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Supplement of

Acidification of the Nordic Seas

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Table S1. Atmospheric CO_2 concentration simulated by the emission-driven NorESM1-ME (Emission) vs the prescribed CO_2 concentration (conc.) used for concentration-driven runs. In parenthesis is shown the corresponding surface pH calculated with characteristic temperature, salinity, A_T, silicate and phosphate values (5 °C, 35, 2300 μmol kg^{-1}, 5 μmol kg^{-1}, 1 μmol kg^{-1}) for the Nordic Seas, assuming that the oceanic pCO_2 equals the atmospheric one.

	1850	2005	2100 (RCP2.6)	2100 (RCP4.5)	2100 (RCP8.5)
Emission	284 (8.17)	393 (8.05)	447 (8.00)	583 (7.89)	1097 (7.63)
Conc.	284 (8.17)	379 (8.06)	421 (8.02)	538 (7.92)	936 (7.70)
Diff	0 (0.00)	+14 (-0.01)	+26 (-0.02)	+45 (-0.03)	+161 (-0.07)

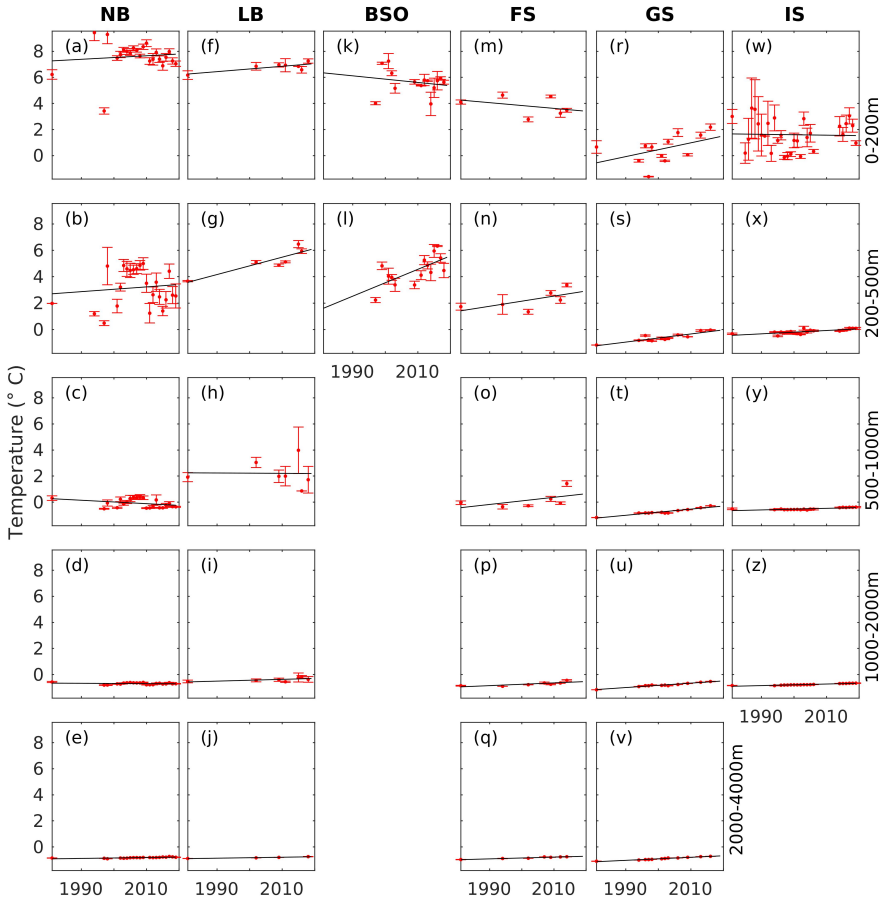

Figure S1. Annual mean temperature in °C (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. Bold numbers indicate that the trends are significantly different from zero. The solid black line show the trend estimate from the linear regression.

Table S2. Temperature trends ± standard error (°C 10^{-3} yr^{-1}) calculated from the data presented in Figure S1, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1).

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	13.5±28.1	**20.5±7.5**	-25.4±36.4	-21.9±27.5	52.9±32.0	-3.3±20.0
200-500	18.0±34.6	**65.8±16.6**	**101.8±32.2**	38.5±22.1	**30.8±5.0**	**12.7±2.7**
500-1000	-13.1±8.1	1.3±35.1		27.4±22.1	**23.6±2.4**	**6.1±1.2**
1000-2000	-1.2±1.8	6.8±4.0		**10.4±3.6**	**17.0±1.2**	**6.0±0.5**
2000-4000	**3.5±0.7**	**3.7±0.7**		**6.8±0.8**	**11.7±0.7**	

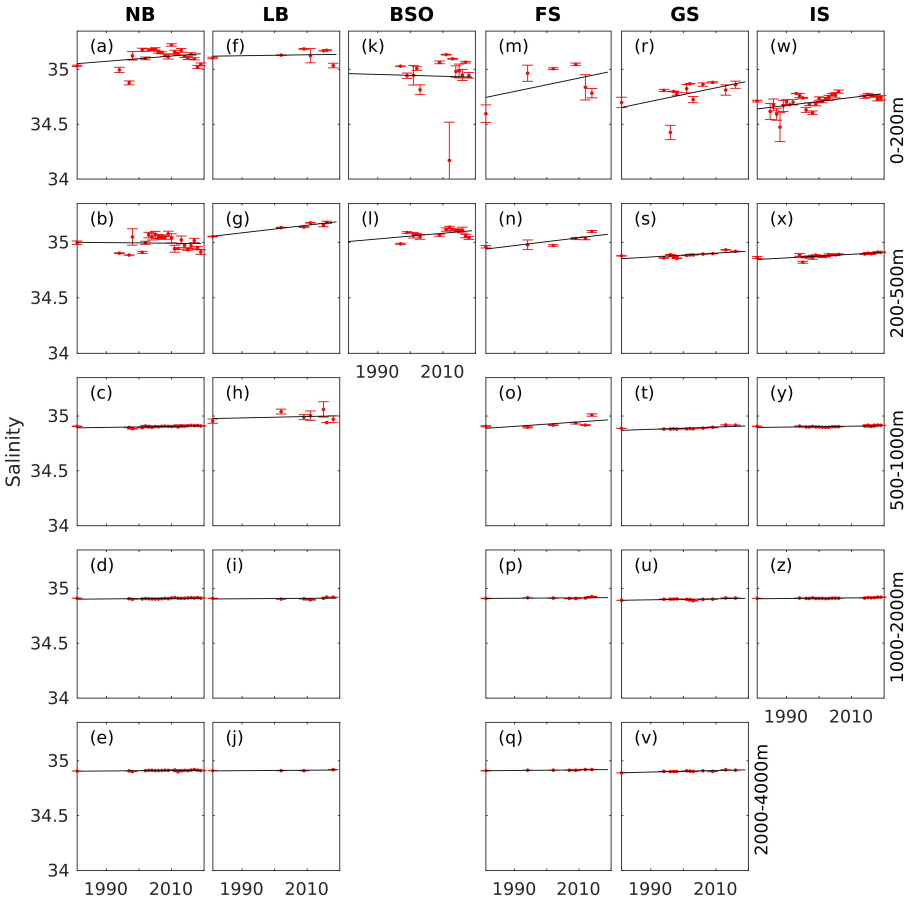

Figure S2. Annual mean salinity (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression.

Table S3. Salinity trends ± standard error (10^{-3} yr^{-1}) calculated from the data presented in Figure S2, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	2.39±1.81	0.43±1.81	-0.84±9.41	6.08±5.94	6.16±3.75	**3.61±1.02**
200-500	-0.28±1.48	**3.42±0.50**	2.57±1.41	**3.52±1.14**	**1.73±0.51**	**1.61±0.32**
500-1000	**0.48±0.16**	0.64±1.52		2.04±1.25	**1.03±0.32**	**0.41±0.13**
1000-2000	**0.27±0.09**	0.21±0.30		0.19±0.21	**0.47±0.2**	**0.28±0.07**
2000-4000	**0.23±0.11**	0.22±0.17		**0.28±0.08**	**0.68±0.11**	

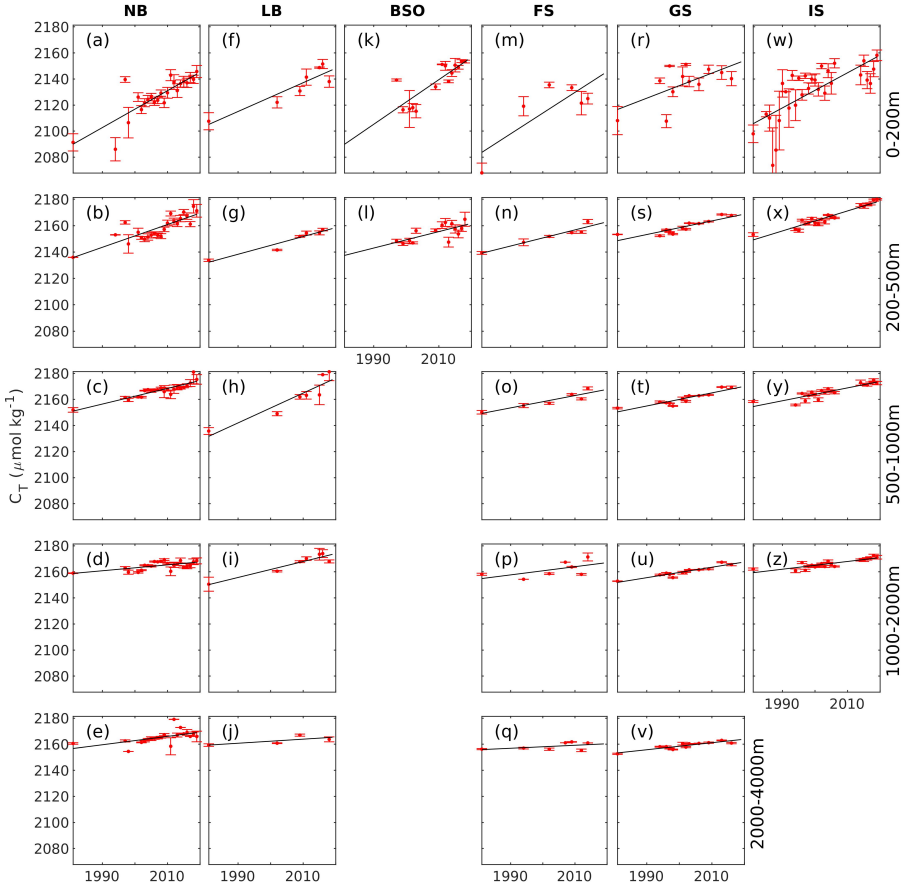

Figure S3. Annual mean Dissolved Inorganic Carbon (C_T) in μmol kg^{-1} (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression.

Table S4. C_T trends $\pm$ standard error (μmol kg^{-1} yr^{-1}) calculated from the data presented in Figure S3, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	**1.42±0.21**	**1.10±0.22**	**1.71±0.35**	1.59±0.58	**0.96±0.39**	**1.35±0.25**
200-500	**0.86±0.12**	**0.67±0.10**	**0.62±0.18**	**0.61±0.09**	**0.52±0.09**	**0.76±0.05**
500-1000	**0.60±0.07**	**1.14±0.21**		**0.47±0.10**	**0.50±0.07**	**0.49±0.06**
1000-2000	**0.23±0.06**	**0.61±0.10**		0.31±0.19	**0.40±0.05**	**0.28±0.04**
2000-4000	**0.32±0.11**	0.16±0.10		**0.12±0.09**	**0.27±0.04**	

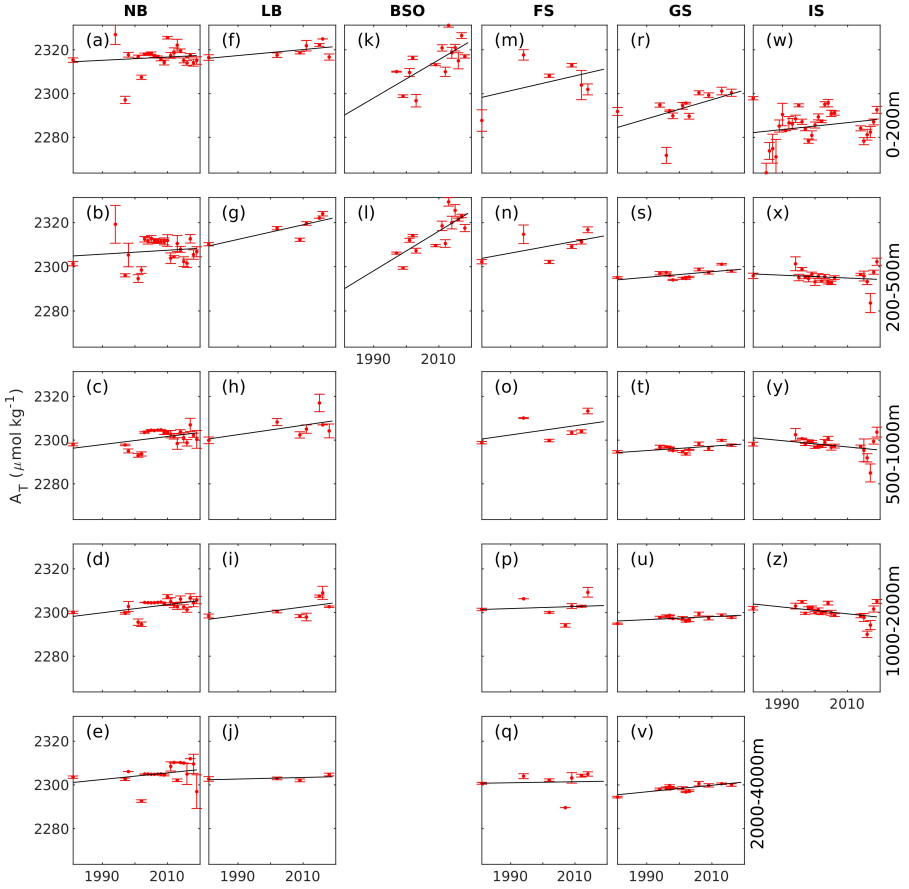

Figure S4. Annual mean total alkalinity (A_T) in μmol kg^{-1} (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression.

Table S5. A_T trends $\pm$ standard error (μmol kg^{-1} yr^{-1}) calculated from the data presented in Figure S4, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	0.07±0.14	0.14±0.10	**0.87±0.28**	0.34±0.38	0.44±0.23	0.16±0.13
200-500	0.09±0.15	0.33±0.13	**0.90±0.21**	0.27±0.20	0.13±0.06	-0.06±0.09
500-1000	0.18±0.09	0.22±0.17		0.21±0.20	0.10±0.05	-0.14±0.09
1000-2000	**0.19±0.07**	0.20±0.13		0.05±0.18	0.07±0.04	-0.16±0.08
2000-4000	0.15±0.11	0.04±0.05		0.02±0.20	**0.15±0.04**	

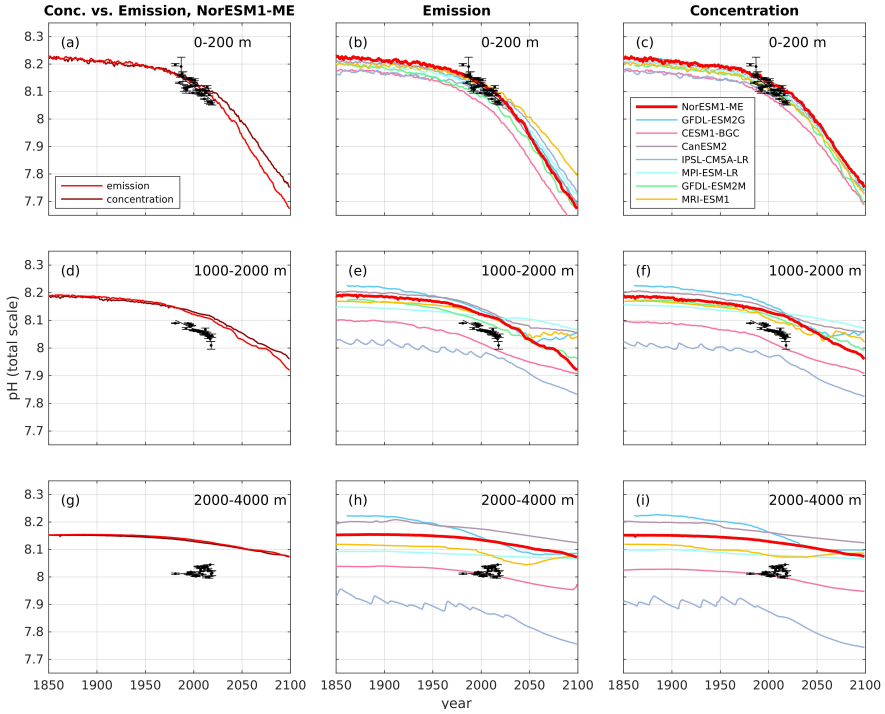

Figure S5. Nordic Seas mean pH evolution from 1850-2099 under the historical and RCP8.5 scenario, in the emission-driven versus the concentration-driven NorESM1-ME (left column), the ensemble of emission-driven ESM's (middle column), and the ensemble of concentration-driven ESM's (right column) at 0-200m (upper row), 1000-2000m (middle row) and 2000-4000m (lower row). The black dots with errorbars show annual means of observations with standard deviations.

Table S6. Change in pH calculated by applying the modelled change in C_T and A_T in the esmRCP8.5 scenario, between 1996-2005 and 2090-2099, to the GLODAP climatology, in the 8 different ESMs.

Depth (m)	0-200	1000-2000	2000-4000
NorESM1-ME	0.42	0.19	0.05
GFDL-ESM2G	0.37	0.09	0.03
CESM1-BGC	0.40	0.11	0.04
CanESM2	0.36	0.11	0.02
IPSL-CM5A-LR	0.29	0.13	0.09
MPI-ESM-LR	0.35	0.06	0.01
GFDL-ESM2M	0.37	0.14	0.04
MRI-ESM1	0.27	0.09	0.01

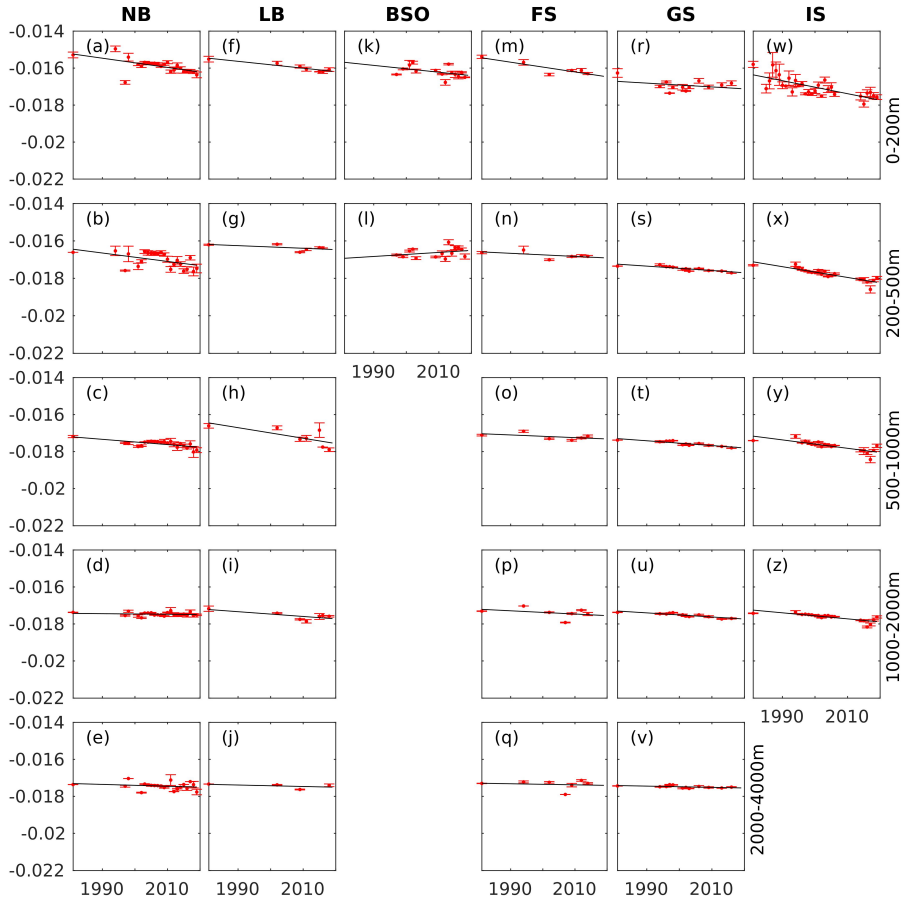

Figure S6. Annual mean uncertainty in pH (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression.

Table S7. Trends in pH uncertainty ± standard error (10^{-3} yr^{-1}) calculated from the data presented in Figure S6, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	**-0.02±0.01**	**-0.02±0.00**	-0.02±0.01	**-0.03±0.01**	-0.01±0.01	**-0.04±0.01**
200-500	**-0.02±0.01**	-0.01±0.00	-0.01±0.01	-0.01±0.01	**-0.01±0.00**	**-0.03±0.00**
500-1000	**-0.01±0.00**	-0.03±0.01		-0.01±0.01	**-0.01±0.00**	**-0.02±0.00**
1000-2000	-0.00±0.00	-0.01±0.01		-0.01±0.01	**-0.01±0.00**	**-0.02±0.00**
2000-4000	-0.00±0.01	-0.00±0.01		-0.00±0.01	-0.00±0.00	

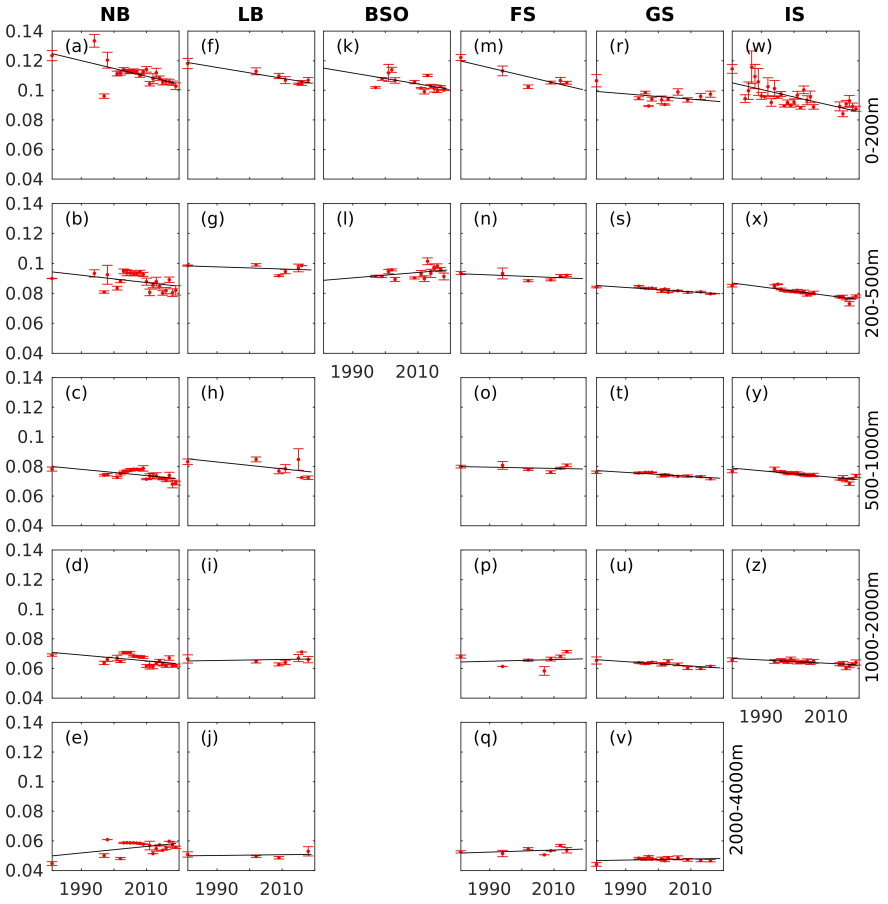

Figure S7. Annual mean uncertainty in Ω_{Ar} (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression.

Table S8. Trends in Ω_{Ar} uncertainty $\pm$ standard error (10^{-3} yr^{-1}) calculated from the data presented in Figure S7in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	**-0.53±0.14**	**-0.37±0.05**	**-0.37±0.15**	**-0.51±0.14**	-0.18±0.14	**-0.50±0.10**
200-500	**-0.25±0.12**	-0.07±0.10	0.18±0.13	-0.09±0.07	**-0.15±0.03**	**-0.29±0.03**
500-1000	**-0.21±0.07**	-0.23±0.16		-0.04±0.07	**-0.14±0.02**	**-0.20±0.03**
1000-2000	**-0.20±0.07**	0.04±0.09		0.06±0.17	**-0.15±0.03**	**-0.11±0.02**
2000-4000	**0.22±0.10**	0.03±0.08		0.07±0.07	0.04±0.05	

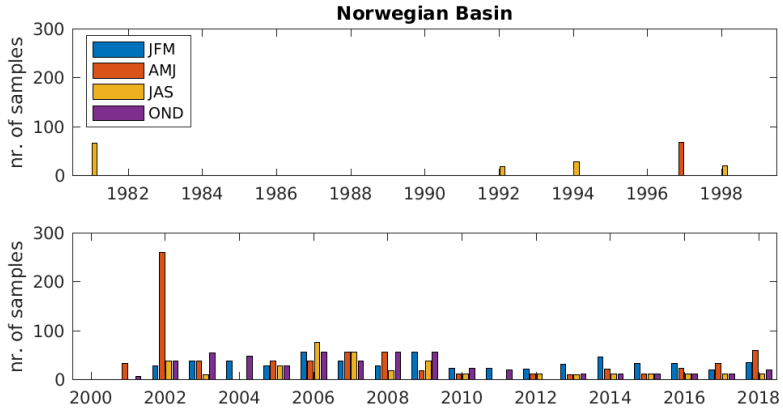

Figure S8. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Norwegian Basin (NB).

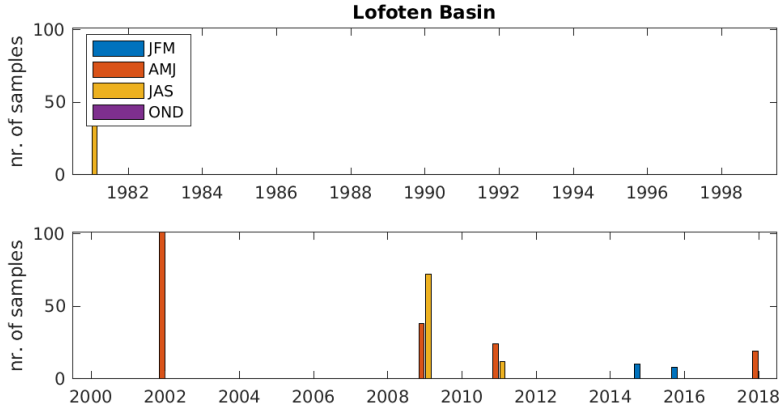

Figure S9. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Lofoten Basin (LB).

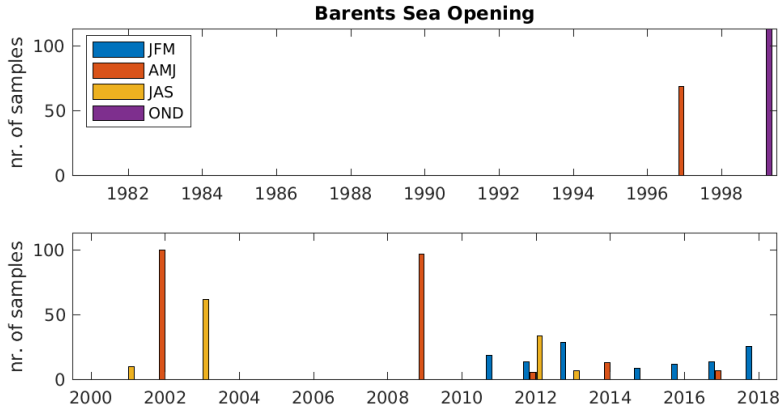

Figure S10. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Barents Sea Opening (BSO).

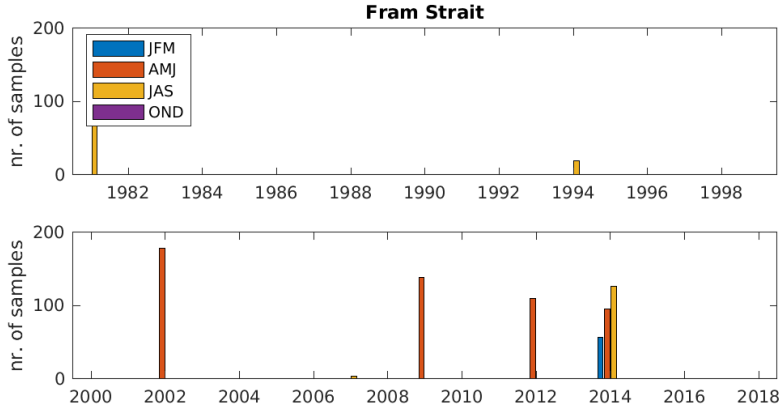

Figure S11. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Fram Strait (FS).

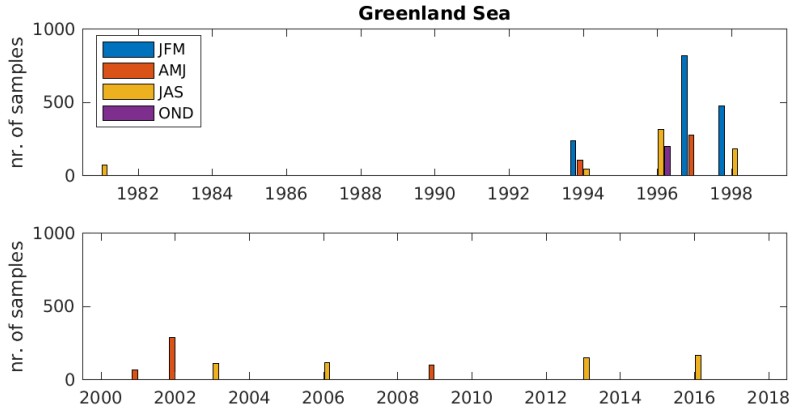

Figure S12. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Greenland Sea (GS).

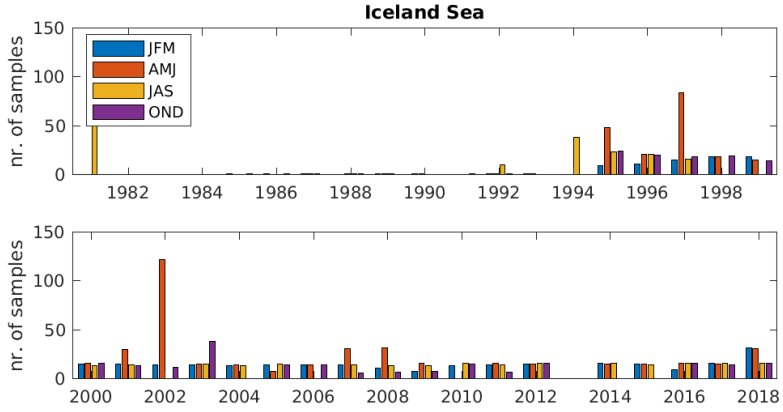

Figure S13. Number of measurements per season (JFM: January-March, AMJ: April-June, JAS:July-September, OND: October-December) and year, Iceland Sea (IS).

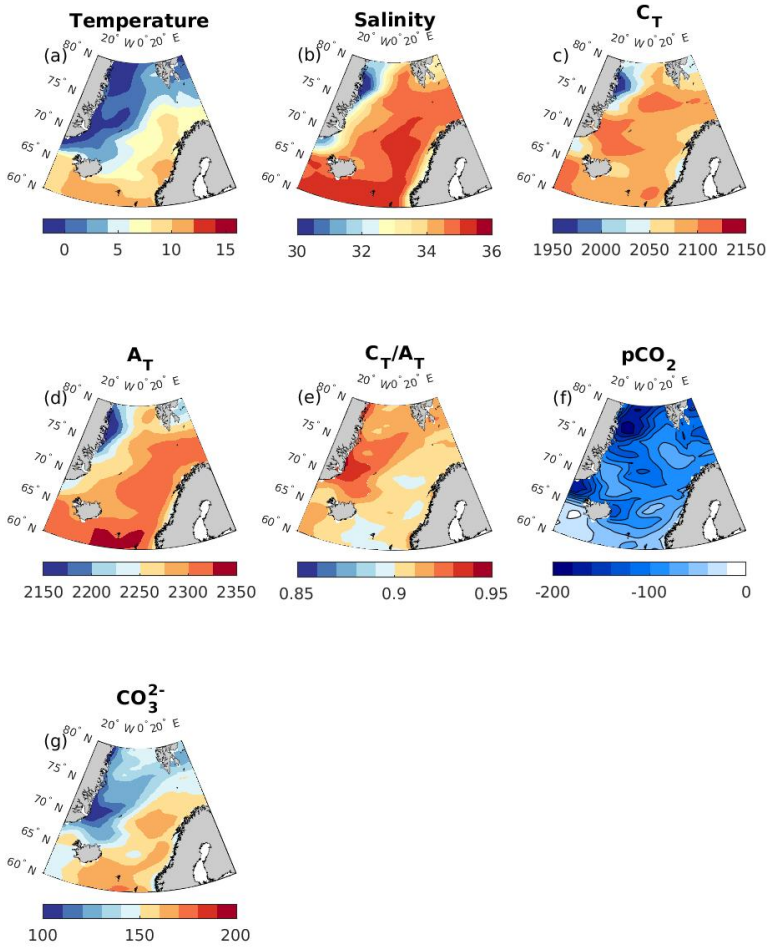

Figure S14. Distribution of surface a) temperature (°C) b) salinity, c) C_T (μmol kg^{-1}), d) A_T (μmol kg^{-1}), e) C_T/A_T, f) pCO_2 (in μatm) difference between the sea surface and the atmosphere, and g) carbonate ions (CO_3^{2-},μmol kg^{-1}), calculated from the GLODAPv2 climatology.

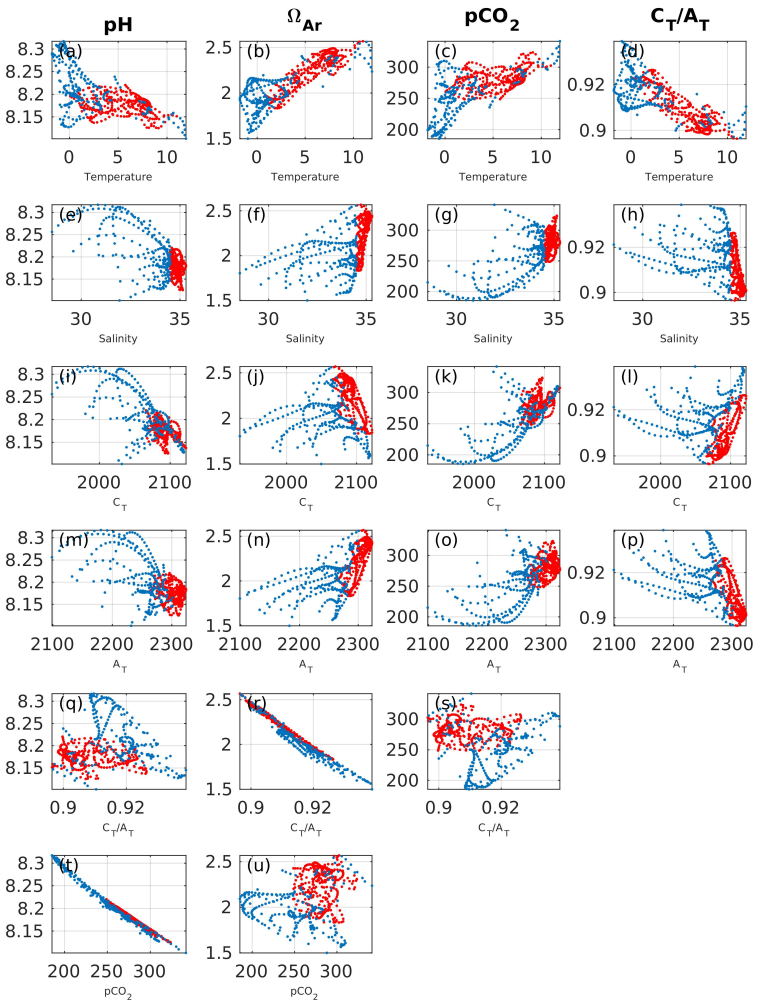

Figure S15. Scatter plots of surface pH (first column), Ω_{Ar} (second column), pCO_2 (μatm, third column) and C_T/A_T (fourth column), against temperature (°C, a-d), salinity (e-h), C_T (μmol kg^{-1}, i-l), A_T (μmol kg^{-1}, m-p), C_T/A_T (q-s), and pCO_2 (μatm,t-u), from the GLODAPv2 climatology, in Atlantic Water (red, salinity>34.5) and low-salinity waters (blue, salinity<34.5). See Fig. 3a in the main manuscript for the spatial distribution of the water masses. Each circle represents a value from one grid cell.

Table S9. Spatial correlation between various chemical and physical properties in the Nordic Seas surface (0 m) waters. Numbers in bold indicate significant correlation.

	pH	Ω_{Ar}	$p\mathrm{CO}_2$	C_T+A_T
Temperature	**-0.58**	**-0.86**	**0.66**	**-0.79**
Salinity	**-0.68**	**0.46**	**0.71**	**-0.35**
C_T	**-0.75**	-0.07	**0.74**	0.07
A_T	**-0.64**	**0.63**	**0.69**	**0.5**
C_T+A_T	-0.02	**-0.99**	-0.09	
$p\mathrm{CO}_2$	**-0.99**	**-0.23**		

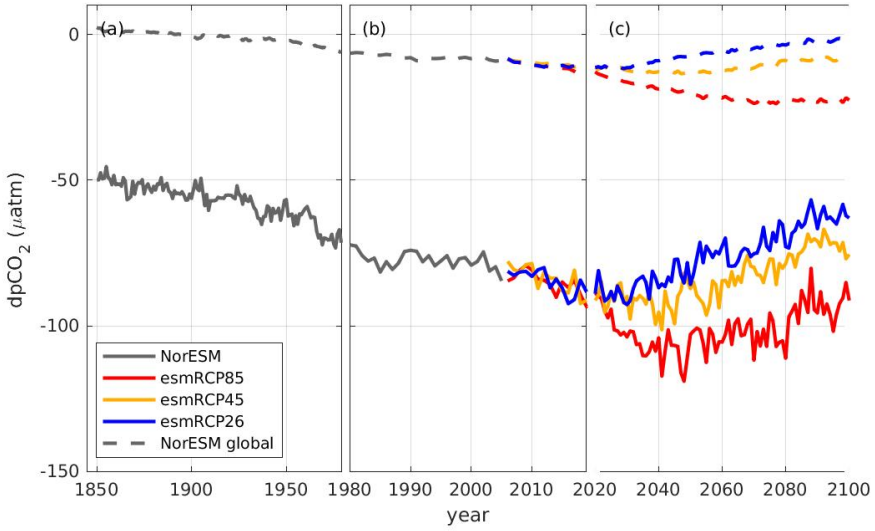

Figure S16. The evolution of the pCO_2 (in μatm) difference between the surface ocean and the atmosphere in the Nordic Seas (solid line) and the global ocean (dashed line), as simulated by the NorESM1-ME emission driven historical run (gray) and the RCP2.6 (blue), RCP4.5 (yellow), and RCP8.5 (red) scenarios.

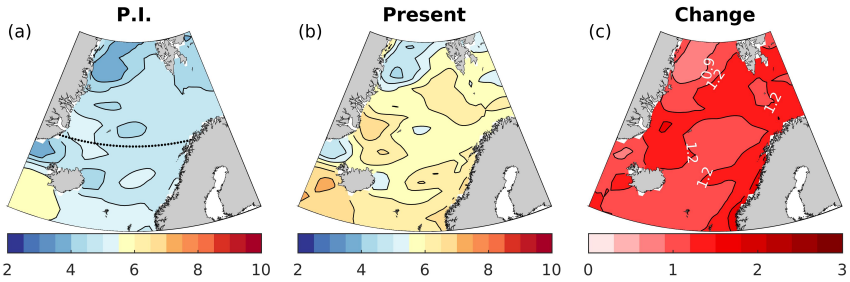

Figure S17. Maps of surface water (0 m) H^+ (nmol kg^{-1} for pre-industrial (P.I., 1850-1859) , present-day (1996-2005), and the change in between the two periods. The maps were calculated from the GLODAPv2 gridded climatologies (Lauvset et al., 2016) applying the simulated changes by NorESM1-ME.

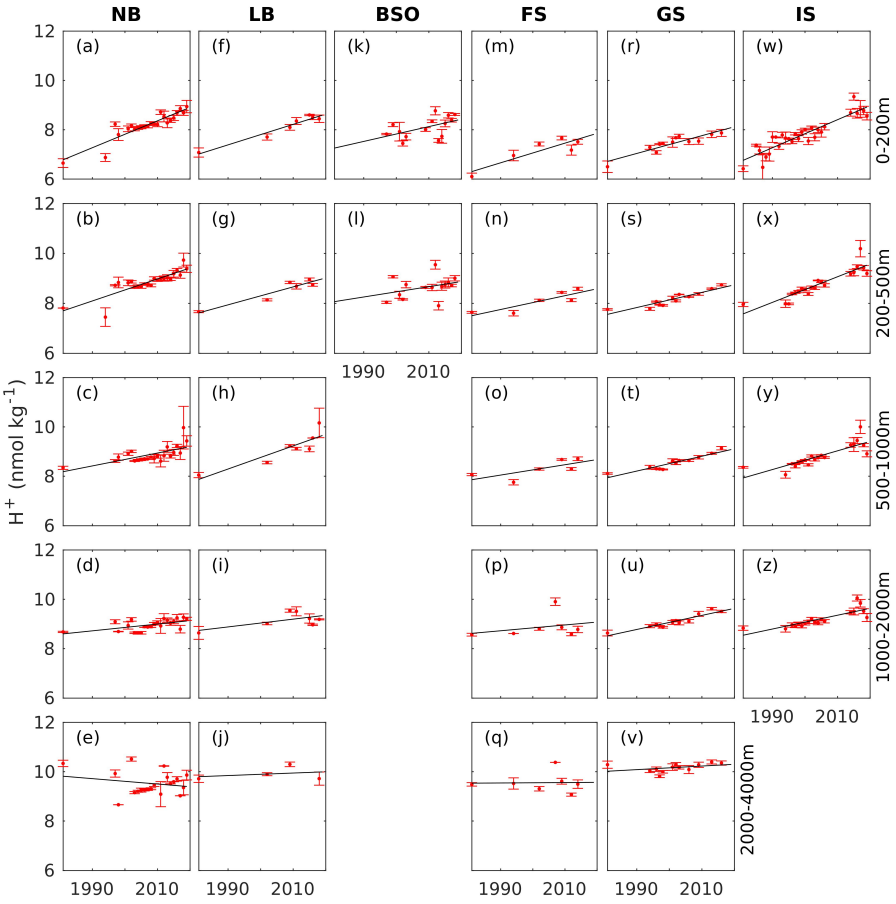

Figure S18. Annual mean H^+ (nmol kg^{-1}, red dots) with standard deviation (error bars), at five different depth levels in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). The solid black line show the trend estimate from the linear regression.

Table S10. H^+ trends ± standard error (10^{-11} mol kg^{-1} yr^{-1}) calculated from the data presented in Fig. S18, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	**5.45±0.55**	**4.15±0.44**	3.00±1.41	**3.98±1.03**	**3.61±0.53**	**5.68±0.50**
200-500	**4.41±0.60**	**3.59±0.63**	2.07±1.62	**2.76±0.78**	**3.04±0.40**	**5.13±0.59**
500-1000	**2.61±0.66**	**4.69±1.09**		2.09±0.98	**3.01±0.36**	**3.8±0.63**
1000-2000	**1.37±0.45**	1.58±0.85		1.17±1.71	**2.85±0.33**	**2.80±0.47**
2000-4000	-1.09±1.2	0.51±1.17		0.08±1.55	0.73±0.52	

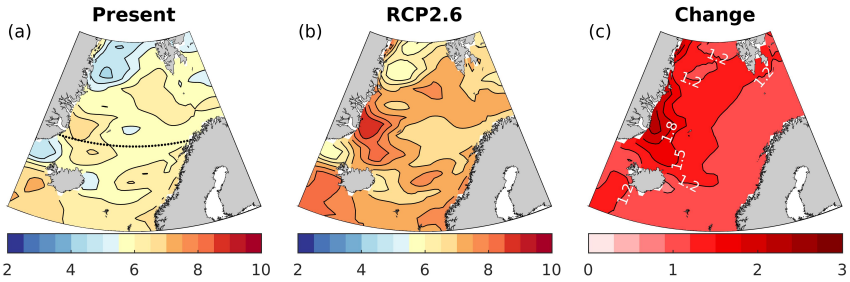

Figure S19. Maps of surface water (0 m) H^+ (nmol kg^{-1} for present-day (1996-2005), future RCP2.6 (2090-2099), and the change in between the two periods. The maps were calculated from the GLODAPv2 gridded climatologies (Lauvset et al., 2016) applying the simulated changes by NorESM1-ME.

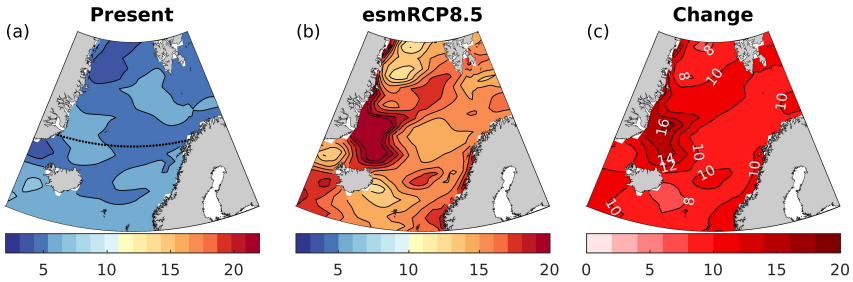

Figure S20. Maps of surface water (0 m) H^+ (nmol kg^{-1} for present-day (1996-2005), future RCP8.5 (2090-2099), and the change in between the two periods. The maps were calculated from the GLODAPv2 gridded climatologies (Lauvset et al., 2016) applying the simulated changes by NorESM1-ME.

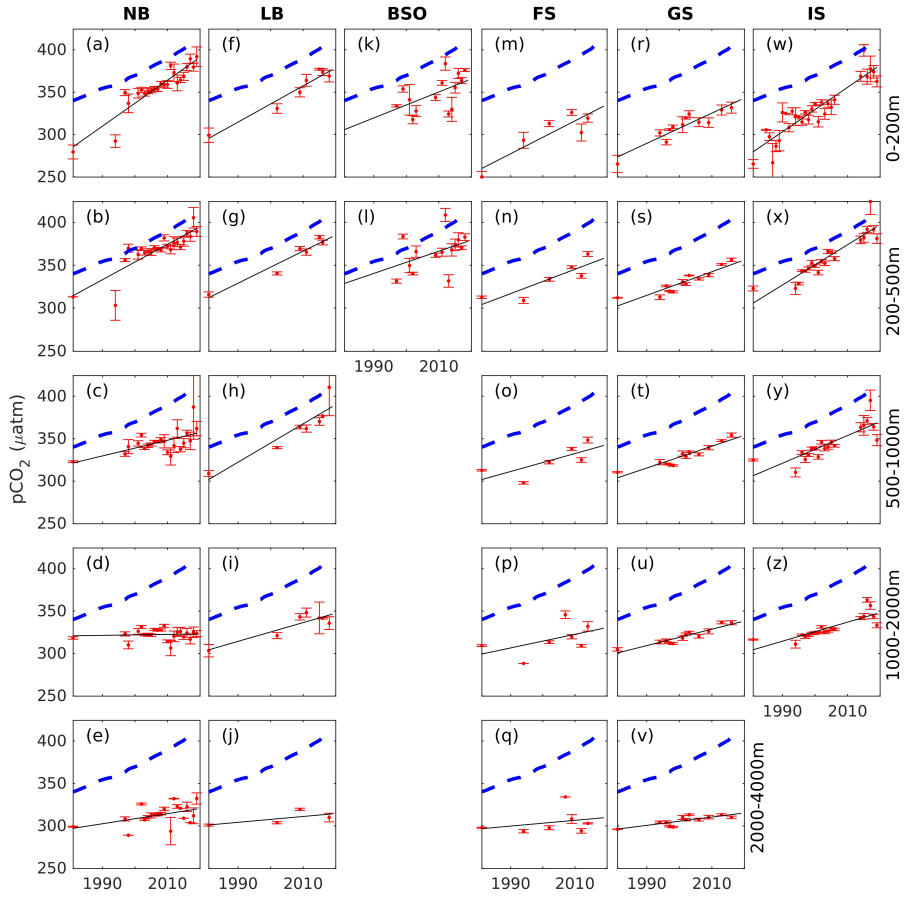

Figure S21. Annual mean pCO_2 in μatm, (red dots) with standard deviation (error bars) in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1), at five different depth levels. The solid black line show the trend estimate from the linear regression. The dashed blue line shows the atmospheric pCO_2 from the Mauna Loa records.

Table S11. pCO_2 trends $\pm$ standard error (μatm yr^{-1}) calculated from the data presented in Figure S21, in the Norwegian Basin (NB), Lofoten Basin (LB), Barents Sea Opening (BSO), Fram Strait (FS), Greenland Sea (GS) and the Iceland Sea (IS) (defined in Fig. 1). Bold numbers indicate that the trends are significantly different from zero.

Depth (m)	NB	LB	BSO	FS	GS	IS
0-200	**2.72±0.24**	**2.13±0.24**	1.53±0.71	**1.94±0.50**	**1.78±0.24**	**2.62±0.23**
200-500	**2.06±0.27**	**1.87±0.25**	1.30±0.77	**1.42±0.41**	**1.38±0.19**	**2.35±0.26**
500-1000	**0.92±0.28**	**2.26±0.43**		1.06±0.47	**1.29±0.15**	**1.63±0.28**
1000-2000	0.06±0.16	**1.11±0.25**		0.80±0.60	**0.97±0.12**	**1.12±0.18**
2000-4000	**0.60±0.27**	0.35±0.29		0.34±0.52	**0.49±0.11**	
Atmosphere	**1.80±0.03**					