Changes in the freshwater export from the Arctic under doubling of CO_2

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Introduction

For the 21st century, climate models predict an intensification of the hydrological cycle and a disappearance of the perennial sea-ice cover in the Arctic. Due to the associated freshening of the upper ocean and the phase shift from solid to liquid freshwater (FW) storage in the Arctic, model simulations consistently show an increase in the liquid FW export from the Arctic Ocean (e.g., Holland et al. 2006, 2007; Arzel et al. 2007; Koenigk et al. 2007). Given that the FW export has the potential to affect the deep water formation in the North Atlantic, understanding these changes is important. Furthermore, changes in the ocean circulation within the Arctic can have large impacts on the FW pathways in the Arctic, with potentially important implications for the stratification of the upper ocean, biological activity, and contaminant transport.

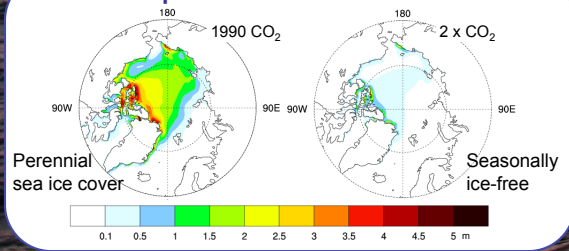
Objective

How does the FW export from the Arctic Ocean and the circulation in the Arctic Ocean change in a seasonally ice-free and warmer Arctic Ocean?

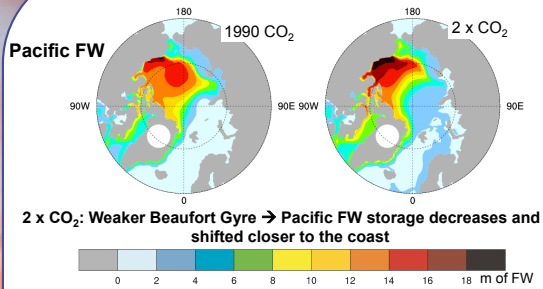
Model

- The CCSM3 is a fully coupled global climate model, which includes models for the atmosphere, the ocean, the sea-ice, and the land surface.
- Its atmospheric component has a spectral truncation of T85 (about 1.4°). The ocean model has a 1° rotated orthogonal grid, in which the North Pole is displaced to Greenland, and 40 vertical levels.
- Passive tracers have been added to the ocean model to trace FW from all Arctic sources (runoff, Pacific FW inflow, Atlantic FW inflow, net sea ice melt (NSIM), precipitation, evaporation) → see Jahn et al. (2010)
- The simulation analyzed here is started from a 1990 equilibrium simulation, with CO_2 increasing for 70 years by 1% until CO_2 has doubled, followed by 50 years with constant 2 x 1990 CO_2 levels. Results are based on 50-year averages at 1990 and 2 x 1990 CO_2.

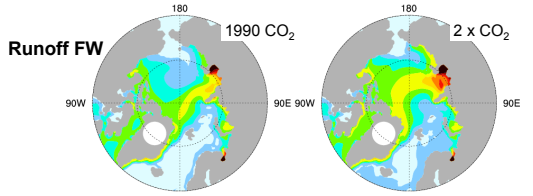
September sea ice thickness



Distribution of freshwater



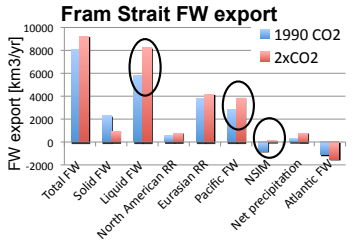
2 x CO_2: Weaker Beaufort Gyre → Pacific FW storage decreases and is shifted closer to the coast



2x CO_2: Runoff remains on shelf longer and enters the central Arctic Ocean further east → runoff storage in the Arctic increases

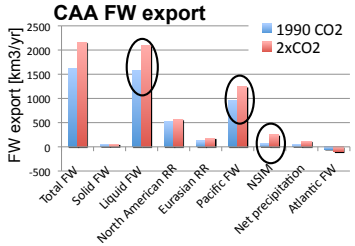
→ Overall more cyclonic ocean circulation in response to more positive AO forcing in the warmer climate of the 2 x CO_2 simulation

Freshwater export



Liquid FW export increases by 42%, total FW export by 13%

→ mainly due to increase in Pacific FW export and the export of positive NSIM , whereas ice export decreases



Total FW export and liquid FW export increase by 33%

→ mainly due to increase in Pacific FW and NSIM export

Preliminary results

- Liquid FW export increases due to increased export of Pacific FW and net sea ice melt (NSIM)
- The ocean circulation becomes more cyclonic, in response to changes in the atmospheric circulation, which leads to release of Pacific FW from the Beaufort Gyre, and storage of runoff on the Eurasian shelf → even though runoff into the Arctic Ocean increases, the export of FW from runoff from the Arctic Ocean remains almost constant
- The total FW export is increased more strongly in the CAA than in Fram Strait, which is important as the Labrador Sea deep water formation appears to be more sensitive to an increase in the liquid FW export from the Arctic Ocean than the Greenland Sea (Holland et al., 2006; Koenigk et al., 2007)

Future work

- Investigate ocean circulation changes in 21st century ensemble simulations, to validate that a shift towards a more positive AO and more cyclonic ocean circulation in the Arctic is a robust feature in a warmer Arctic Ocean without summer sea ice
- Investigate the reason for the change in the atmospheric forcing over the Arctic Ocean and the role of the sea-ice decline in this
- Analyze transient changes in the FW export under increasing atmospheric CO_2 levels
- Investigate the potential effect of FW distribution changes on biological activity and stratification

References

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