**Variability of Arctic Ocean freshwater storage in a coupled climate model (D7)**  
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**Motivation**  
The upper ocean gyres of the Arctic Ocean constitute a reservoir of freshwater. Accumulated liquid freshwater has exhibited a strong increase during the last decade, potentially linked to climate change. Sudden release of excess freshwater from the Arctic may influence the sub-polar ocean circulation, the rate and properties of the North Atlantic deep water formation. Here we report on variability of comparable magnitude in a free, multi-centennial pre-industrial control simulation with the coupled climate model EC-Earth.

**Variability and exchanges**

Multi-decadal variability of integrated liquid FW content in the Arctic Ocean in EC-Earth simulations under three forcing scenarios, a 600 year control simulation using fixed preindustrial forcing (black), a historic simulation using time-varying forcing 1850-2006 (green) and a future scenario based on the RCP8.5 emission scenario (red) for the period 2006 to 2100.

Normalized liquid (a, black) and solid (e, grey) Arctic Ocean FW content compared with liquid (a, red) and solid (e, blue) export through the Fram Strait. FW content and ice volume series are normalized against the Arctic Ocean ice-volume variability and transports against variability of the Fram Strait ice export.

The autocorrelations are shown in (b) and (f) together with the lagged correlation (dash-dot) for lags up to 25 years using de-trended time-series. Colour coded histograms present the distribution of the normalized time series of volume (c,g) and transports (d,h).

Modelled Arctic Ocean FW content variability for liquid (black, a,b) and solid (c, grey) fractions. In (a), the FW content variability is compared with the explained variability from individual branches of exchange ($T^{\text{FW, L}}$, $T^{\text{FW, S}}$) applying a constant source term (see text for details), Fram Strait (red), Nares Strait (blue), Bering Strait (green) and the CAA (Lancaster Sound, orange) and Fram Strait ice export (grey). Arctic Ocean sea-ice volume variability is compared separately in (c) with the variability explained by the Fram Strait (red) and Nares Strait (blue), respectively. The explained variability of the Arctic Ocean FW inventory by the combined liquid FW transports (red) and total (liquid + solid, blue) transports is compared in (b) with the true modelled inventory.

**Conclusions**

- It is shown that the volume of liquid freshwater in the Arctic Ocean is largely unconstrained in the model and associated with a multi-decadal de-correlation time-scale.
- This may be explained by absorption of uncorrelated fluctuations in modelled exchanges with the neighbouring ocean regions and, between liquid and solid phases.
- In contrast, the volume of sea-ice in the Arctic Ocean is highly constrained explained by a positive relation between the magnitude of storage and export. It is demonstrated that this coupling does not exist in the model for the storage of liquid freshwater controlled by multiple exchange systems.
- A simple approach is used to diagnose the changes in storage from the exchanges through individual ocean gateways. Multi-decadal variability in freshwater storage can be inferred from all exchange systems, though the largest amplitude is associated with the Fram Strait liquid freshwater export.
- Considering liquid and solid components independently reveals an important role of transfer between phases in forming the decadal to centennial variability in the liquid freshwater storage.
- An inverse relation between freshwater storage in the Arctic Ocean and Sub-polar region can be established whereby sub-polar decrease aligns with periods of accumulation in the Arctic Ocean. The opposite relation exists but shows less robust.
- Parallel to these changes are high amplitude interannual to decadal anomalies in the intensity of the sub-polar gyre circulation of 5-10 Sv ($15v = 10^6\text{ m}^3\text{s}^{-1}$). Intensification is found to link to the accumulating phases of the Arctic Ocean freshwater inventory.
- Also changes in the Atlantic Meridional Overturning Circulation (AMOC) locks only to this phase and exhibits an increase of up to 1 Sv in low and mid-latitude intensity.

**Arctic sub-polar coupling**

Coupled Arctic Ocean and sub-polar variability: the absolute strength of the SPG (green) and sub-polar liquid freshwater storage (red), note the different axis and the reversed scale for the fresh water content (right). Anomalies are shown for the intensity of the AMOC at 36N (blue). Background colours depict the variability of the total, liquid and solid Arctic Ocean FW reservoir. A low-pass, phase conserving filter has been applied to all annual mean time-series with a cut-off of 8 years.

Segments of the control integration are defined by a continuous decreasing (left) and increasing (right) tendency of total Arctic Ocean liquid and solid freshwater volume. Shown are segments where the tendency in total FW content exceeds a +/- 1 std. dev. criteria. In (a,b) the evolution of liquid (black) and solid (grey) Arctic Ocean FW content is compared with the liquid storage in the sub-polar Atlantic (red). Anomalies in the absolute strength of the SPG (green, c,d) and the intensity of the AMOC at 36N (blue, e,f) are calculated for the same segments referenced to the initial value. A low-pass, phase conserving filter has been applied to all annual mean time-series with a cut-off of 8 years.

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