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Transports through the Arctic gateways linked to the ocean gyres in the Carbon Dioxide removal CMIP6 simulations

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What?

- Variability of the Arctic gyres can change Arctic–Nordic Sea connectivity.
- The gyres impact exports of freshwater, heat and biogeochemical tracers from the Arctic to the North Atlantic.
- Potential link with Sub-Polar Gyre *(SPG)* and Atlantic Meridional Overturning Circulation *(AMOC)* variability: impacts on European and Global ocean climates.

Why this matters?

- Gyres play a key role in connecting Arctic and North Atlantic.
- Potentially week deep-waters connectivity between the Arctic and North Atlantic at present.
- The connectivity is variable and may change in the future.

How?

- Examine ocean barotropic stream-functions of mean oceanic flow in UKESM runs under the scenarioMIP CMIP6 emission driven overshoot scenario with carbon dioxide removal esm-SSP534-ov[1].
- Vertically integrated oceanic barotropic stream functions (BSF) are calculated for non-divergent oceanic flow[2] and provide information on the depth-averaged oceanic circulation, large scale ocean gyres and transports through hydrographic transects/mooring arrays, such as RAPID, OSNAP and Arctic gateways.

What is found?

- By the 2040s, the Beaufort Gyre (BG) is weak, whereas the Subpolar Gyre (SPG) and Subtropical Gyre (STG) are strong (Figure 1a).
- During further increase of CO_2 in the 2040s–2060s, the Beaufort Gyre (BG) is getting stronger, whereas the Subpolar Gyre (SPG) and Subtropical Gyre (STG) weaken (Figure1a,b).
- During the Carbon Dioxide Removal (2060s–2090s), BG strengthens and SPG and STG further weakens (Figure 1c,d).
- Cyclonic gyres in the Greenland, Iceland and Norwegian seas – the Nordic Seas Gyres (NSG) are becoming stronger through the 2040-2090s. – Potential future change in the oceanic pathways between the Arctic and the North Atlantic.
- Model volume fluxes show changes in the Barents Sea, and in the Fram, and Davis straits partitioning between the decades. Bering Strait inflow is stable (Table 1).
- Historical fluxes are within observational uncertainties (Figure 2, Table 1).
- Different trends in the North Atlantic ocean heat transport due to overturning and gyres and different reversibility at latitudes between 26°N and 80°N in the CMIP6 UKESM runs also suggest the loss of immediate oceanic connectivity between the Atlantic and the Arctic via Nordic Seas (Figure 3a).
- The delay lag between atmospheric CO_2 (magenta line in Figure 3a) and oceanic heat response can provide an Early Warning Signal (EWS) for the AMOC and heat transport changes (Figure 3a).
- UKESM CMIP6 overshoot experiments exhibit a hysteresis in the AMOC, suggesting that the AMOC does not recover to the same level as before the mitigation even if the atmospheric CO_2 concentration does (Figure 3b).
- Arctic becomes decoupled from the North Atlantic (Figure 4).

Table 1. Modelled and observed ocean volume fluxes through the Arctic gateways in the UKESM integrations under the CMIP6 emission driven overshoot scenario esm-SSP534-ov. (-e) is from the Arctic.

Period	Observations (present)		1997-2014		2040s	2060s	2090s
Gateway	Mean (Sv)	STD (Sv)	Net Mean (Sv)	Net STD (Sv)	Net Mean (Sv)	Net Mean (Sv)	Net Mean (Sv)
Bering Strait	1.00	0.70	1.20	0.80	0.78	0.91	0.84
Barents Sea	2.30	0.70	3.00	0.50	5.13	5.09	5.47
Davis Strait	-1.60	0.50	-1.80	0.60	-1.96	-1.65	-2.24
Fram Strait	-2.20	2.10	-2.40	0.98	-4.37	-4.82	-4.38
Hudson Strait	-0.10	0.10	-0.01	0.01	-0.01	-0.005	-0.001
Jones Sound (closed)	-0.30	0.10	0.00	0.00	0.00	0.00	0.00
Lancaster Sound	-0.69	0.30	-0.23	0.10	-0.23	-0.24	-0.36
Nares Strait	-0.87	0.10	-0.55	0.50	-0.71	-0.53	-0.77

References

[1]Jones et al. (2020), Earth System Grid Federation, 10.22033/ESGF/CMIP6.12203.

[2]Griffies et al. (2016), H26, Geosci. Model Dev., 9, 3231–3296, 10.5194/gmd-9-3231-2016.

[3]Robson et al. (2020), JAMES, e2020MS002126, 10.1029/2020MS002126.

[4]Sina et al. (2023), ESD, (in review), 10.5194/egusphere-2023-2589.

[5]Rynders et al. (2024), 10.5194/egusphere-egu24-18992.

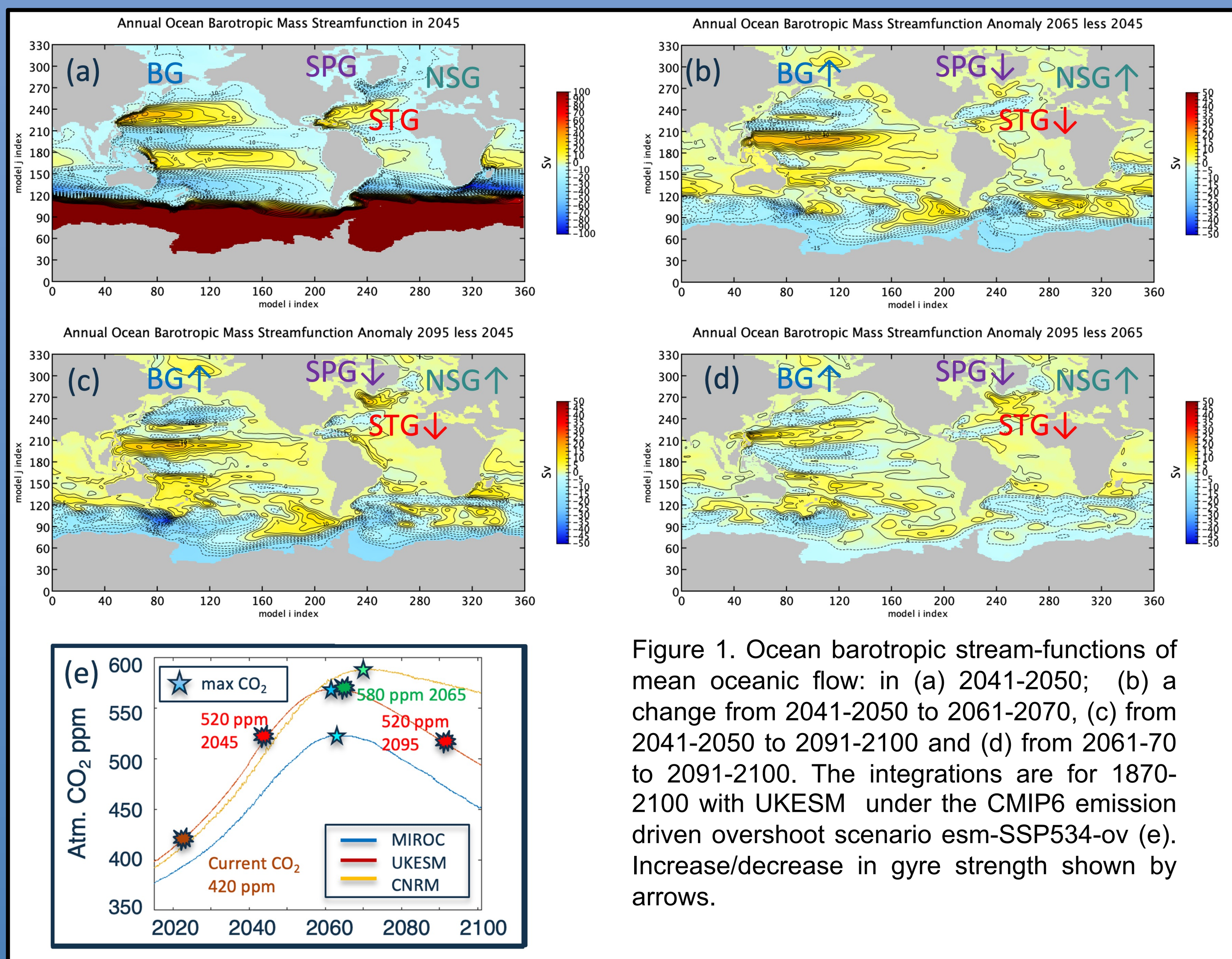

Figure 1. Ocean barotropic stream-functions of mean oceanic flow: in (a) 2041-2050; (b) a change from 2041-2050 to 2061-2070, (c) from 2041-2050 to 2091-2100 and (d) from 2061-70 to 2091-2100. The integrations are for 1870-2100 with UKESM under the CMIP6 emission driven overshoot scenario esm-SSP534-ov (e). Increase/decrease in gyre strength shown by arrows.

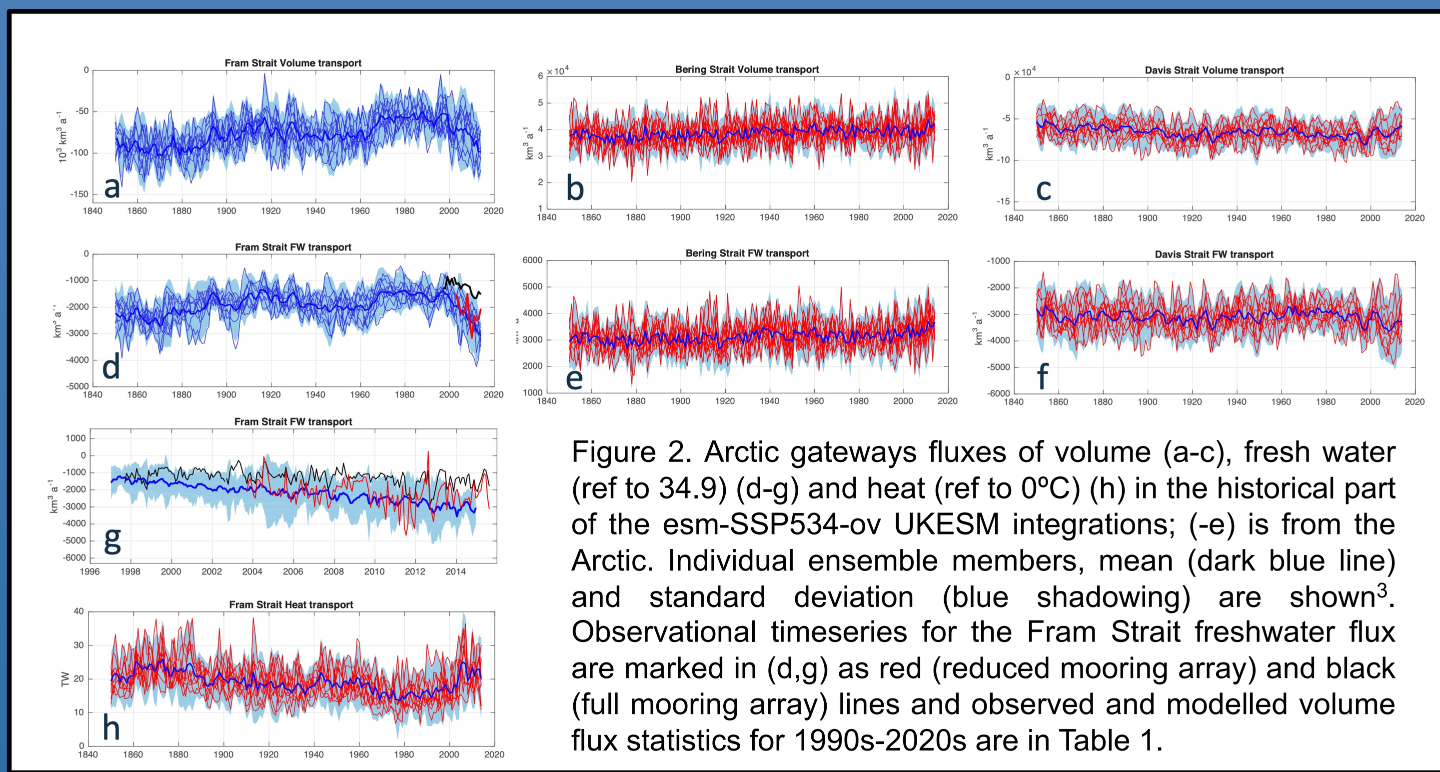

Figure 2. Arctic gateways fluxes of volume (a-c), fresh water (ref to 34.9) (d-g) and heat (ref to 0ºC) (h) in the historical part of the esm-SSP534-ov UKESM integrations; (-e) is from the Arctic. Individual ensemble members, mean (dark blue line) and standard deviation (blue shadowing) are shown[3]. Observational timeseries for the Fram Strait freshwater flux are marked in (d,g) as red (reduced mooring array) and black (full mooring array) lines and observed and modelled volume flux statistics for 1990s-2020s are in Table 1.

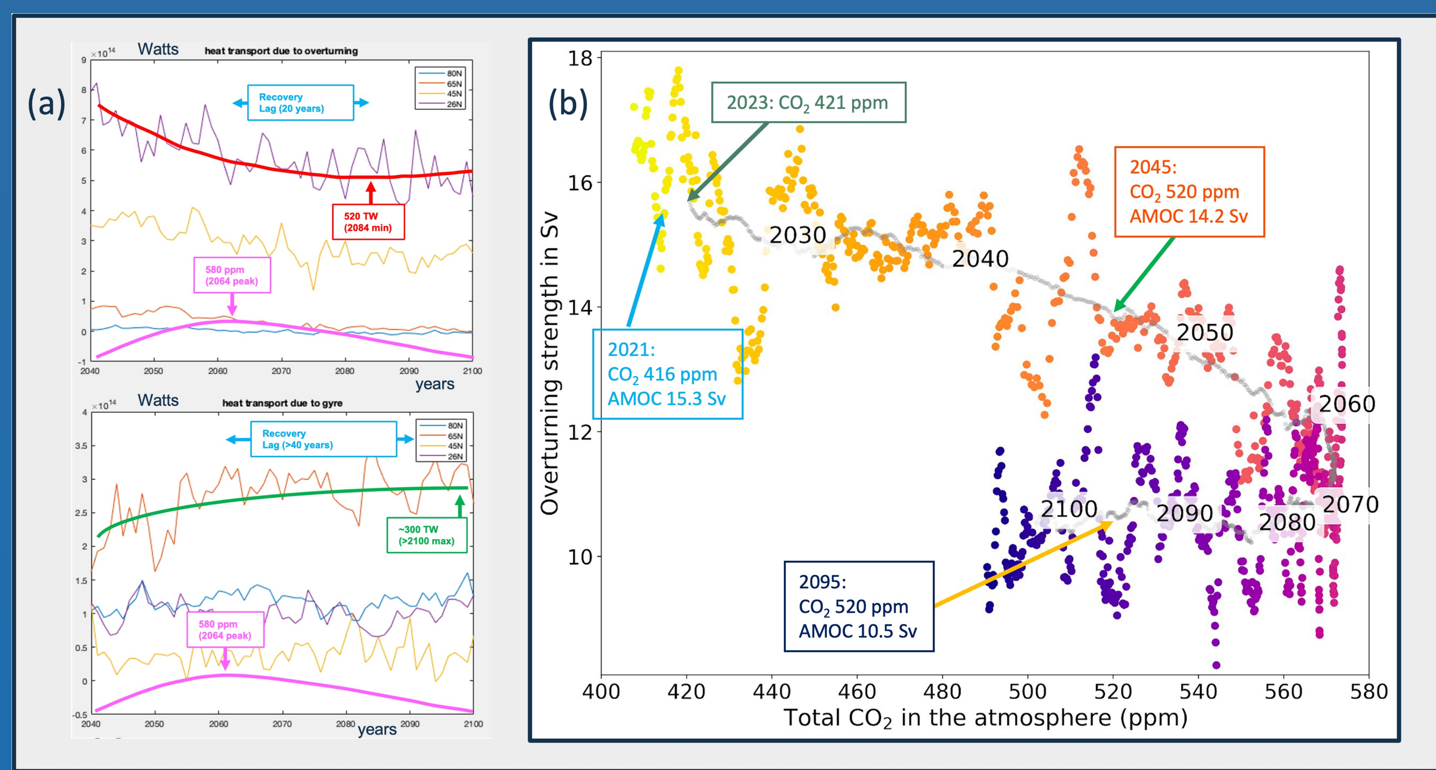

Figure 3. (a) Changes in the North Atlantic ocean heat transport at various latitudes (coloured lines) due to overturning (top), and gyres (bottom), – delay lag in transports recovery is shown; (b) apparent hysteresis in AMOC in overshoot esm-SSP534-ov emission scenario in CMIP6 UKESM run[4], details in [5].

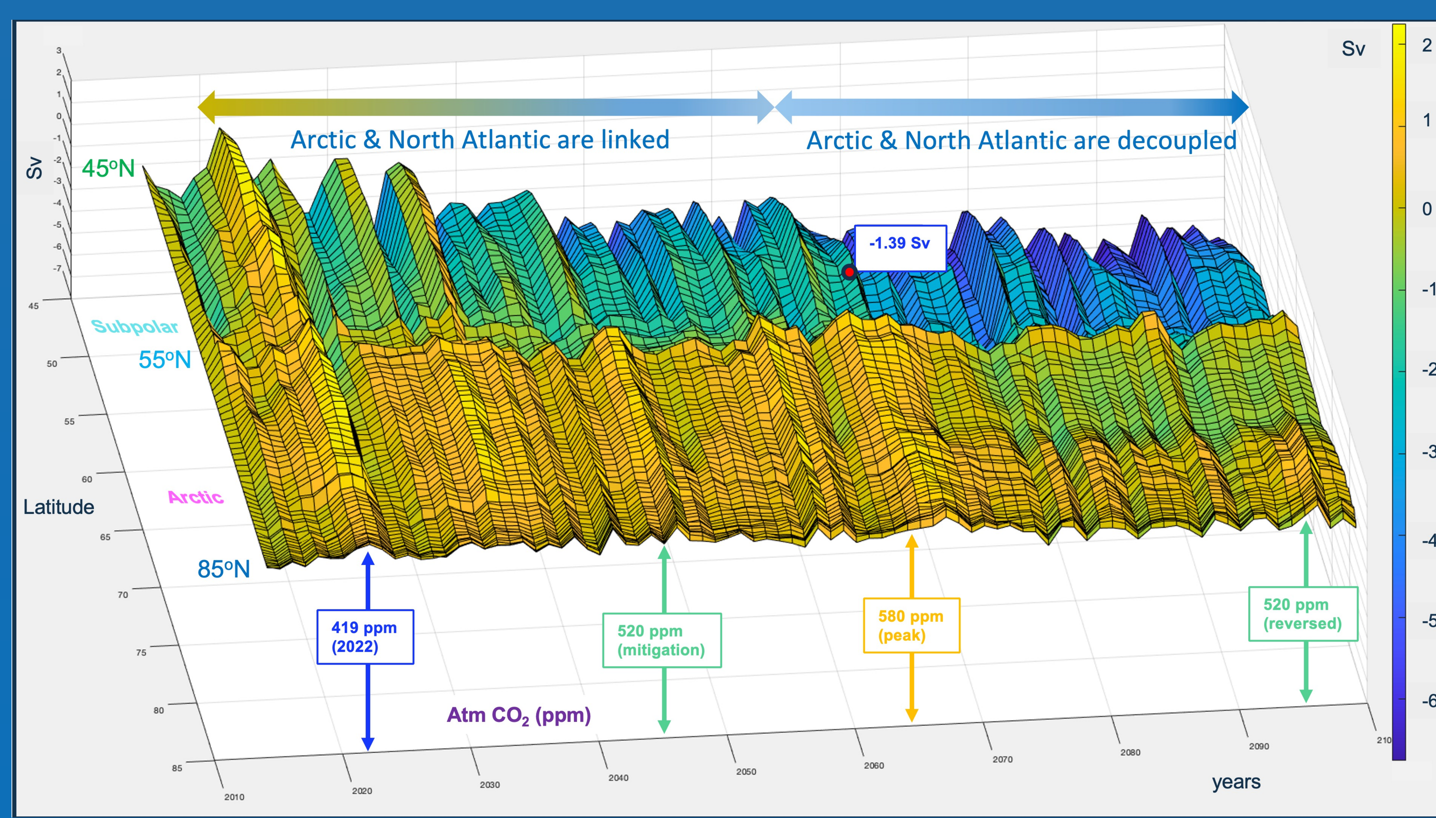

Figure 4. Hovmöller diagram of the North Atlantic Overturning (AMOC) strength anomaly shows decoupling of the North Atlantic and Arctic overturning after the 2060s. UKESM scenario esm-SSP534-ov.

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