Supporting Information for "Anthropogenic attribution of the increasing seasonal amplitude of surface ocean pCO_2 "

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References

Fay, A. R., Gregor, L., Landschützer, P., McKinley, G. A., Gruber, N., Gehlen, M., ... Zeng, J. (2021). Seaflux: harmonization of air–sea co_2 fluxes from surface pco_2 data products using a standardized approach. *Earth System Science Data*, *13*(10), 4693–4710. Retrieved from `https://essd.copernicus.org/articles/13/4693/2021/`

doi: 10.5194/essd-13-4693-2021

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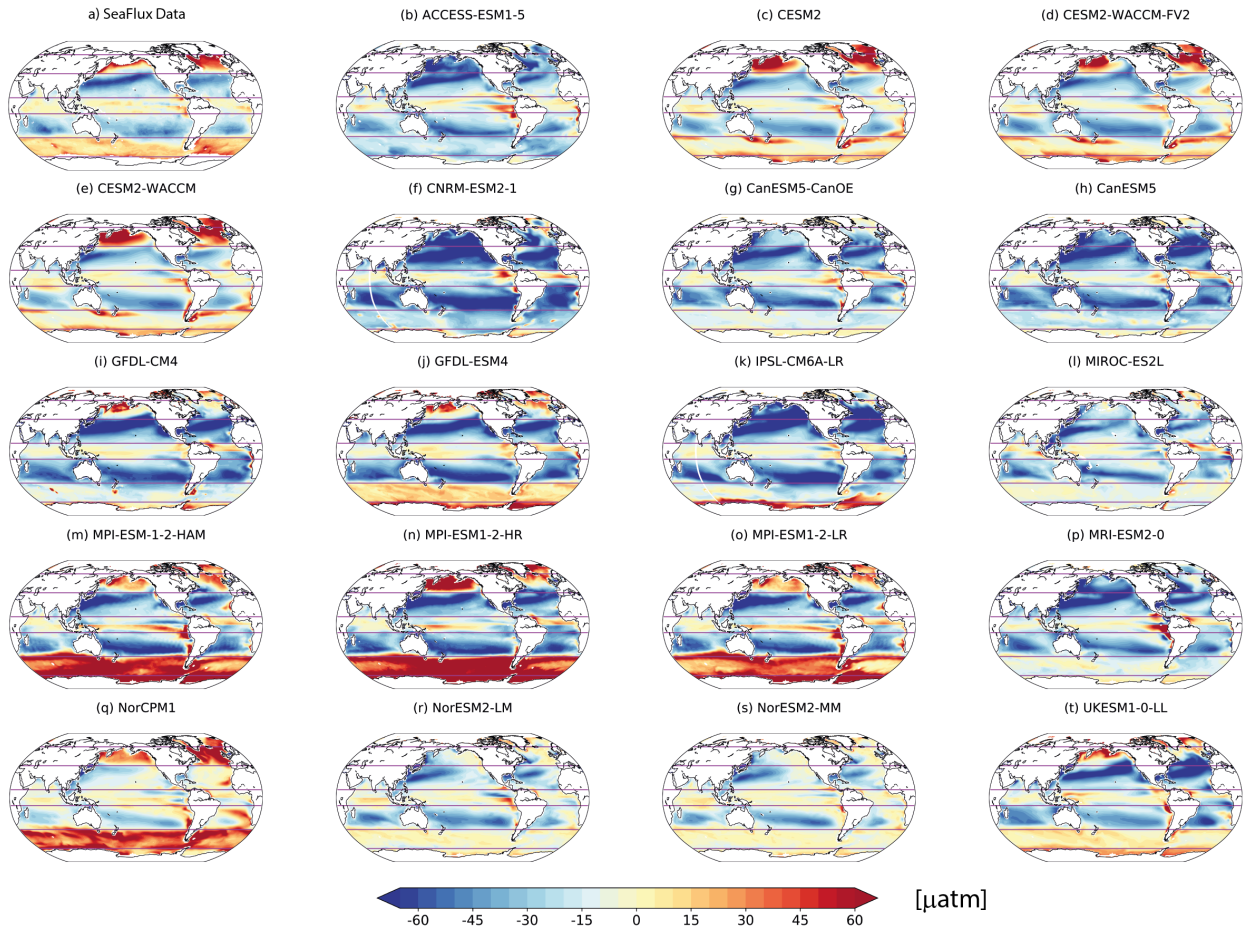

Figure S1. Climatology of the surface ocean pCO_2 seasonal cycle difference over 25 years (1990-2014) for (a) the median of the six observation-based products included in the SeaFlux data (Fay et al., 2021) and (b-t) from Earth System Model simulations (HIST). The seasonal cycle difference is the difference between the winter and summer mean ((DJF) minus (JJA) in the northern hemisphere and (JJA) minus (DJF) in the Southern Hemisphere).

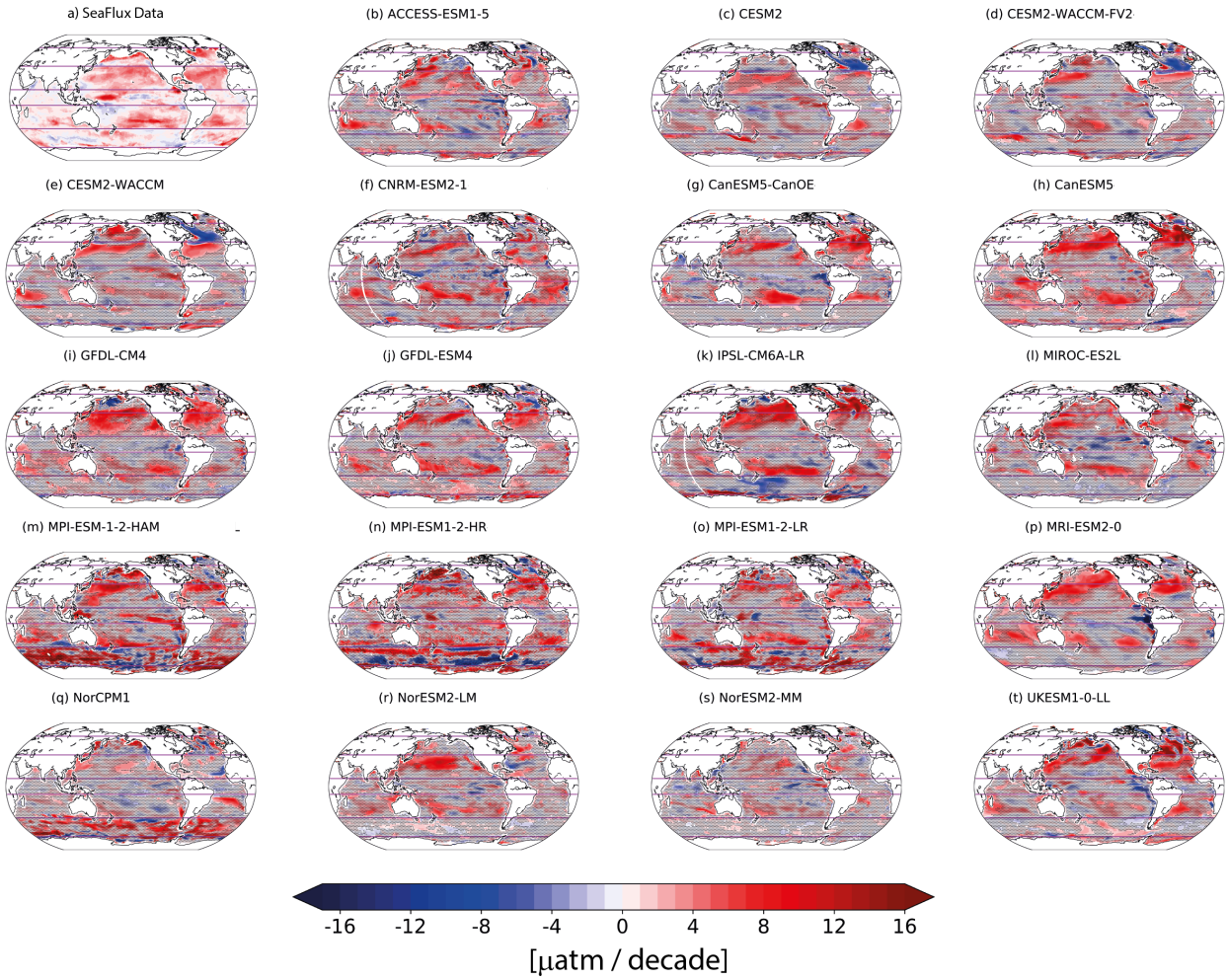

Figure S2. Observation-based (a) and simulated linear trends in the pCO_2 seasonal cycle amplitude over the period 1990-2014. Panel (a) displays the median for each grid-cell and for the linear trends derived from each of the six observation-based products included in the SeaFlux data (Fay et al., 2021). Only grid cells where all products have data are included. Earth System Models were run under anthropogenic and natural forcing (HIST). Dots indicate where the slope is not significant (95% confidence interval). The seasonal cycle amplitude is the absolute difference between the winter and summer mean ($|(DJF) - (JJA)|$).

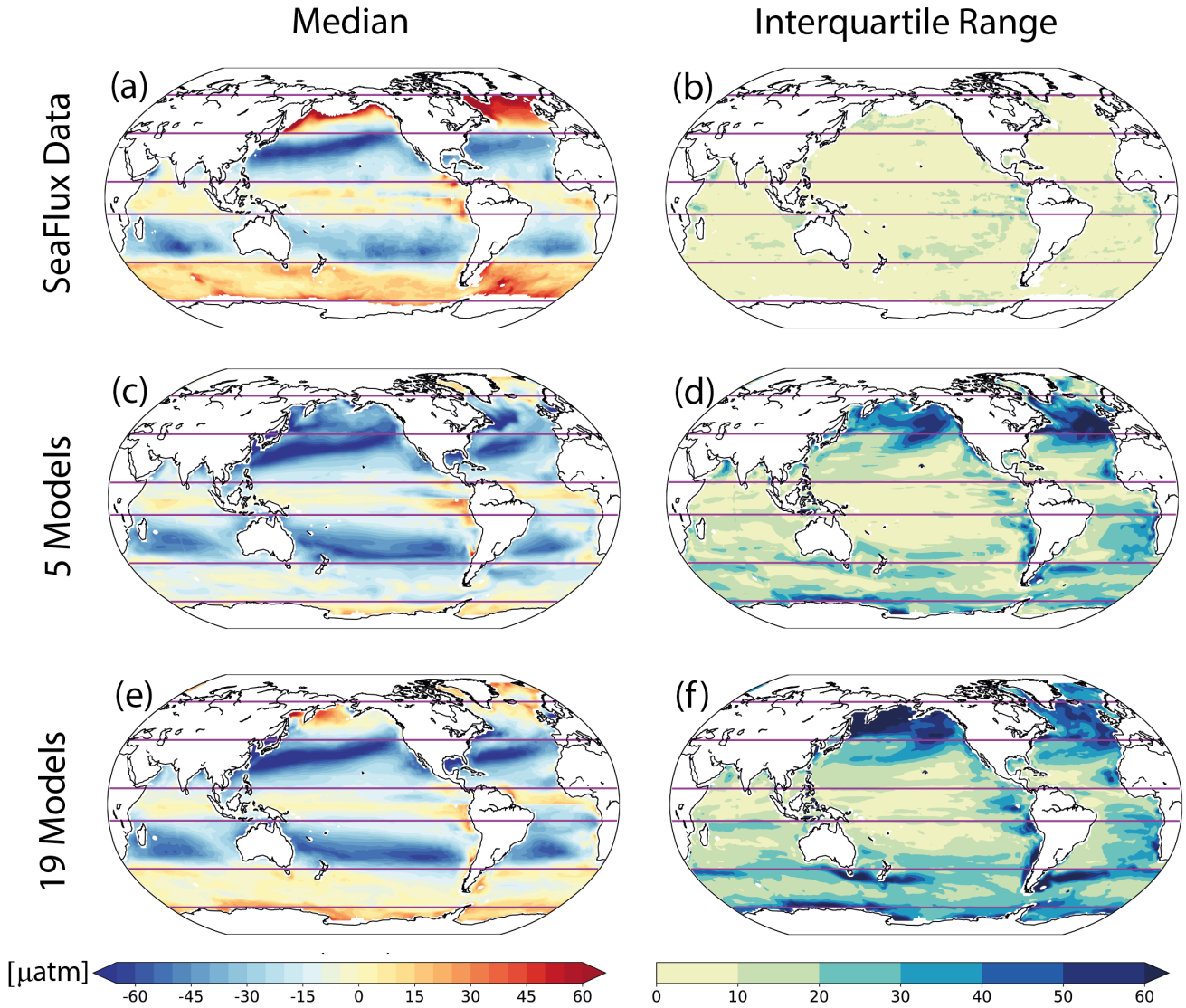

Figure S3. Climatology of the surface ocean pCO_2 seasonal cycle difference over 25 years (1990-2014) estimated from observation-based products and Earth System Model simulations (HIST). Median and Interquartile Range for the six products included in the SeaFlux data (Fay et al., 2021) (a,b), the five models shown in Fig. 1 (c,d), and the 19 models shown in Fig. S1 (e,f). The seasonal cycle difference is the difference between the winter and summer mean ((DJF) minus (JJA) in the northern hemisphere and (JJA) minus (DJF) in the Southern Hemisphere).

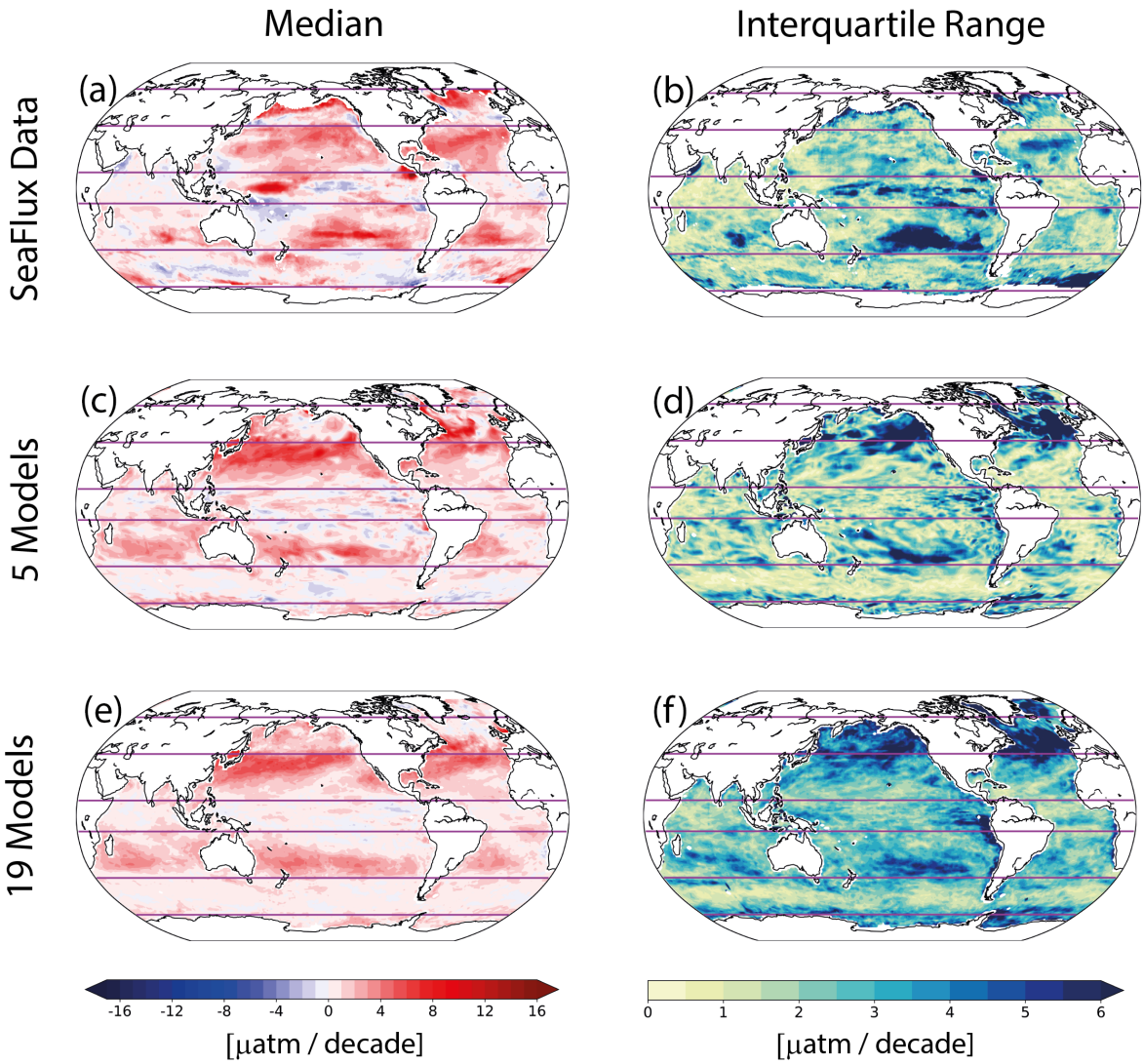

Figure S4. Simulated trends in the pCO_2 seasonal cycle amplitude over the period 1990-2014. Median and Interquartile Range for the six products shown in Fig. 2 (a,b), the five models shown in Fig. 2 (c,d) and the 19 models shown in Fig. S2 (e,f). Earth System Models were run under anthropogenic and natural forcing (HIST). The seasonal cycle amplitude is the absolute difference between winter and summer mean ($|(DJF) - (JJA)|$).

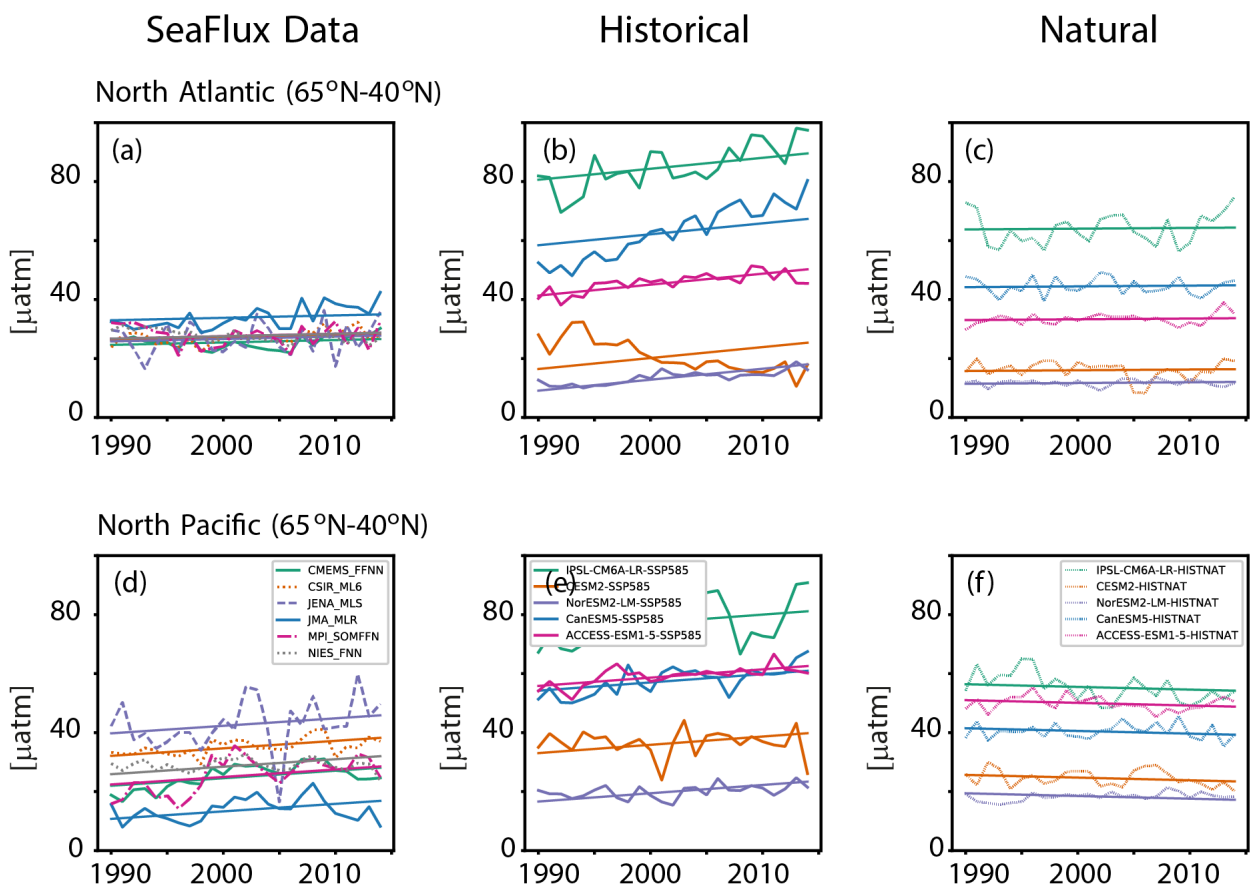

Figure S5. Same as Figure 3 of the main text but for the northern North Atlantic and northern North Pacific. Temporal evolution of the seasonal amplitude in pCO_2. Regional averages are for the ensembles of observational products (left) and simulations with historical (middle) and natural forcing only (right) for 1990-2014. Results from linear regressions are shown by thin solid lines, with identical slope, β, for each ensemble within a region following the ANCOVA model. Seasonal amplitudes are computed by first averaging the pCO_2 data over each region for 3-monthly periods and then taking the absolute difference between winter and summer values ($|DJF - JJA|$).

Table S1. As Table 1 in the main text but for the period 1982 to 1990. Temporal trends in the seasonal cycle amplitude of pCO_2 and attribution to anthropogenic forcing. Trends (β) and their standard errors (s, in parentheses) are estimated for five regions and 1982-2014 from data-based products (OBS) (Fay et al., 2021), and from results of five CMIP6 models (Gillett et al., 2016) with prescribed natural (HISTNAT), and natural and anthropogenic forcing (HIST). Trends significantly different from zero are shown in bold (based on a t-test at the 5% level of significance). For regions where trends are significant (detected) in the observations, the difference between simulated and observed trends is quantified using t-statistics (bold if not significant at the 5% level of significance) with effective degrees of freedom ν given in parentheses. Data are available from 1982 onward for CSIR-ML6, JENA-MLS, and MPI-SOMFFN, from 1985 onward for CMEMS-FFN and NIES-FNN, and from 1990 onward for JMA-MLR.

	Trend: $\beta(s)$ [μatm/decade]			$T(\nu)$ statistics for attribution	
Region	OBS	HIST	HISTNAT	OBS-HIST	OBS-HISTNAT
65°N-40°N	**1.48** (0.62)	**3.28** (0.47)	-0.32 (0.27)	-2.31 (64)	2.67 (37)
40°N-10°N	**2.09** (0.33)	**2.53** (0.22)	0.21 (0.13)	**-1.13** (53)	5.31 (34)
10°N-10°S	0.46 (0.48)	0.23 (0.20)	-0.03 (0.12)		
10°S-40°S	**1.83** (0.38)	**1.31** (0.14)	0.08 (0.08)	**1.29** (34)	4.55 (28)
40°S-65°S	**0.89** (0.38)	0.14 (0.19)	0.05 (0.11)	**1.76** (40)	2.12 (30)

Table S2. As Table 1 in the main text and Table S1 but for the northern North Pacific (65°N-40°N) and the northern North Atlantic (65°N-40°N).

	Trend: $\beta(s)$ [μatm/decade]			$T(\nu)$ statistics for attribution	
Region	OBS	HIST	HISTNAT	OBS-HIST	OBS-HISTNAT
		Period 1982-2014			
northern North Atlantic	0.41 (0.67)	**3.53** (0.64)	-0.15 (0.37)		
northern North Pacific	**2.31** (0.96)	**3.08** (0.56)	-0.47 (0.33)	**-0.70** (46)	2.73 (32)
		Period 1990-2014			
northern North Atlantic	0.83 (0.95)	**3.71** (0.96)	0.26 (0.55)		
northern North Pacific	2.54 (1.31)	**2.81** (0.80)	-0.91 (0.46)		

Table S3. As Table 1 in the main text and Table S1 and S2 but for trends in the seasonal cycle difference (SD) for 1990-2014. SD is the winter minus summer difference ((DJF)-(JJA) in the northern hemisphere and tropical regions and (JJA-DFJ) for 10°S-40°S and 40°S-65°S) of surface ocean pCO_2.

	Trend: $\beta(s)$ [μatm/decade]			$T(\nu)$ statistics for attribution	
Region	OBS	HIST	HISTNAT	OBS-HIST	OBS-HISTNAT
65°N-40°N	**1.81** (0.83)	**-4.46** (0.56)	0 (0.33)	6.26 (38)	**2.03** (24)
40°N-10°N	**-1.99** (0.39)	**-2.7** (0.34)	-0.22 (0.20)	**1.37** (53)	-4.01 (28)
10°N-10°S	0.43 (1.04)	-0.09 (0.37)	-0.18 (0.21)		
10°S-40°S	**-1.82** (0.4)	**-1.47** (0.22)	-0.01 (0.13)	**-0.76** (30)	-4.27 (22)
40°S-65°S	0.89 (0.45)	0.25 (0.28)	**-0.33** (0.16)		
northern North Atlantic	0.83 (0.95)	**-6.19** (0.78)	-0.54 (0.45)		
northern North Pacific	2.54 (1.31)	**-2.95** (0.80)	0.50 (0.46)		