Supporting Information for "Long-term global ocean heat content change driven by sub-polar surface heat fluxes"

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Introduction This document outlines further details of the suite of CMIP6 models used in this study, as well as the steps taken to analyse the CMIP6 diagnostics.

Text S1 provides information on the specific CMIP6 model members studied and the relevant references (shown in Table S1). Text S2 lays out the procedure for calculating the OHC and surface heat flux tendencies in the CMIP6 models.

Text S1.

Table S1 summarises the models and ensemble members used in this study. Only the first ensemble member was used from each model because all ensemble members from a given model tended to produce similar results.

	Model Name	Ensemble Member	Data Citations
1	ACCESS-CM2	r1i1p1f1	Dix et al. (2019a, 2019b)
2	ACCESS-ESM1-5	r1i1p1f1	Ziehn et al. (2019a, 2019b)
3	CAMS-CSM1-0	r1i1p1f1	Rong (2019a, 2019b)
4	CanESM5	r1i1p1f1	Swart et al. (2019c, 2019d)
5	CanESM5-CanOE	r1i1p2f1	Swart et al. (2019a, 2019b)
6	CESM2	r1i1p1f1	Danabasoglu (2019c); Danabasoglu et al. (2019)
7	CESM2-FV2	r1i1p1f1	Danabasoglu (2019a, 2019b)
8	CESM2-WACCM-FV2	r1i1p1f1	Danabasoglu (2019d, 2019e)
9	CESM2-WACCM	r1i1p1f1	Danabasoglu (2019f, 2019g)
10	CIESM	r1i1p1f1	Huang (2019a, 2019b)
11	CMCC-CM2-SR5	r1i1p1f1	Lovato and Peano (2020a, 2020b)
12	CNRM-CM6-1	r1i1p1f2	Voldoire (2018a, 2018b)
13	CNRM-ESM2-1	r1i1p1f2	Seferian (2018a, 2018b)
14	EC-Earth3	r1i1p1f1	EC-Earth (2019a, 2019b)
15	EC-Earth3-Veg	r1i1p1f1	EC-Earth (2019c, 2019d)
16	EC-Earth3-Veg-LR	r1i1p1f1	EC-Earth (2020a, 2020b)
17	GFDL-ESM4	r1i1p1f1	Krasting et al. (2018a, 2018b)
18	GISS-E2-1-G	r1i1p1f1	NASA-GISS (2018a, 2018b)
19	GISS-E2-1-G-CC	r1i1p1f1	NASA-GISS (2019a, 2019b)
20	HadGEM3-GC31-LL	r1i1p1f3	Ridley et al. (2019, 2018)
21	IPSL-CM6A-LR	r1i1p1f1	Boucher et al. (2018a, 2018b)
22	MCM-UA-1-0	r1i1p1f1	Stouffer (2019a, 2019b)
23	MPI-ESM-1-2-HAM	r1i1p1f1	Neubauer et al. (2019a, 2019b)
24	MPI-ESM1-2-HR	r1i1p1f1	Jungclaus et al. (2019a, 2019b)
25	MPI-ESM1-2-LR	r1i1p1f1	Wieners et al. (2019a, 2019b)
26	NorCPM1	r1i1p1f1	Bethke et al. (2019a, 2019b)
27	NorESM2-LM	r1i1p1f1	Seland et al. (2019a, 2019b)
28	NorESM2-MM	r1i1p1f1	Bentsen et al. (2019a, 2019b)
29	SAM0-UNICON	r1i1p1f1	Park and Shin (2019a, 2019b)
30	UKESM1-0-LL	r1i1p1f2	Tang et al. (2019a, 2019b)

Table S1. CMIP6 models used in this study. The data citations correspond to the historical and piControl experiments, respectively.

Text S2.

In order to calculate the OHC tendency in temperature coordinates for each CMIP6 model, OHC (calculated using the grid cell volume *volcello* and sea water potential temperature *thetao* model diagnostics) was binned in temperature coordinates to yield annual mean time series for both the historical and piControl experiments. Model drift was then quantified by fitting a cubic polynomial to the full length of the piControl time series at each temperature interval. The time period in the piControl experiment that parallels the 1970–2014 period was identified using the branch time information provided in the file metadata, so that the correct segment of the cubic polynomial could then be subtracted from the historical experiment in order to produce a de-drifted OHC time series at each temperature interval. The slope of the linear regression of each de-drifted time series was taken as an estimate of the OHC tendency. Model drift, and therefore the effect of de-drifting, was most pronounced in the deep waters corresponding to temperatures colder than $\sim 7.5°$C.

In order to calculate the surface heat flux tendency in temperature coordinates, the net surface heat flux (taken from the *hfds* diagnostic) was binned in surface temperature coordinates to yield a time-integrated annual time series for both the historical and piControl experiments. The time-integrated surface heat flux anomaly, Q_{cum}, was then calculated by taking the difference between the historical and piControl time series:

$$Q_{cum}(\Theta^*, t) = \int\int\int_{\Theta_1^* < \Theta(x,y,t) < \Theta_2^*} Q dxdydt|_{historical} - \int\int\int_{\Theta_1^* < \Theta(x,y,t) < \Theta_2^*} Q dxdydt|_{control}, \tag{1}$$

where Q is the net surface heat flux in W/m^2, $[\Theta_1^*, \Theta_2^*]$ are the lower and upper temperature bounds respectively and $\Theta(x, y, t)$ is the sea surface temperature.

The surface-integrated heat flux for temperatures warmer than Θ^*, $\mathcal{F}(\Theta^*, t)$, is then given by:

$$\mathcal{F}(\Theta^*, t) = \int_{\Theta^*}^{\Theta^*_{max}} \frac{\partial Q_{cum}}{\partial t} d\Theta^*. \tag{2}$$

Finally, the surface heat flux tendency is approximated as the slope of the linear regression of the time series of $\mathcal{F}$ from 1970 to 2014.

It is worth noting that there can be substantial drift in CMIP6 time-integrated ocean surface fluxes due to non-closure of the heat budget [Irving, Hobbs, Church, and Zika (2020)], however by taking the difference between the historical and piControl experiments when calculating the time-integrated surface heat flux anomaly, that drift is effectively removed. All terms binned in temperature are subsequently interpolated onto temperature-percentile space.

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