Supplementary Information for

A frequent ice-free Arctic is likely to occur before the mid-21st century

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Supplementary Table 1

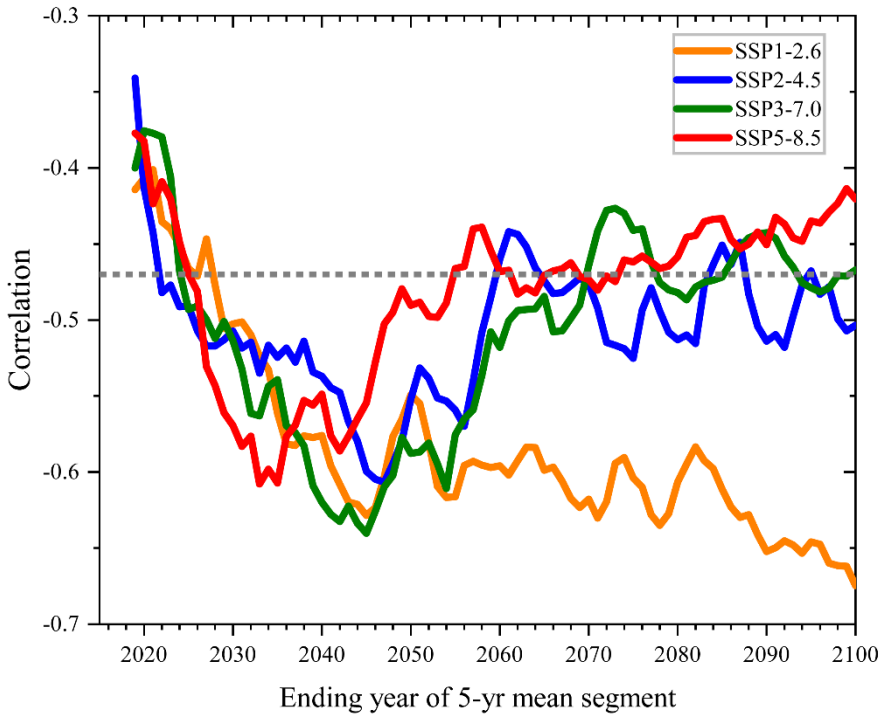
Supplementary Figure 1-6

Supplementary Table 1| Details of CMIP6 models, grouped by modeling center, used in this study.

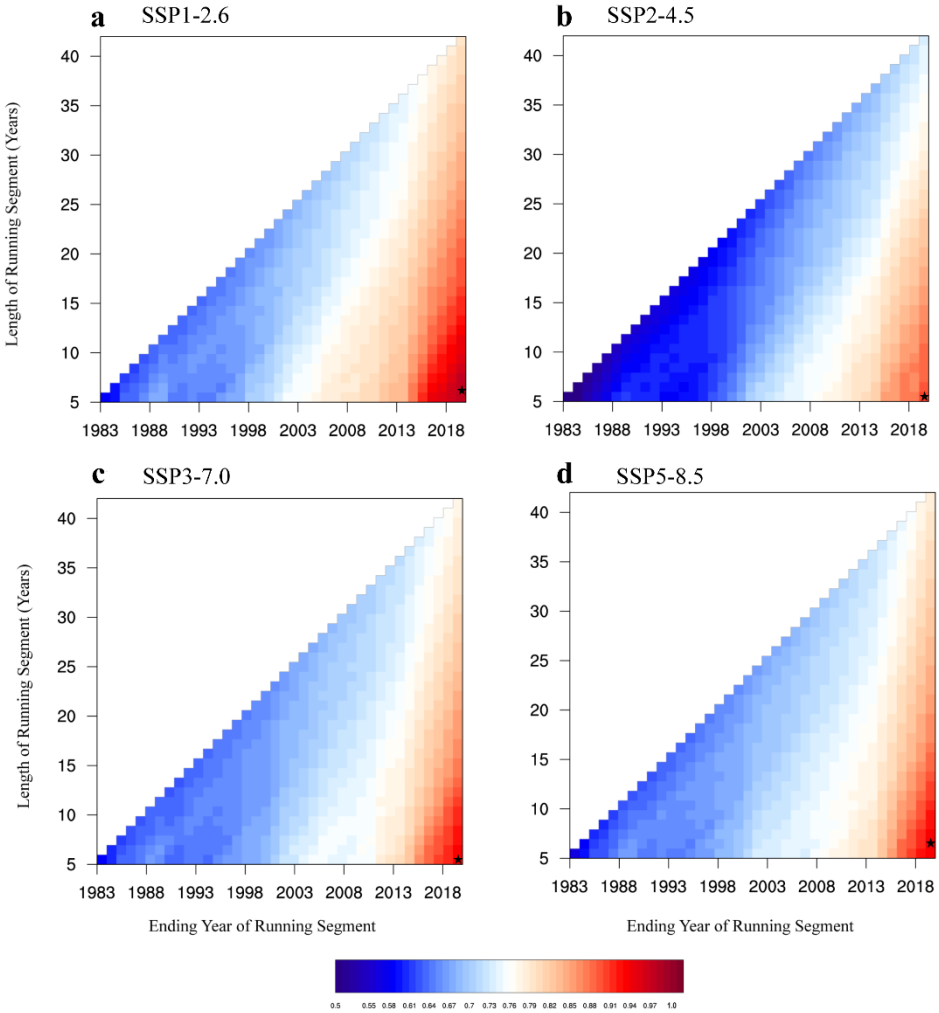
Modeling Center Number	Modeling Center	Nation	Model Name
1	Australian Research Council Centre of Excellence for Climate System Science (CSIRO-ARCCSS)	Australia	ACCESS-CM2 (https://doi.org/10.22033/ESGF/CMIP6.4271)
			ACCESS-ESM1-5 (https://doi.org/10.22033/ESGF/CMIP6.4272)
2	Beijing Climate Center, China Meteorological Administration (BCC)	China	BCC-CSM2-MR (https://doi.org/10.22033/ESGF/CMIP6.2948)
3	Canadian Centre for Climate Modeling and Analysis (CCCma)	Canada	CanESM5 (https://doi.org/10.22033/ESGF/CMIP6.10260)
			CanESM5-CanOE (https://doi.org/10.22033/ESGF/CMIP6.10203)
4	Community Earth System Model Contributors (NCAR)	USA	CESM2 (https://doi.org/10.22033/ESGF/CMIP6.7627)
			CESM2-WACCM (https://doi.org/10.22033/ESGF/CMIP6.10071)
5	Centre National de Recherches Météorologiques (CNRM-CERFACS)	France	CNRM-CM6-1 (https://doi.org/10.22033/ESGF/CMIP6.4066)
			CNRM-CM6-1-HR (https://doi.org/10.22033/ESGF/CMIP6.4067)
6	EC-Earth-Consortium	Europe	EC-Earth3 (https://doi.org/10.22033/ESGF/CMIP6.4700)

			EC-Earth3-Veg (https://doi.org/10.22033/ESGF/CMIP6.4706)
7	Chinese Academy of Science (CAS)	China	FGOALS-f3-L (https://doi.org/10.22033/ESGF/CMIP6.3355)
			FGOALS-g3 (https://doi.org/10.22033/ESGF/CMIP6.3356)
8	NOAA Geophysical Fluid Dynamics Laboratory (GFDL)	USA	GFDL-ESM4 (https://doi.org/10.22033/ESGF/CMIP6.8597)
9	NASA Goddard Institute for Space Studies (GISS)	USA	GISS-E2-1-G (https://doi.org/10.22033/ESGF/CMIP6.7127)
10	Met Office Hadley Centre (MOHC)	UK	UKESM1-0-LL (https://doi.org/10.22033/ESGF/CMIP6.6113)
11	Institute for Numerical Mathematics (INM)	Russia	INM-CM4-8 (https://doi.org/10.22033/ESGF/CMIP6.5069)
			INM-CM5-0 (https://doi.org/10.22033/ESGF/CMIP6.5070)
12	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (University of Tokyo), and National Institute for Environmental Studies (MIROC)	Japan	MIROC6 (https://doi.org/10.22033/ESGF/CMIP6.5603)
			MIROC-ES2L (https://doi.org/10.22033/ESGF/CMIP6.5602)

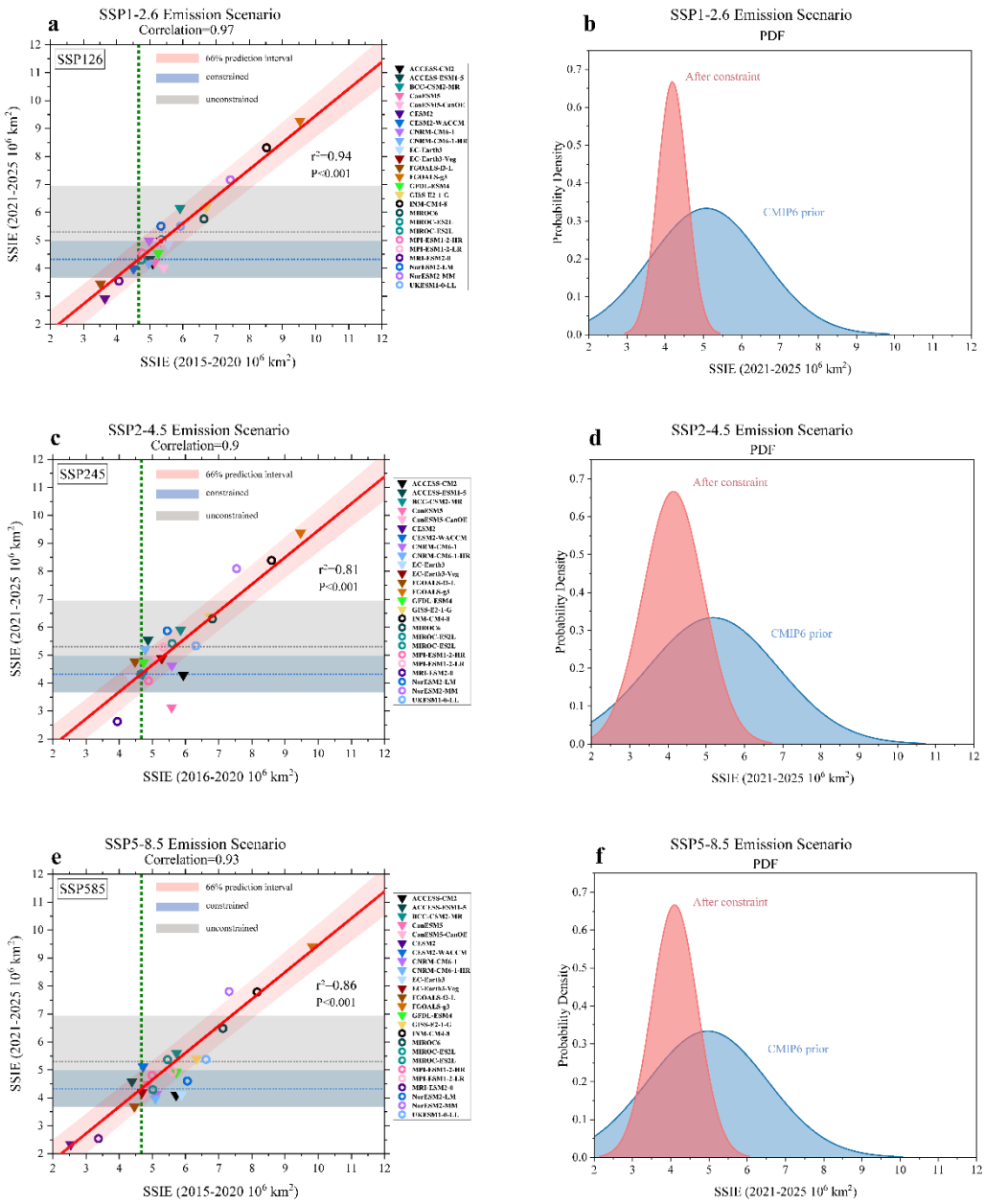
13	Max Planck Institute for Meteorology (MPI)	Germany	MPI-ESM1-2-HR (https://doi.org/10.22033/ESGF/CMIP6.6594)
			MPI-ESM1-2-LR (https://doi.org/10.22033/ESGF/CMIP6.6595)
14	Meteorological Research Institute (MRI)	Japan	MRI-ESM2-0 (https://doi.org/10.22033/ESGF/CMIP6.6842)
15	Norwegian Climate Centre (NCC)	Norway	NorESM2-LM (https://doi.org/10.22033/ESGF/CMIP6.8036)
			NorESM2-MM (https://doi.org/10.22033/ESGF/CMIP6.8040)



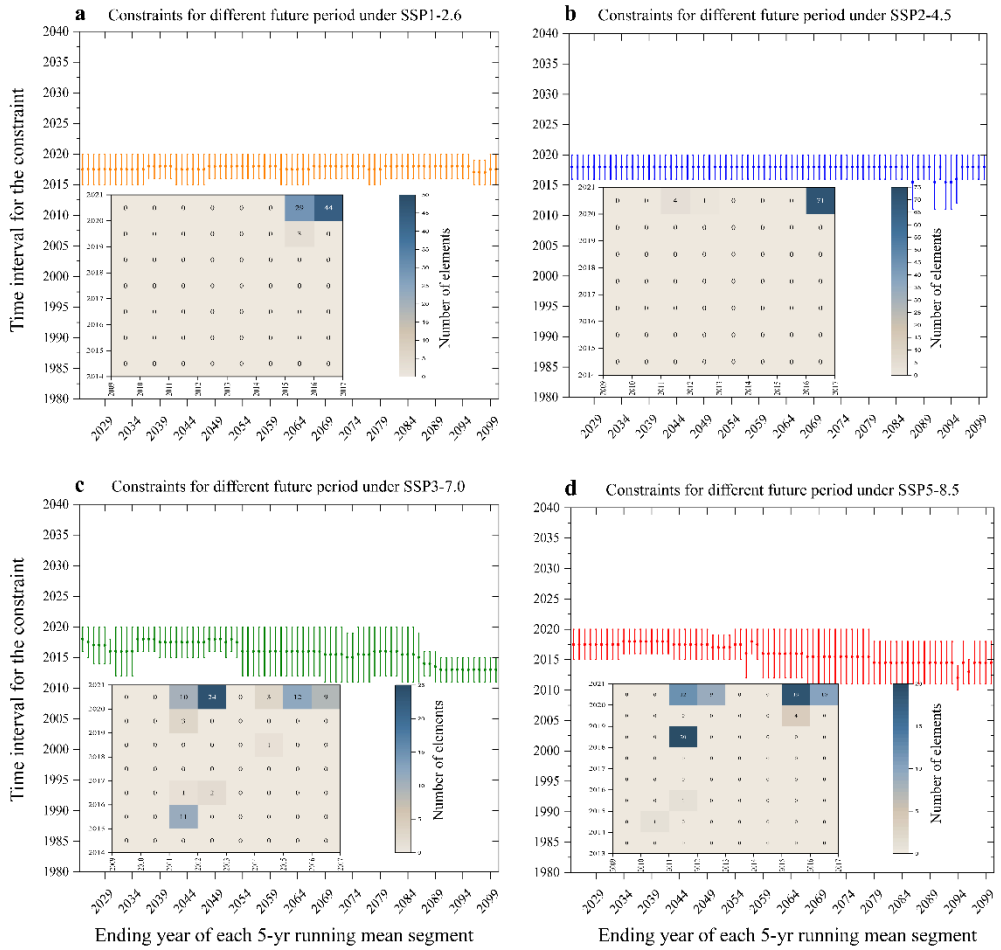
Supplementary Figure 1 | Inter-model correlations between ECS and projected SSIE. Inter-model correlations between ECS and the projected 5-yr mean SSIE over different periods from 2016 to 2100 under different emission scenarios. The dashed grey horizontal line represents the 99% confidence level.



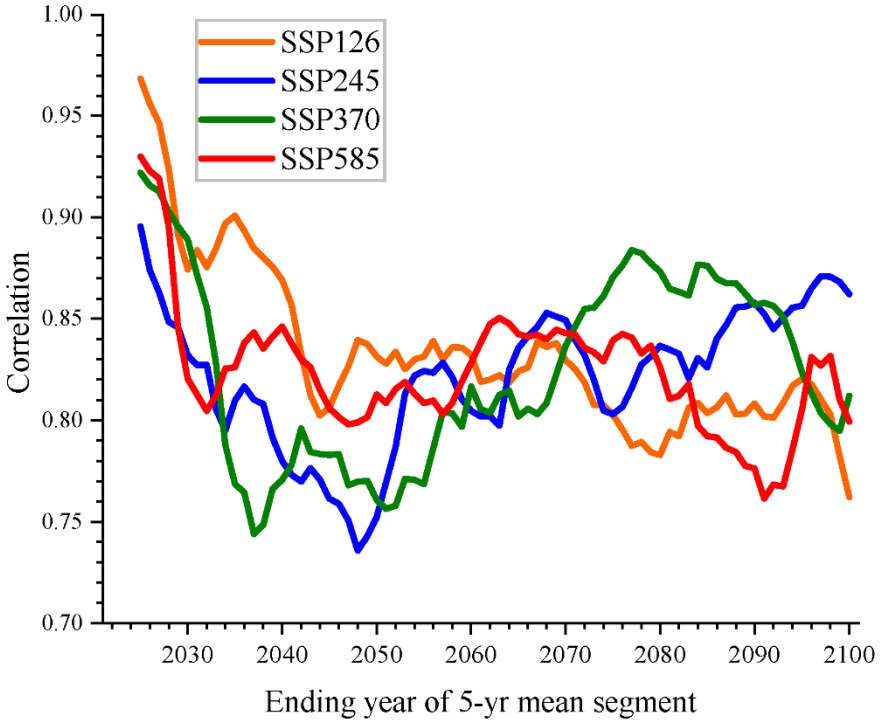
Supplementary Figure 2 | Historical constraints for future SSIE mean state during 2021-2025. Inter-model correlations between the simulated SSIE changes over different periods and the projected SSIE changes (2021-2025) across 25 CMIP6 models under the four emission scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5). The black stars mark the historical periods that are most related to the projected SSIE changes.



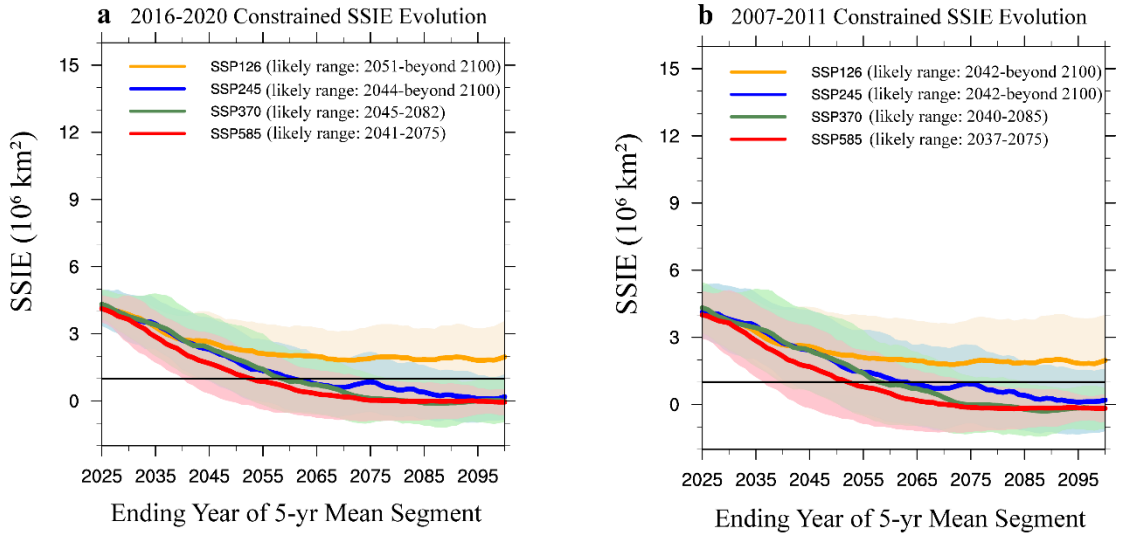
Supplementary Figure 3 | Emergent constraints on the projected 2021-2025 SSIE. The same as Fig. 2b and 2c, but for different emission scenarios: SSP1-2.6 (a, b), SSP2-4.5 (c, d), and SSP5-8.5 (e, f).



Supplementary Figure 4 | Historical constraints for different future periods. a, the whiskers show the different historical constraints for each projected 5-yr SSIE segment under the SSP1-2.6 emission scenario, in which the endpoints of the whisker represent the starting and ending year of the running mean segment of the constraints. The heat map denotes the distribution of the historical constraints, with the x-axis and y-axis representing the starting and ending year of the running mean segment. **b, c, d,** the same as **a**, but for different emission scenarios.



Supplementary Figure 5 | Inter-model correlations between historical constraints and projected SSIE. Inter-model correlations between historical constraints and the corresponding projected 5-yr mean SSIE over different periods from 2025 to 2100 under different emission scenarios.



Supplementary Figure 6 | Constrained SSIE evolution. The same as Fig. 3 except a constant predictor is used to constrain the future SSIE change. The constraints in **a** and **b** are the SSIE mean state during 2016-2020 and 2007-2011, respectively.