Coupled stratosphere-troposphere-Atlantic multidecadal oscillation and its importance for near-future climate projection

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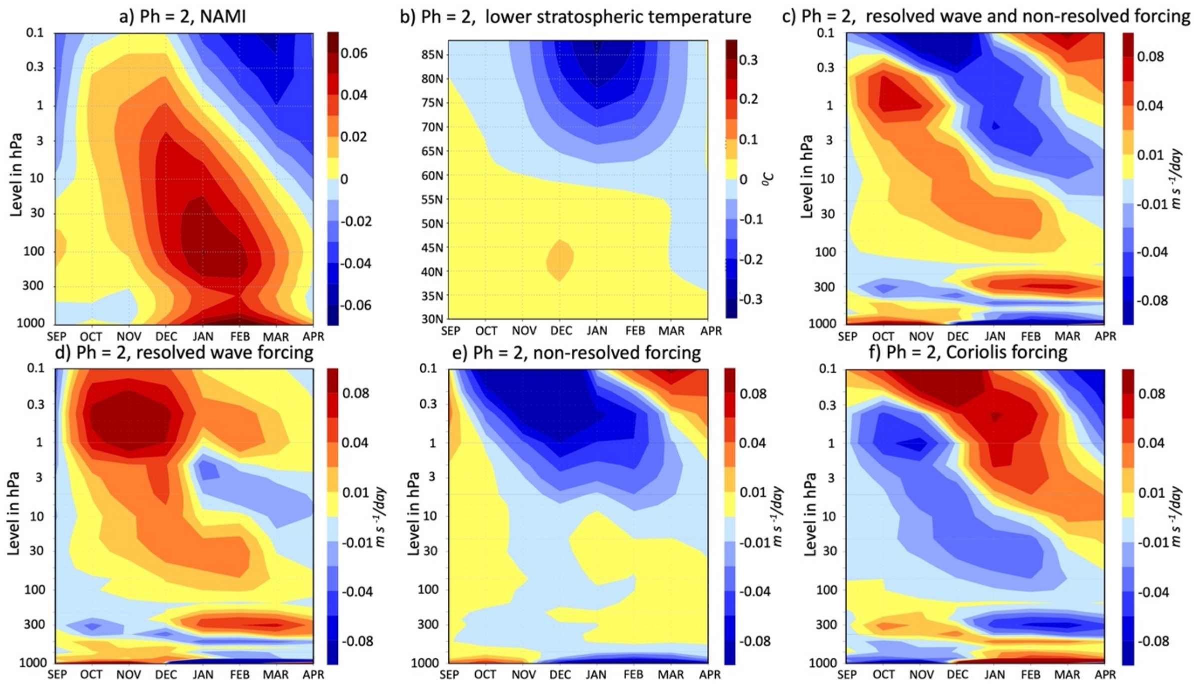
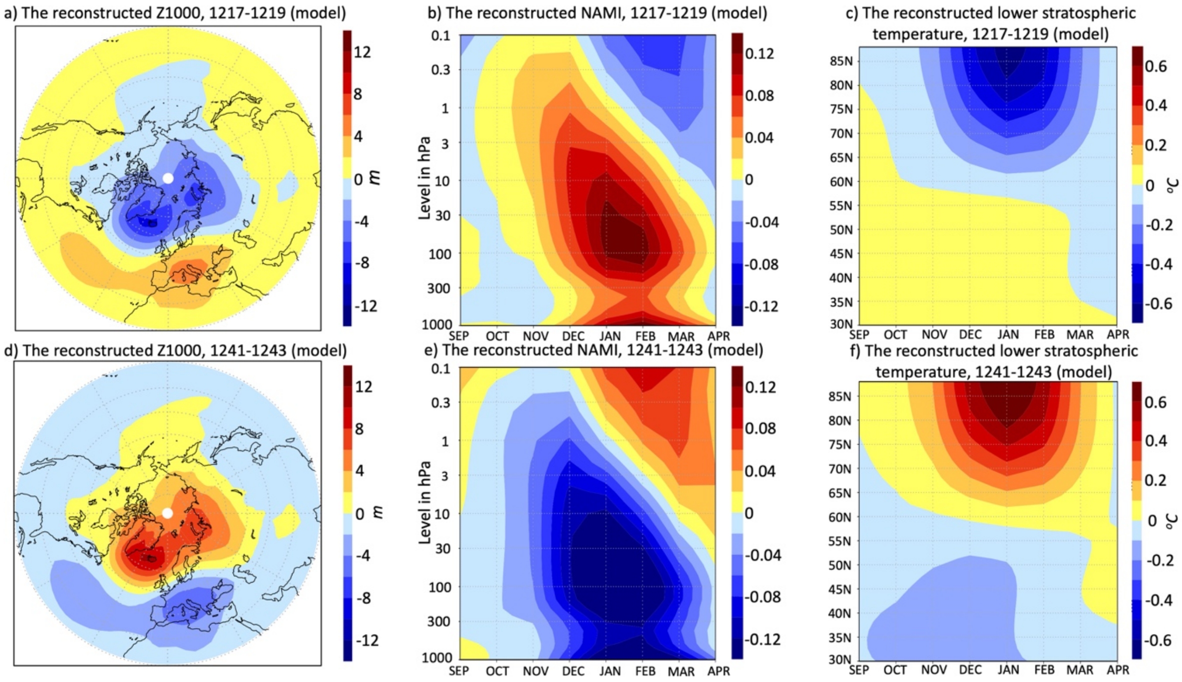
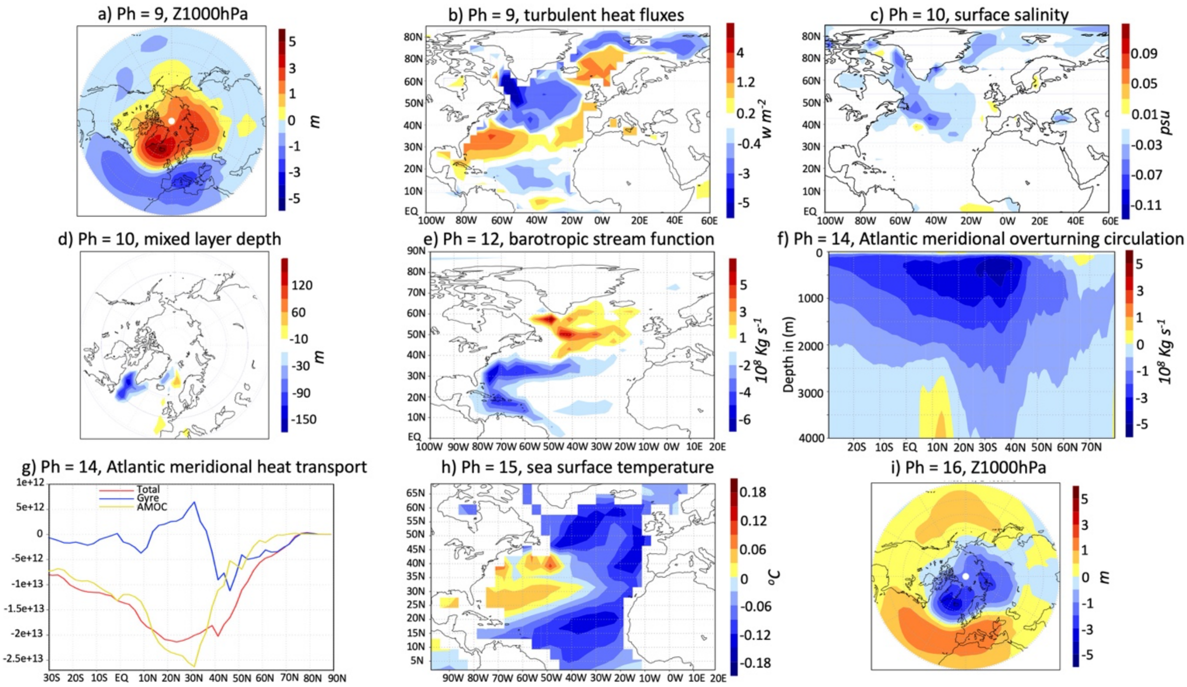


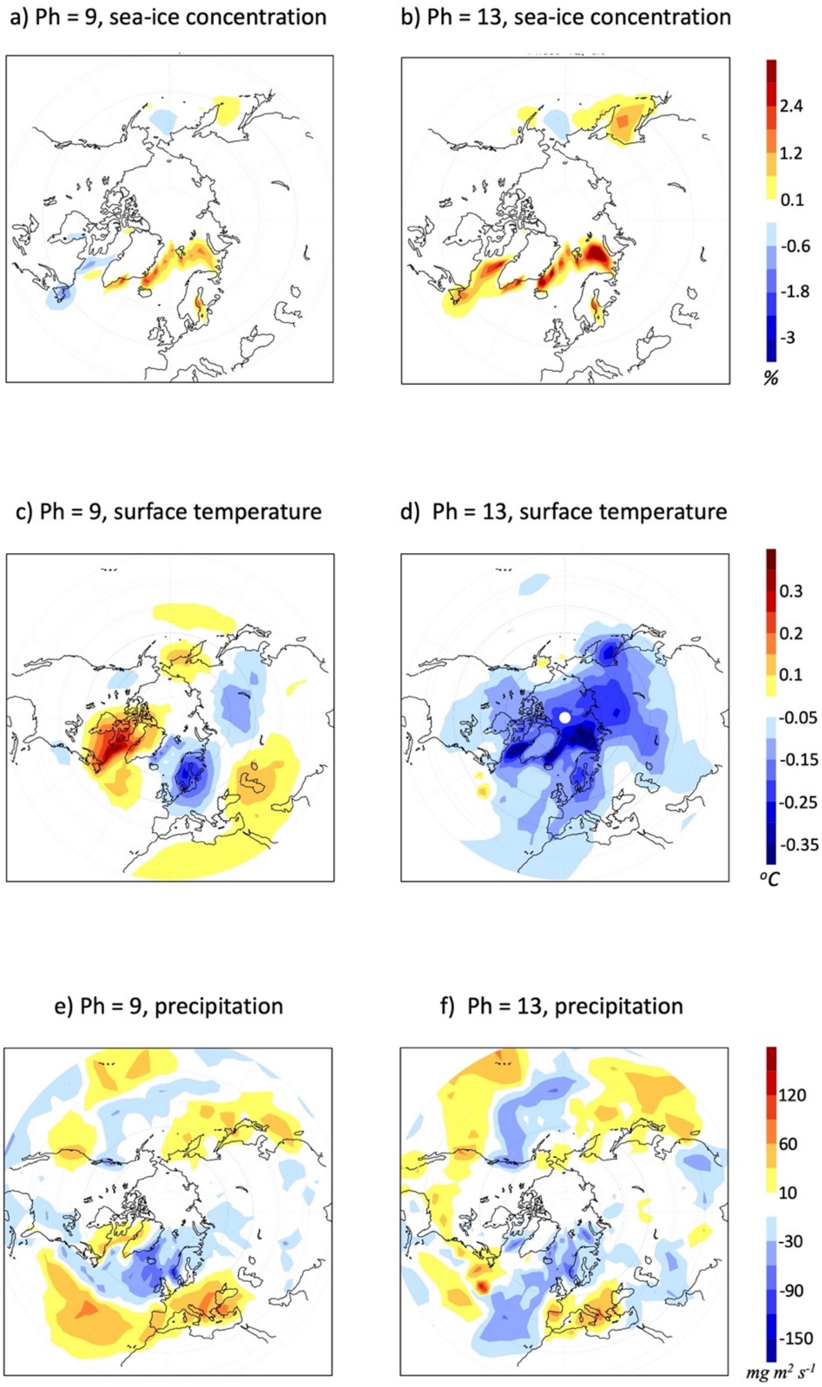
Supplementary fig. 1: The dynamics of the seasonal evolution of the stratosphere/troposphere coupled system in the coupled multidecadal stratosphere/troposphere/ocean oscillation. Similar to Fig. 5 but for the phase 2, where the. NAO is positive. (a) The seasonal evolution of reconstructed (Methods) multidecadal NAM-index during the phase 2 at different levels between 1000 and 0.1 *hPa.* (b) The zonally averaged lower stratospheric temperature (100-70hPa) during the phase 2 *(in °C)*. (c) The combined contribution of resolved wave and non-resolved parameterized forcing (*in m* s^{-1}*/day*) during phase 2. (d-e) As in (c) but for resolved wave and non-resolved forcing, separately (*in m* s^{-1}*/day*). (f) The Coriolis torque of the residual circulation (*in m* s^{-1}*/day*).



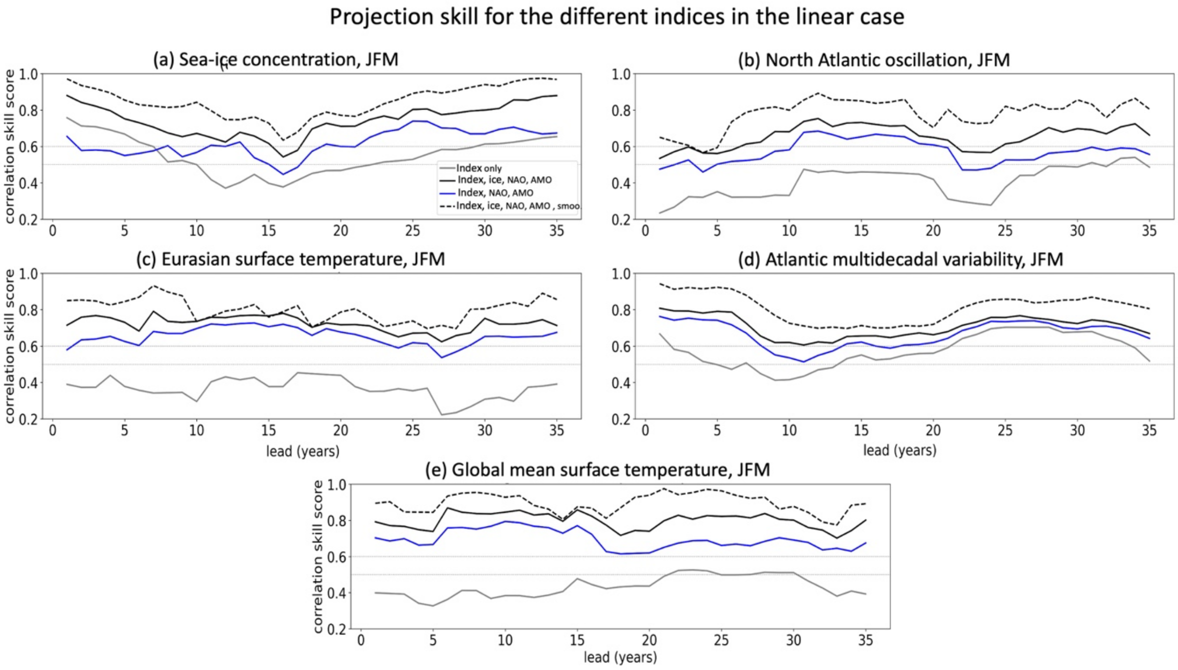
Supplementary fig. 2: The reconstructed atmospheric anomalies during the strongest changes of the Damped Oscillation: (a) and (d) represents the reconstructed 1000hPa geopotential height during the strong reconstructed positive NAO event in 1217-1219 and negative event in 1241-1243 respectively (in *m*). (b) and (e) are like (a) and (d) respectively but for the seasonal evolution of the NAMI. (c) and (f) are like (b) and (e) but for the seasonal evolution of the lower stratospheric temperature (in ^{o}C). The individual atmospheric changes due to the coupled stratosphere/troposphere/ocean oscillation are comparable to the changes in the reanalysis (Fig 1e-f and Fig. 2)



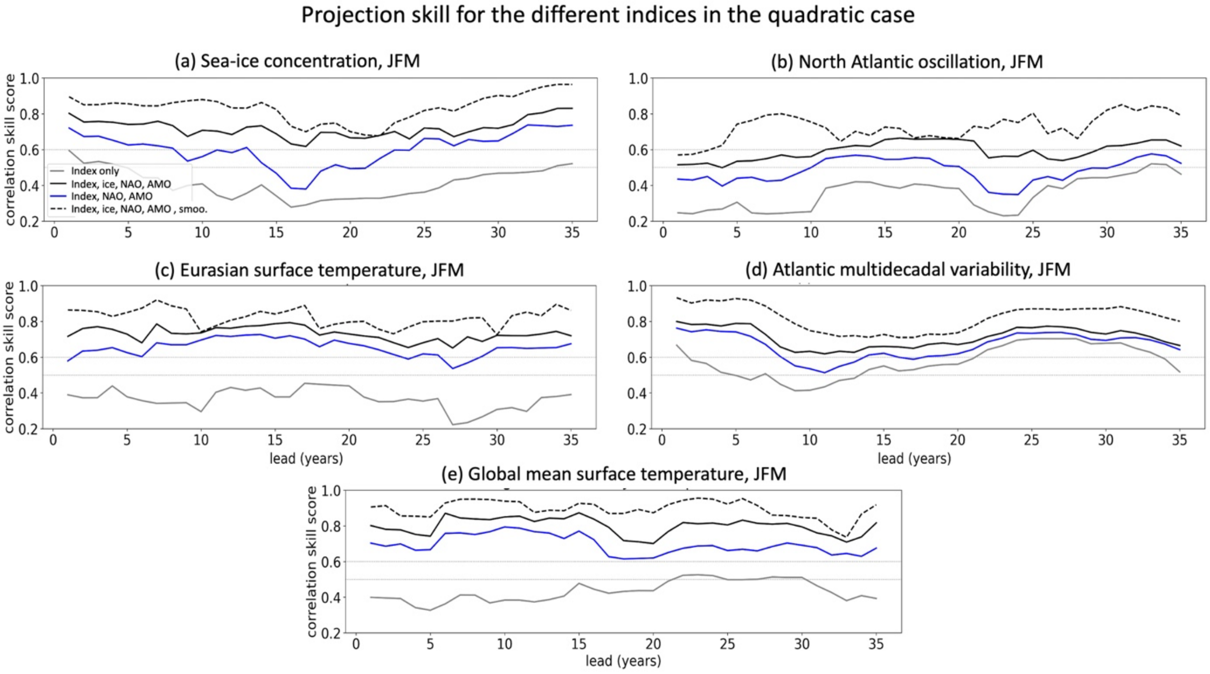
Supplementary fig. 3: Dynamics of the damped coupled stratosphere/troposphere/ocean oscillation (reversed case): (a-i) similar to Fig. 4 but for the reversed case, (a-b) The reconstructed 1000hPa geopotential height (in *m*) and upward oceanic turbulent heat fluxes (in $w\ m^{-2}$) respectively at phase 9. (c-d) surface salinity (in *psu*) and mixed layer depth (in *m*) during phase 10, respectively. (e) Barotropic mass stream function during phase 13 (in $10^8\ Kg\ s^{-1}$). (f) Latitude-depth section of the meridional overturning mass stream function in the Atlantic Ocean (north of 30°S) during phase 14 (in $10^8\ Kg\ s^{-1}$). (g) The zonally averaged poleward Atlantic heat transport (during the phase 14, in *W*) by the total oceanic circulation (red), the AMOC (yellow) and the oceanic gyre (blue). (h) The reconstructed SST anomalies at phase 15 (in °*C*) and finally (i) the reconstructed 1000-hPa geopotential heights at phase 16 (in *m*).



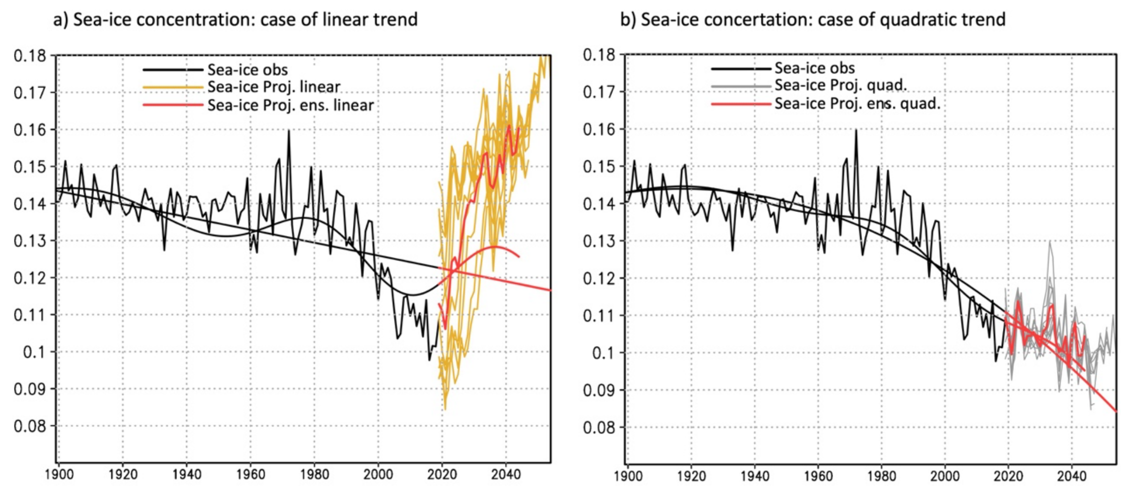
Supplementary fig. 4: **Impact of the coupled multidecadal stratosphere/troposphere/ocean oscillation on the sea-ice and surface temperature:** a-f are like Fig. 6b-g respectively but for phase 9 (where the negative NAO is high in the phase composite) instead of phase 1, and for phase 13 (where sea-ice extension is highest and high-latitude oceanic meridional heat transport are weakest in the phase composite) instead of phase 4.



Supplementary fig. 5 The correlation skill score using linearly detrended sea-ice: The correlation skill score for the projected wintertime (JFM) indices (presented in Fig. 6) for the case, where the sea-ice index is detrended using linear trend (Methods). The correlation skill scores are presented for the indices representing the wintertime (a) sea-ice concertation, (b) NAO-index, (c) Eurasian surface temperature, (d) North Atlantic SST, and (e) global mean surface temperature. The cases, where the projection was performed from: the index itself only are presented in grey, from all other indices outside the sea-ice in blue and from all indices including the index itself in black. The dashed black line represents correlation skill score for the smoothed prediction of indices (i.e. data used for black solid line were smoothed to obtain the black dashed line). The basic variables used for the projection of all indices are the North Atlantic SST, Arctic sea-ice concentration and NAOI. For the other indices the index itself is additionally used.

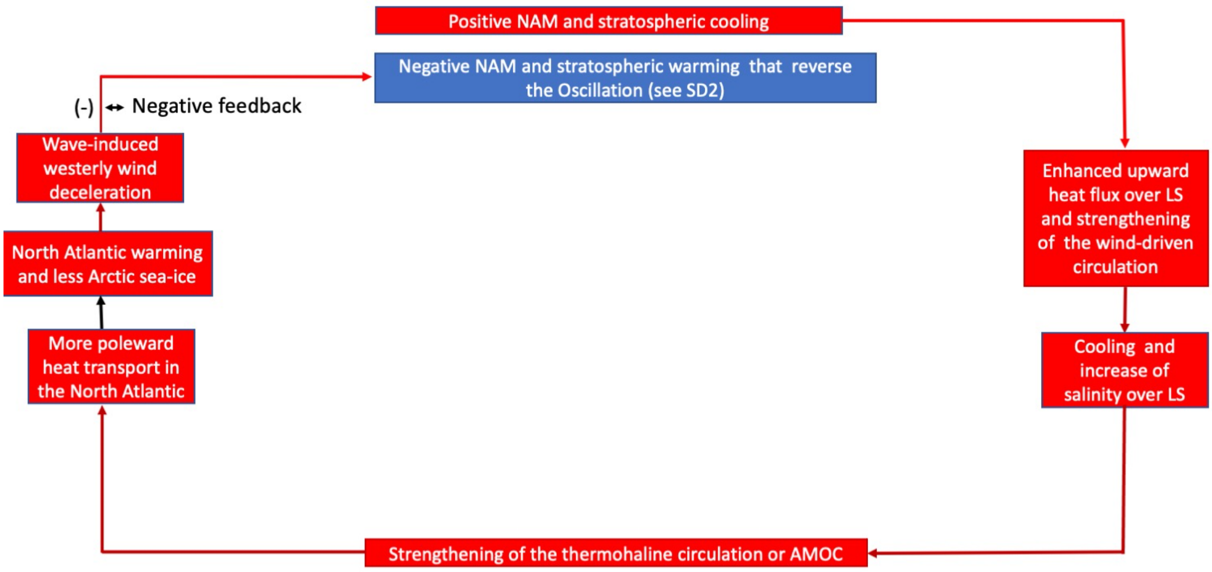


Supplementary fig. 6: **The correlation skill score using quadratically detrended sea-ice:** As in Supplementary fig. 5, but for the predictions using quadratically detrended sea-ice.



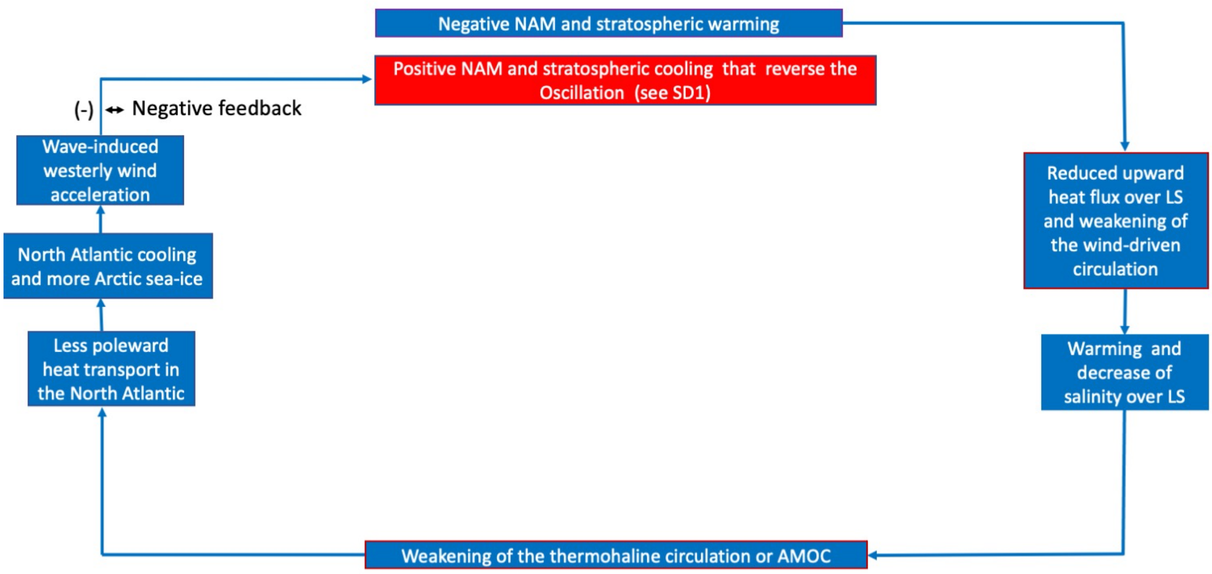
Supplementary fig. 7 The multidecadal historical and predicted sea-ice concentration for the linear and quadratic case: The historical and projected sea ice concentration (in %) and the associated multidecadal fluctuation and trends for the case where the prediction was performed including (a) linearly detrended sea-ice concentration and (b) quadratically detrended sea-ice concentration. The historical and projected multidecadal fluctuations are very high (weak) in the case of linear (quadratic) approximation of the sea-ice trend.

SD1



(-): negative feedback
LS: Labrador Sea

SD2



(-): negative feedback
LS: Labrador Sea

Supplementary fig. 8: Structure diagrams (SD) showing the mechanisms and feedbacks maintaining the stratosphere/troposphere/ocean-coupled oscillation in warm (SD1) and cold (SD2) AMV-phase (see main text for more details): Wave-maintained positive NAM in SD1 is associated with stratospheric cooling and strong westerlies that enhance the upward turbulent heat flux over the Labrador Sea (LS) and strengthen the wind-driven subpolar and subtropical oceanic gyres. This results in cooling and enhanced salinity over the LS and therefore enhanced convection and delayed strengthening of the Atlantic thermohaline circulation. The net result is an increase of poleward heat transport by both AMOC and Atlantic gyres, which leads to North Atlantic Warming and Arctic sea-ice melting. These reverse the NAM in the coupled stratosphere/troposphere system into negative phase due to the enhanced convergence of atmospheric resolve waves. The negative NAM reverses all oceanic changes into opposite phase (SD2), which bring the oscillation into the atmospheric initial conditions of SD1. In this oscillation, the positive (negative) NAO and associated delayed arctic sea-ice melting (formation) act to enhance (reduce) the surface temperature and precipitation over the North Eurasian sector and decrease (increase) the precipitation over Mediterranean areas.