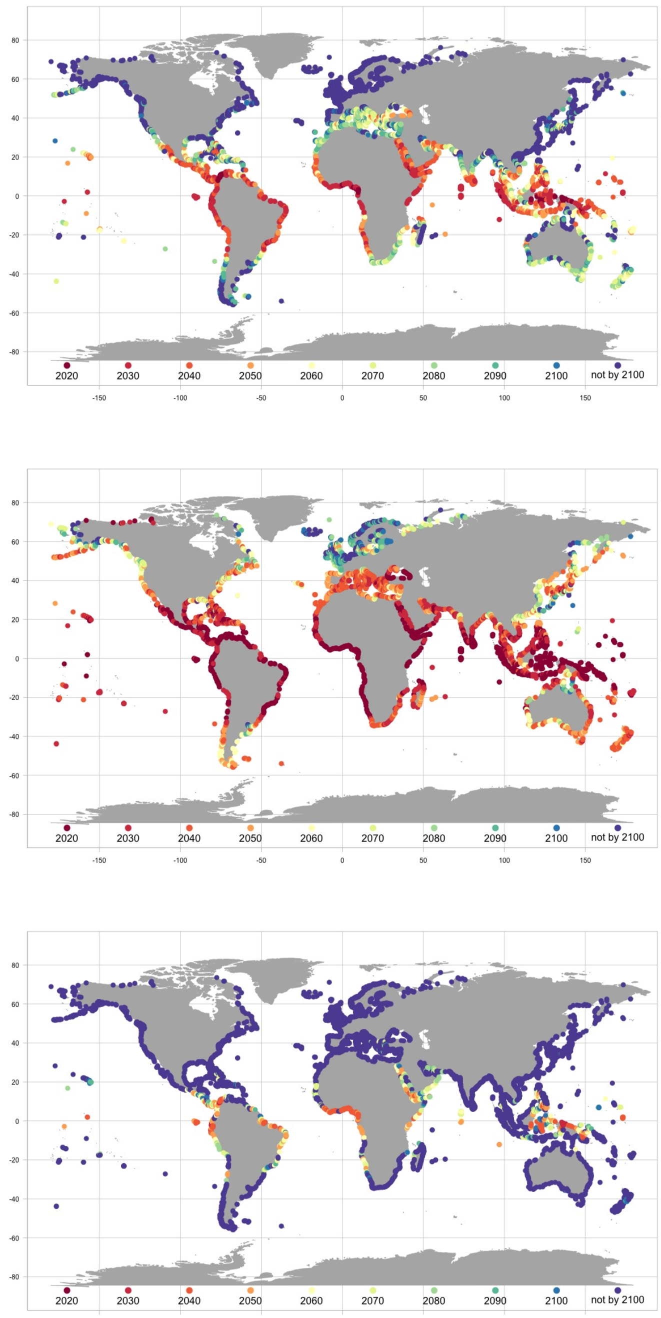




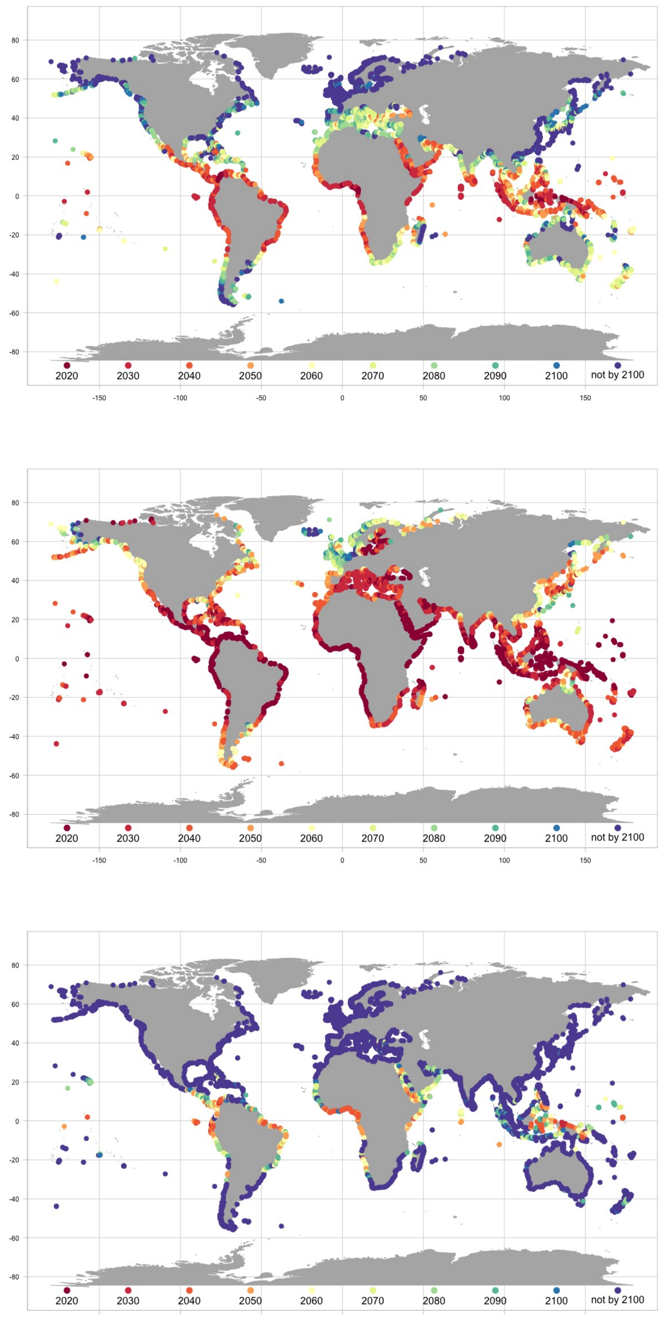
Supplementary Figure 10. RSLC by 2100 for 5.0 °C. Median projections of relative sea level change by 2100 for 5.0 °C by the two methods (top: Vega-Westhoff et al. (2019); bottom: Rasmussen et al. (2018). Units are cm. referenced to 2000.



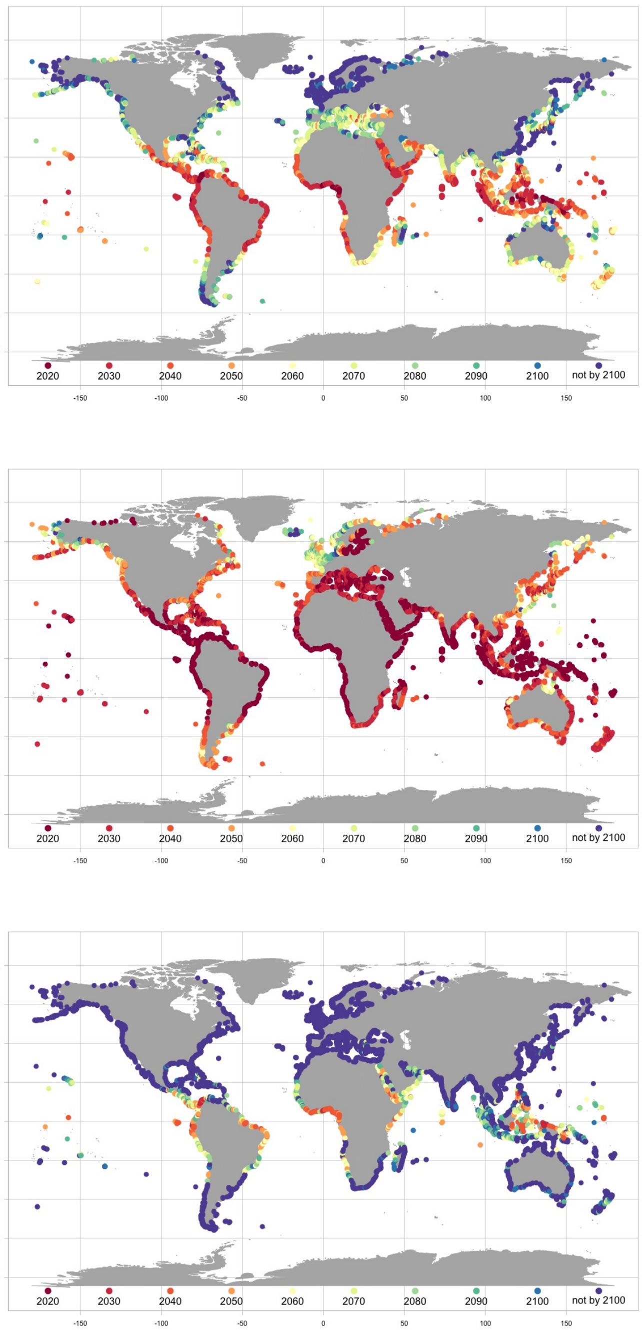
Supplementary Figure 11. RSLC by 2100 for 5.0 °C+. Median projections of relative sea level change by 2100 for 5.0 °C including the contribution of ice-sheet estimated according to SEJ. These are available only for the method from Rasmussen et al., 2018. Units are cm. referenced to 2000.



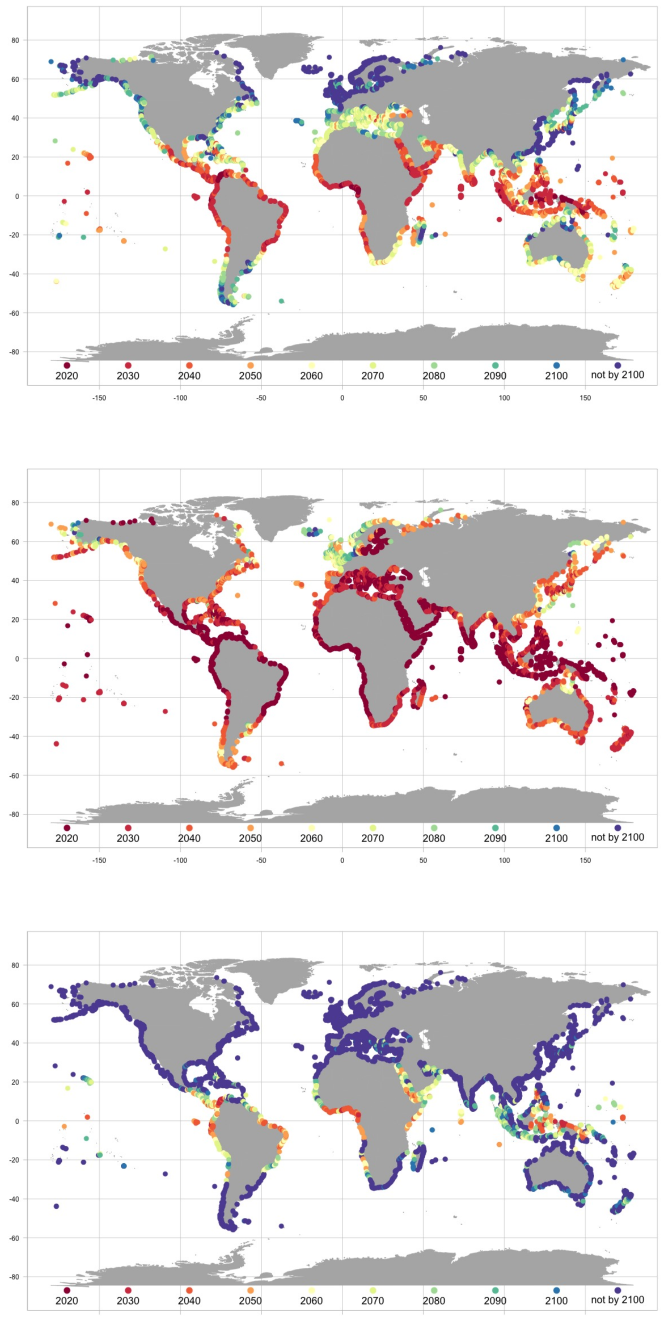
Supplementary Figure 12. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for $1.5\,^{\circ}$C**).** Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at $1.5\,^{\circ}$C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



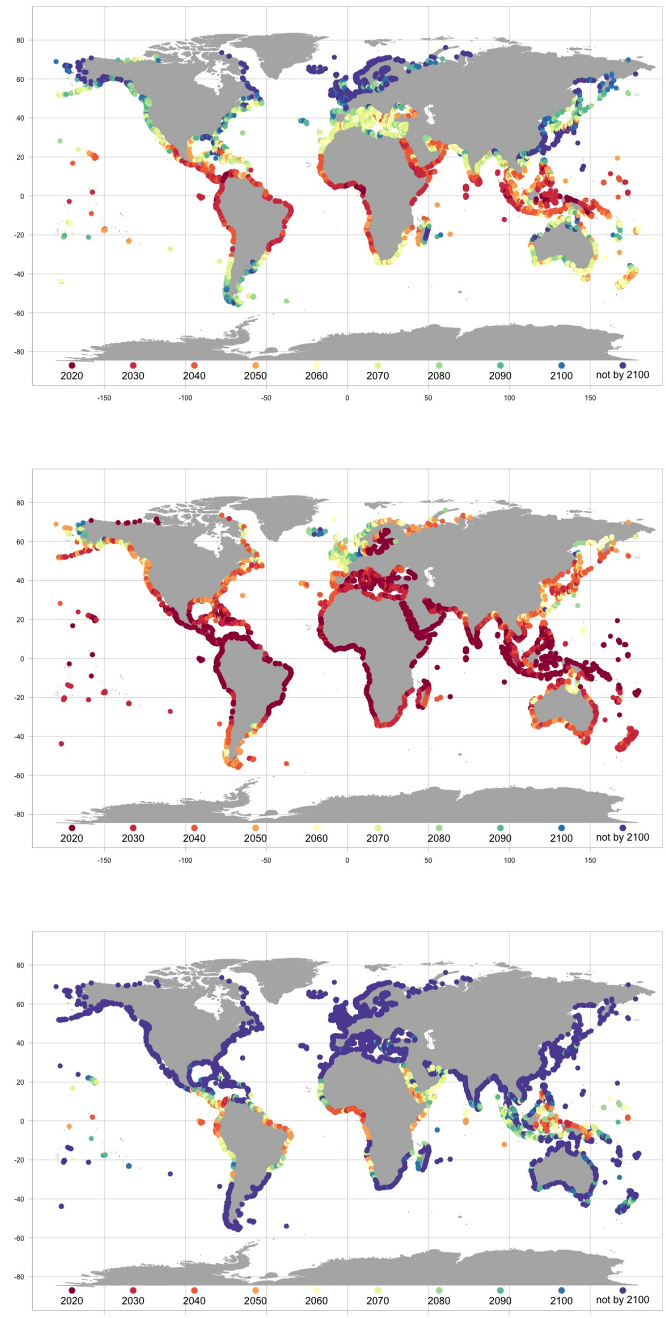
Supplementary Figure 13. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for $2.0\,^{\circ}$C**).** Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at $2.0\,^{\circ}$C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



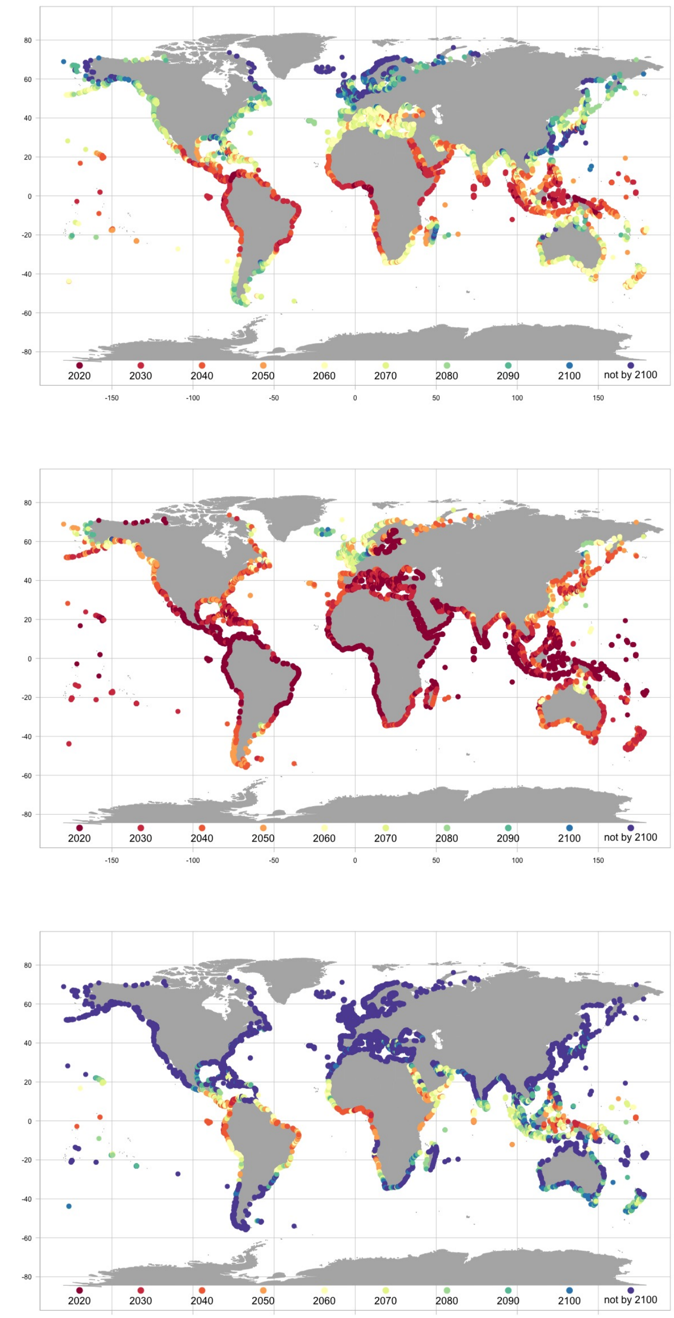
Supplementary Figure 14. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 2.0 °C+**).** Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 2.0 °C by 2100 (including the contribution of ice-sheet estimated according to SEJ). Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



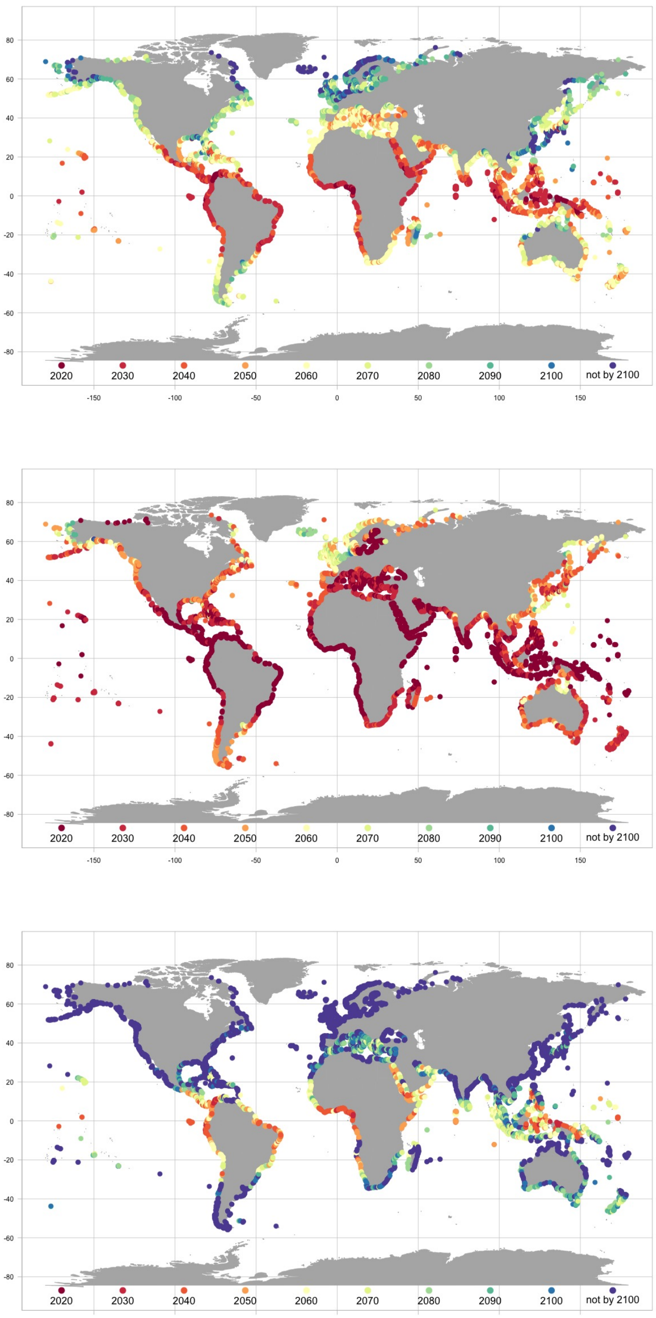
Supplementary Figure 15. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 2.5 °C**)**. Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 2.5 °C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5$^{\text{th}}$ and 95$^{\text{th}}$ quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



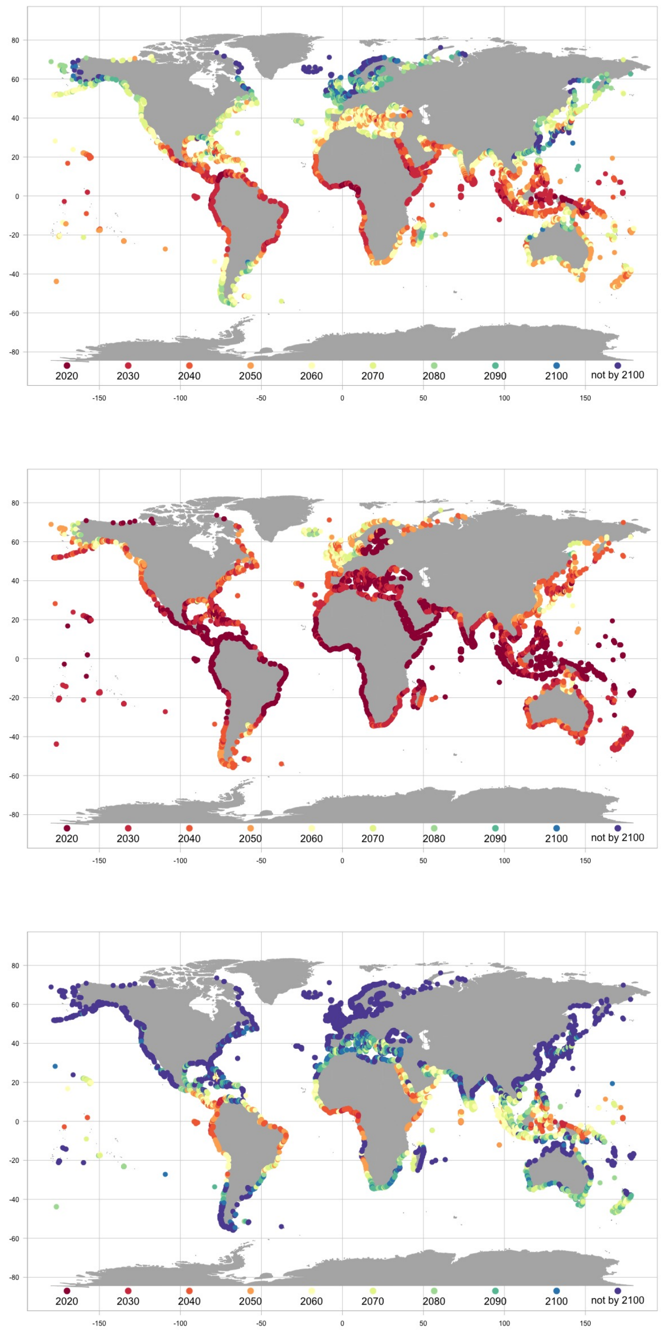
Supplementary Figure 16. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 3.0 °C**)**. Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 3.0 °C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



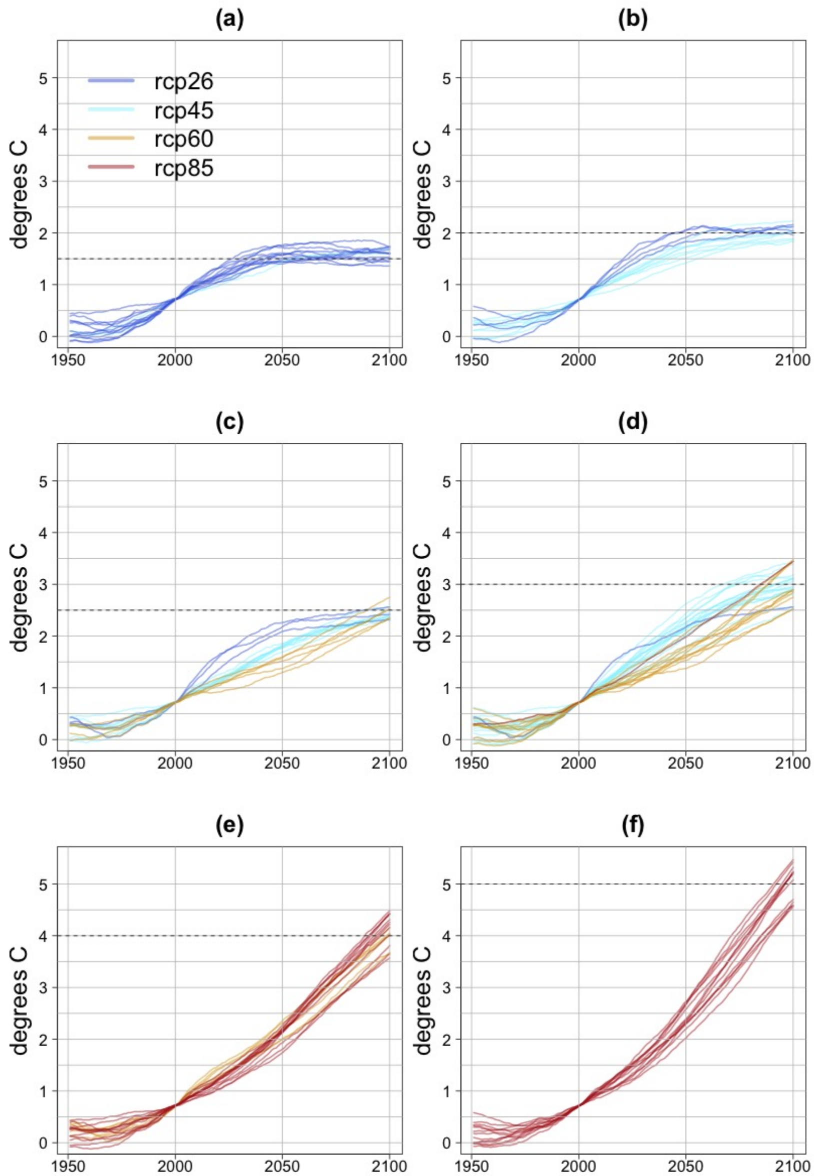
Supplementary Figure 17. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 4.0 °C**).** Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 4.0 °C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



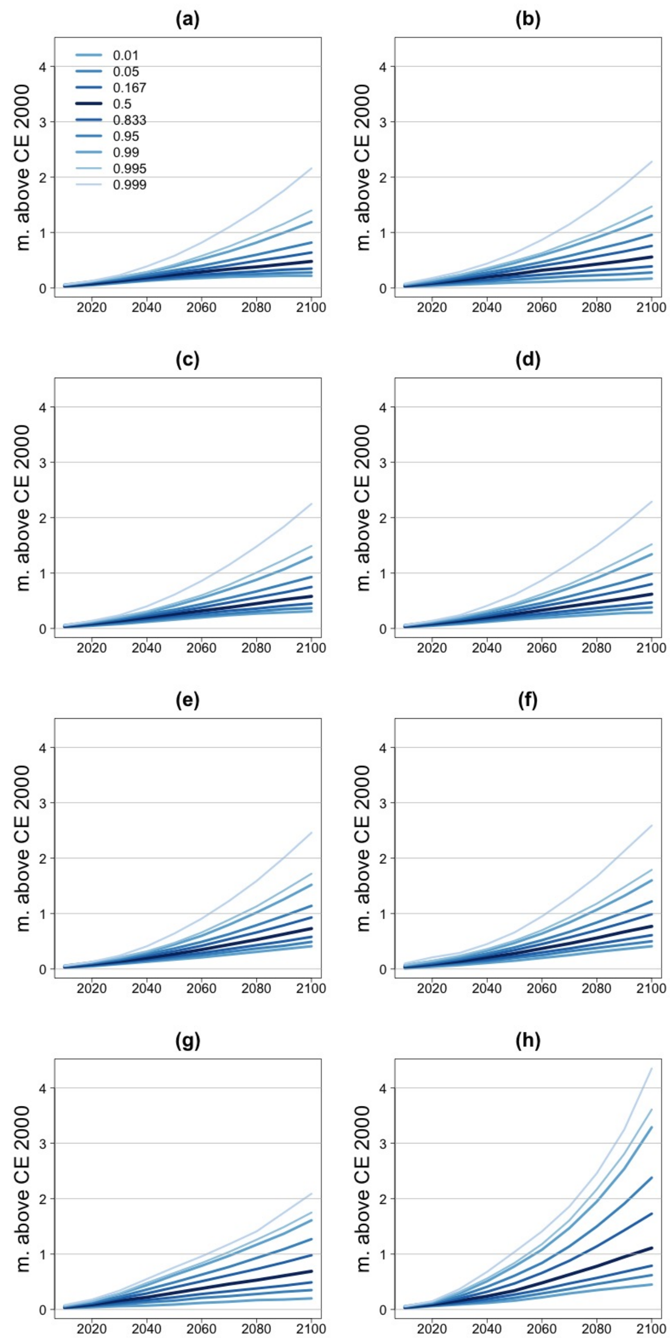
Supplementary Figure 18. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 5.0 °C**)**. Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 5.0 °C by 2100. Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



Supplementary Figure 19. Decade by which the present-day 100-yr ESL event becomes at least annual (Results for 5.0 °C+). Decade by which the present-day 100-yr ESL event becomes at least annual, for 7,283 locations at which ESL estimates from the two model-based studies are available, and considering only the global warming trajectories ending at 5.0 °C by 2100 (including the contribution of ice-sheet estimated according to SEJ). Central estimate, lower and upper bound are shown from top to bottom respectively. These results are based on combining all four distributions into an overall distribution by a full convolution, and computing median (central estimate, top panel), and 5^{th} and 95^{th} quantiles (lower and upper bound respectively, in the middle and bottom panel). See also Table 2.



Supplementary Figure 20. Trajectories of global surface air temperature from CMIP5 models. These were used to estimate sea level change (SLC) projections at the various global warming levels by the method based on Rasmussen et al., 2018. Different colors indicate different Representative Concentration Pathways (see legend).From (a) to (f) trajectories used to estimate SLC for 1.5 °C,2.0 °C,2.5 °C,3.0 °C,4.0 °C,5.0 °C.



Supplementary Figure 21. Global mean sea level change trajectories derived by the method based on Rasmussen et al., 2018. Different colors indicate different quantiles of the probability distribution with the thickest, darkest line corresponding to the median projection (see legend). From (a) to (f) 2100 SLC for 1.5 °C,2.0 °C,2.5 °C,3.0 °C,4.0 °C,5.0 °C warming with respect to pre-industrial by 2100. Plots along the bottom row (panels (g) and (h)) show the results of including SEJ based estimates of ice-sheet melt contribution for two global warming levels: 2 °C and 5 °C.

Supplementary Tables

	model	RCP	2100 GSAT	Ocean Dynamics	Thermal Expansion	GIC
1.5 °C						
	bcc-csm1-1	rcp26	1.51	X	X	X
	BNU-ESM	rcp26	1.61			
	CCSM4	rcp26	1.44	X	X	X
	FIO-ESM	rcp45	1.7	X		
	GFDL-ESM2G	rcp45	1.6	X		
	HadGEM2-AO	rcp26	1.73			
	IPSL-CM5A-LR	rcp26	1.74	X	X	X
	IPSL-CM5A-MR	rcp26	1.59	X	X	
	MIROC5	rcp26	1.61			
	MPI-ESM-LR	rcp26	1.46	X	X	X
	MPI-ESM-MR	rcp26	1.36	X	X	
	MRI-CGCM3	rcp26	1.72	X	X	X
	NorESM1-M	rcp26	1.53	X	X	X
	NorESM1-ME	rcp26	1.68	X	X	
2.0 °C						
	bcc-csm1-1-m	rcp45	2.12	X	X	
	CanESM2	rcp26	2.04	X	X	X
	CESM1-BGC	rcp45	2.23	X		
	CESM1-CAM5	rcp26	2.12			
	CSIRO-MK3-6-0	rcp26	2.16		X	
	FGOALS-G2	rcp45	2.01			
	GFDL-ESM2M	rcp45	1.83	X	X	
	GISS-E2-H-CC	rcp45	2.02			
	GISS-E2-R	rcp45	1.88	X	X	X
	GISS-E2-R-CC	rcp45	1.87	X	X	
	HadGEM2-ES	rcp26	1.96	X	X	X
	inmcm4	rcp45	2.04	X	X	X

Supplementary Table 1. Information about CMIP5 simulations used by the method of Rasmussen et al. (2018). CMIP5 models and Representative Concentration Pathway (RCP) used for the calculation of relative sea level change (RSLC) projections at 1.5 °C and 2.0 °C by the method based on Rasmussen et al. (2018), the temperature anomaly reached by 2100, and the RSLC components they provide.

	model	RCP	2100 GSAT	Ocean Dynamics	Thermal Expansion	GIC
2.5 °C						
	CCSM4	rcp45	2.3	X	X	X
	CNRM-CM5	rcp45	2.56	X	X	X
	FIO-ESM	rcp60	2.34	X		
	GFDL-CM3	rcp26	2.56	X	X	X
	GFDL-ESM2G	rcp60	2.35	X	X	
	GFDL-ESM2M	rcp60	2.52	X	X	
	GISS-E2-R	rcp60	2.52	X	X	X
	IPSL-CM5B-LR	rcp45	2.38	X		
	MIROC-ESM	rcp26	2.32	X	X	X
	MIROC-ESM-CHEM	rcp26	2.42	X	X	
	MIROC5	rcp45	2.37		X	X
	MPI-ESM-LR	rcp45	2.39	X	X	X
	MPI-ESM-MR	rcp45	2.38	X	X	
	MRI-CGCM3	rcp45	2.52	X		X
	NorESM1-M	rcp45	2.34	X	X	X
	NorESM1-M	rcp60	2.75	X	X	
	NorESM1-ME	rcp45	2.45	X	X	
3.0 °C						
	ACCESS1-0	rcp45	3.06	X	X	
	ACCESS1-3	rcp45	2.89	X	X	
	bcc-csm1-1	rcp60	2.84	X	X	X
	BNU-ESM	rcp45	2.81			
	CanESM2	rcp45	2.93	X	X	X
	CCSM4	rcp60	2.86	X	X	X
	CESM1-CAM5	rcp45	3.09			
	CMCC-CM	rcp45	2.9	X	X	
	CNRM-CM5	rcp45	2.56	X	X	X
	CSIRO-MK3-6-0	rcp45	2.96		X	
	CSIRO-MK3-6-0	rcp60	3.48		X	
	GFDL-CM3	rcp45	3.44	X		X
	GFDL-CM3	rcp26	2.56	X		X
	GFDL-ESM2M	rcp60	2.52	X		
	GISS-E2-R	rcp60	2.52	X	X	X
	GISS-E2-R	rcp85	3.44	X	X	X
	HadGEM2-AO	rcp45	3.11			
	HadGEM2-AO	rcp60	3.45			
	HadGEM2-CC	rcp45	3.11	X		
	HadGEM2-ES	rcp45	3.13	X		X
	IPSL-CM5A-LR	rcp45	2.88	X	X	X
	IPSL-CM5A-LR	rcp60	3.45	X	X	X
	IPSL-CM5A-MR	rcp45	2.91	X	X	
	MIROC5	rcp60	2.9			X
	MIROC-ESM	rcp45	3.18	X	X	X
	MIROC-ESM-CHEM	rcp45	3.39	X		
	MRI-CGCM3	rcp45	2.52	X		X
	NorESM1-M	rcp60	2.75	X	X	X
	NorESM1-ME	rcp60	2.89			

Supplementary Table 2. Information about CMIP5 simulations used by the method of Rasmussen et al. (2018). CMIP5 models and Representative Concentration Pathway (RCP) used for the calculation of relative sea level change (RSLC) projections at 2.5 °C and 3.0 °C by the method based on Rasmussen et al. (2018), the temperature anomaly reached by 2100, and the RSLC components they provide.

	model	RCP	2100 GSAT	Ocean Dynamics	Thermal Expansion	GIC
4.0 °C						
	bcc-csm1-1	rcp85	4.42	X	X	X
	bcc-csm1-1-m	rcp85	4.16	X	X	
	CESM1-CAM5	rcp60	3.65			
	FGOALS-G2	rcp85	4.02			
	GFDL-CM3	rcp60	4.15	X		X
	GFDL-ESM2G	rcp85	3.81	X		
	GFDL-ESM2M	rcp85	3.65	X		
	HadGEM2-ES	rcp60	4.01	X	X	X
	inmcm4	rcp85	3.57	X	X	X
	IPSL-CM5B-LR	rcp85	4.43	X		
	IPSL-CM5A-MR	rcp60	3.68			
	MIROC5	rcp85	4.31		X	X
	MIROC-ESM	rcp60	4.02	X	X	X
	MIROC-ESM-CHEM	rcp60	4.05	X	X	
	MPI-ESM-MR	rcp85	4.48	X	X	
	MRI-CGCM3	rcp85	4.26	X	X	X
	NorESM1-M	rcp85	4.22	X	X	X
	NorESM1-ME	rcp85	4.42	X	X	
5.0 °C						
	ACCESS1-0	rcp85	5.23	X	X	
	ACCESS1-3	rcp85	5.08	X	X	
	BNU-ESM	rcp85	5.42			
	CCSM4	rcp85	4.58	X	X	X
	CESM1-BGC	rcp85	4.59	X		
	CESM1-CAM5	rcp85	5.2			
	CMCC-CM	rcp85	5.32	X	X	
	CNRM-CM5	rcp85	4.56	X	X	X
	CSIRO-MK3-6-0	rcp85	5.24		X	
	FIO-ESM	rcp85	4.65	X		
	HadGEM2-AO	rcp85	5.21			
	IPSL-CM5A-MR	rcp85	5.47	X	X	
	MPI-ESM-LR	rcp85	4.7	X	X	X

Supplementary Table 3. Information about CMIP5 simulations used by the method of Rasmussen et al. (2018). CMIP5 models and Representative Concentration Pathway (RCP) used for the calculation of relative sea level change (RSLC) projections at 4.0 °C and 5.0 °C by the method based on Rasmussen et al. (2018), the temperature anomaly reached by 2100, and the RSLC components they provide.

	1.5	**2.0**	**2.0+**	**2.5**	**3.0**	**4.0**	**5.0**	**5.0+**	**None**
5th quantile	99%	1%	0%	0%	0%	0%	1%	0%	0%
16.7th quantile	89%	9%	0%	1%	0%	1%	0%	0%	1%
50th quantile	58%	13%	8%	3%	3%	9%	3%	0%	3%
83.3th quantile	25%	5%	4%	1%	5%	18%	4%	4%	32%
95th quantile	10%	3%	7%	1%	2%	9%	3%	5%	61%

Supplementary Table 4. Based on the full convolution approach, percentage of the 179 locations depicted in Figure 1 (left column) at which the frequency of the present-day 100-yr ESL event changes to at least an annual event by 2100, indicating the GWL required. These estimates come from a fully probabilistic representation of the distributions along each row, and we can therefore show a range of quantiles: 5^{th}, 16.7^{th}, 50^{th}, 83.3^{rd} and 95^{th}. Each percentage value under GWLs of 2 °C or higher is to be interpreted as the *additional* fraction of sites experiencing the change (i.e., in addition to the total along the row to its left). Percentages along each row may not add up to 100 exactly because of rounding errors. The + sign associated to 2 °C and 5 °C indicates projections that include SEJ-derived estimates of ice-sheet contribution to RSLC.

	1.5	**2.0**	**2.0+**	**2.5**	**3.0**	**4.0**	**5.0**	**5.0+**	**None**
5th quantile	96%	4%	0%	0%	0%	0%	0%	0%	0%
16.7th quantile	87%	7%	2%	1%	1%	2%	0%	1%	0%
50th quantile	66%	9%	5%	3%	3%	6%	3%	1%	4%
83.3th quantile	31%	4%	4%	11%	4%	10%	6%	4%	26%
95th quantile	16%	3%	4%	2%	1%	6%	15%	7%	46%

Supplementary Table 5. Based on the full convolution approach, percentage of the 7,283 locations depicted in Figure 1 (right column) at which the frequency of the present-day 100-yr ESL event changes to at least an annual event by 2100, indicating the GWL required. These estimates come from a fully probabilistic representation of the distributions along each row, and we can therefore show a range of quantiles: 5^{th}, 16.7^{th}, 50^{th}, 83.3^{rd} and 95^{th}. Each percentage value under GWLs of 2 °C or higher is to be interpreted as the *additional* fraction of sites experiencing the change (i.e., in addition to the total along the row to its left). Percentages along each row may not add up to 100 exactly because of rounding errors. The + sign associated to 2 °C and 5 °C indicates projections that include SEJ-derived estimates of ice-sheet contribution to RSLC.