Revisiting the Arctic freshwater budget from 2004 to 2010

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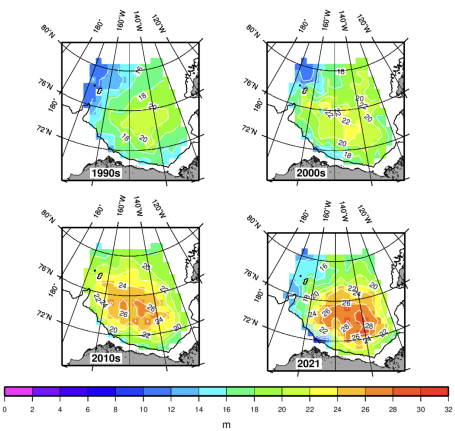
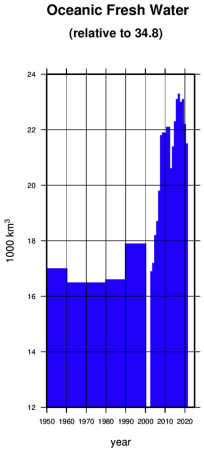
Arctic freshwater accumulation in the 2000s

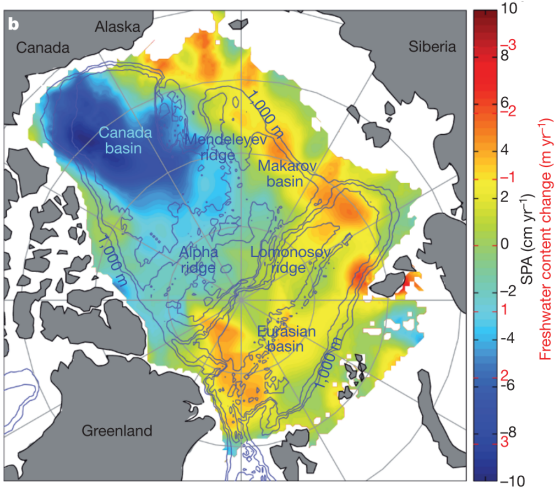
- Beaufort Gyre Observing System (BGOS) shows freshwater accumulation in the Beaufort Gyre relative to historical data
- Interesting evolution through present (not the focus here)





Proshutinsky et al. 2009,2019

Compensation in the Eurasian Basin is less clear



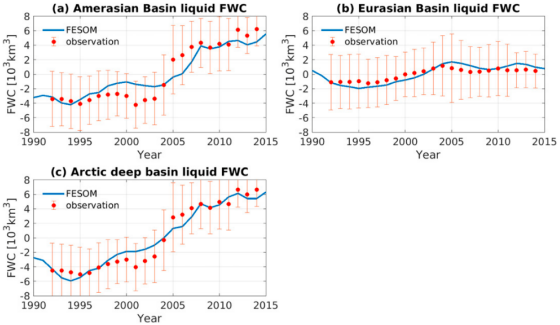


FIG. 3. Anomaly of liquid FWC in the (a) Amerasian basin, (b) Eurasian basin, and (c) Arctic deep basin (sum of the two basins). The liquid FWC observation is described in Rabe et al. (2014). See footnote 2 for the definition of the FWC.

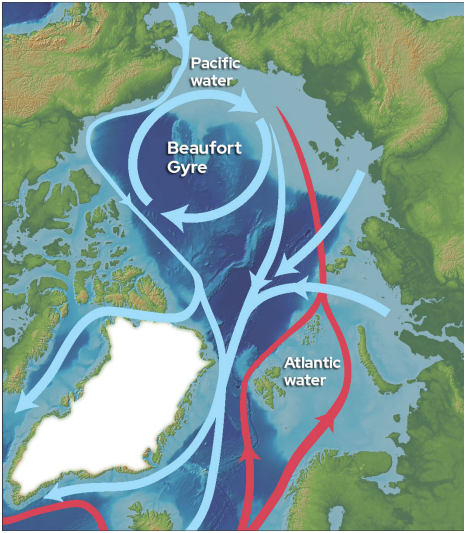
Morison et al. 2012, Wang et al. 2019

Questions addressed from observations:

- To what degree was the accumulation of freshwater in the Beaufort Gyre compensated by a decrease in the Amerasian Basin?
- What were the relative roles of different freshwater sources in the large-scale budget?

Approach:

- Combine observations into an inverse model budget



Budget framework

Apply volume and mass conservation:

$$\frac{dV}{dt} = \Sigma U_{Straits} + \Sigma U_{Sources} + \frac{\alpha Q}{\rho_0 c_p}$$

$$\frac{d(\rho V)}{dt} = \Sigma(\rho U)_{Straits} + \Sigma(\rho U)_{Sources}$$

Interpret further using a linear Equation of State:

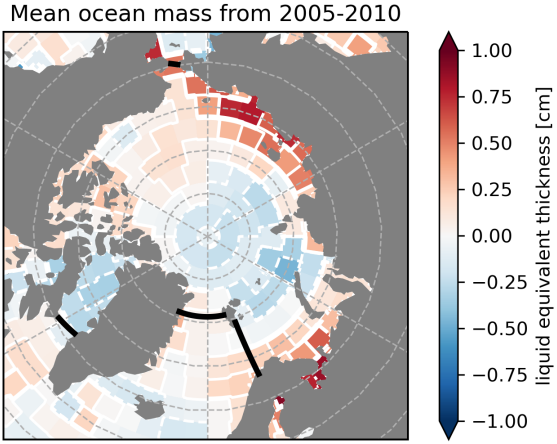
$$\rho = \rho_0 \left[\beta(S - S_0) + \alpha(T - T_0)\right]$$

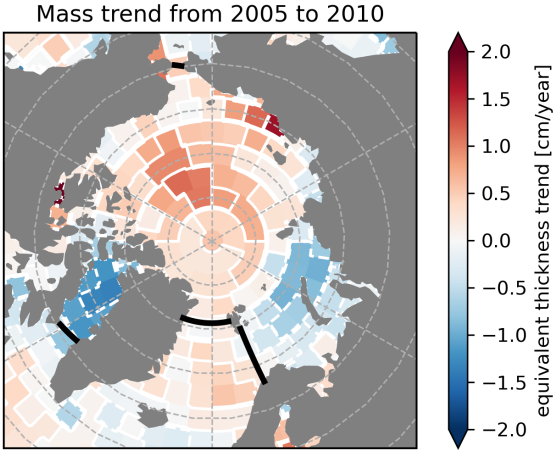
Datasets

- GRACE satellite ocean mass (Watkins et al. 2015)
- Dynamic ocean topography ocean volume (Armitage et al. 2014)
- Strait transport inverse model solution (Tsubouchi et al. 2019)
- World Ocean Atlas 2018 (Locarnini et al. 2018, Zweng et al. 2019)
- Net sea ice melt, precipitation, river runoff from the literature (e.g. Haine et al. 2015)

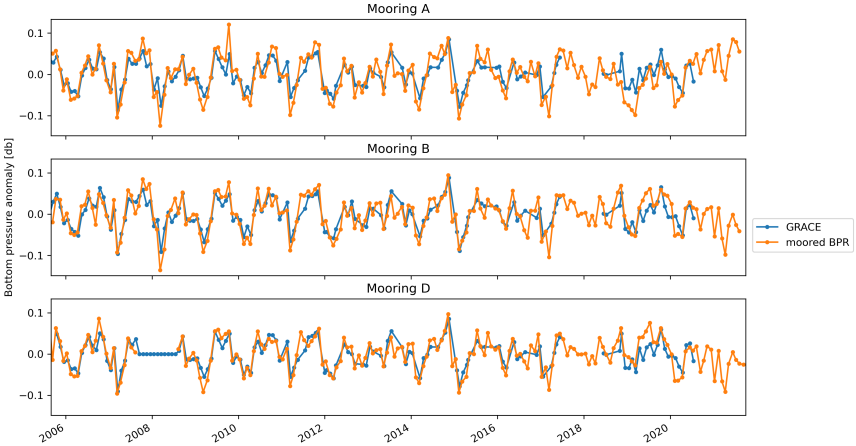
$\rightarrow$ 2004-2010 is an interesting and relatively well-observed time period

Mass change from GRACE

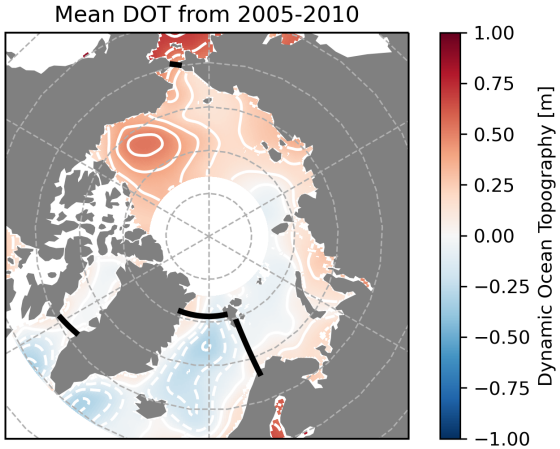


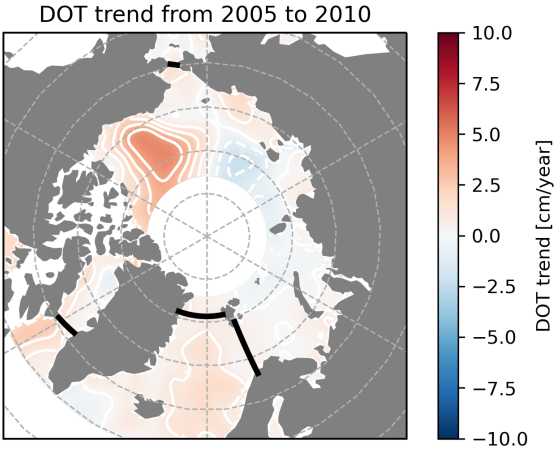


GRACE aside: excellent agreement with BGOS bottom pressure recorder measurements

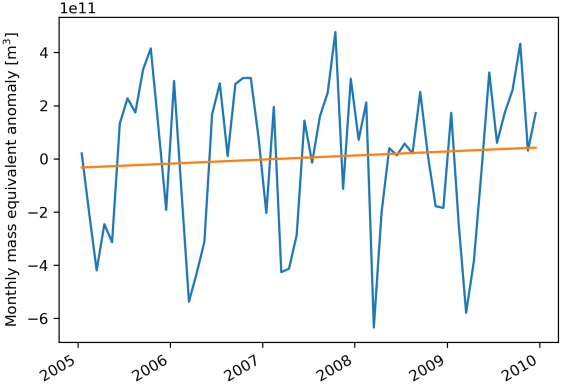


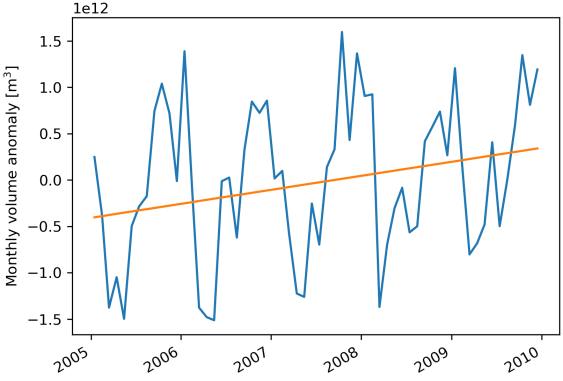
Volume change from altimetry



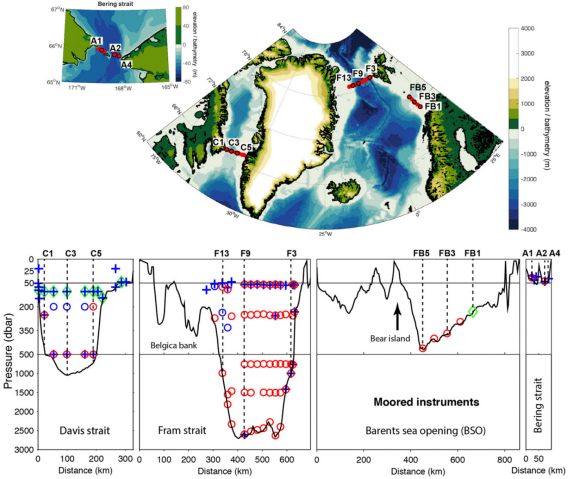


Total mass and volume changes





Oceanic transports in and out of the Arctic



Tsubouchi et al. 2018,2019

Remaining budget terms

- River runoff: 4200 km^3/yr
- Net sea ice melt: 350 km^3/yr
- Net precipitation: 2200 km^3/yr
- Net Greenland melt: 370 km^3/yr
- **Total freshwater source estimate: 7000 km^3/yr, 220mSv**
- Net expansion due to heating: 100 km^3/yr, 3.5mSv (upper bound)

Haine et al. 2015, Tsubouchi et al. 2018

Budget methodology

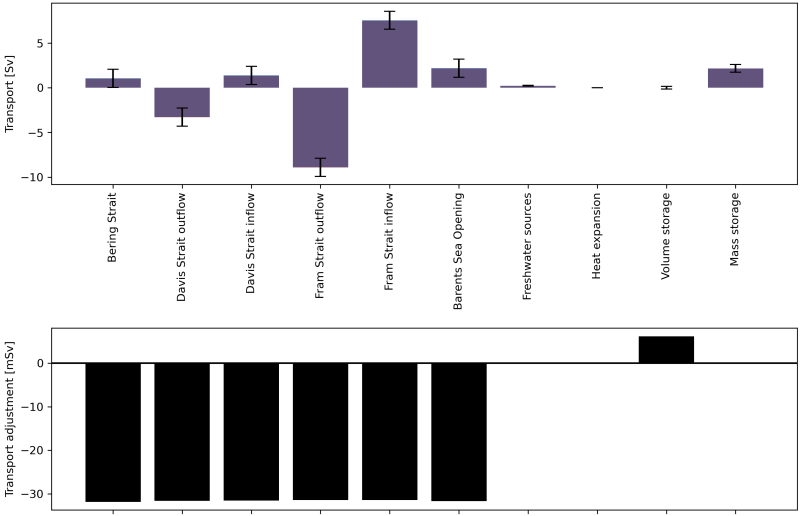
$$\frac{dV}{dt} = \Sigma U_{Straits} + \Sigma U_{Sources} + \frac{\alpha Q}{\rho_0 c_p}$$

$$\frac{d(\rho V)}{dt} = \Sigma(\rho U)_{Straits} + \Sigma(\rho U)_{Sources}$$

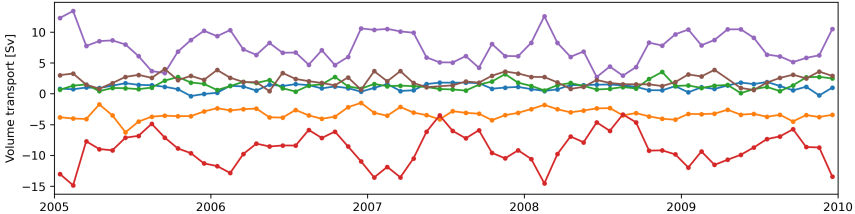
- 10 unknowns: Strait transports (6), freshwater sources (1), expansion due to heating (1), volume storage (1), mass storage (1)
- Strait and freshwater source densities are held constant
- Initial conditions from observations
- Solve linear inverse model with prescribed error on each term

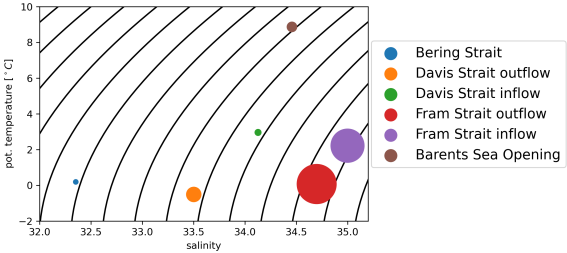
Le Bras et al. 2021

Budget results



Oceanic transport properties

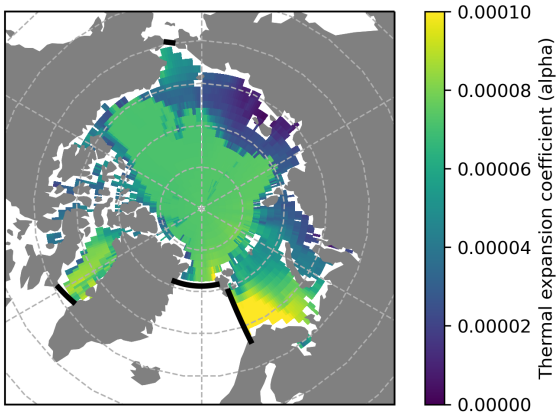


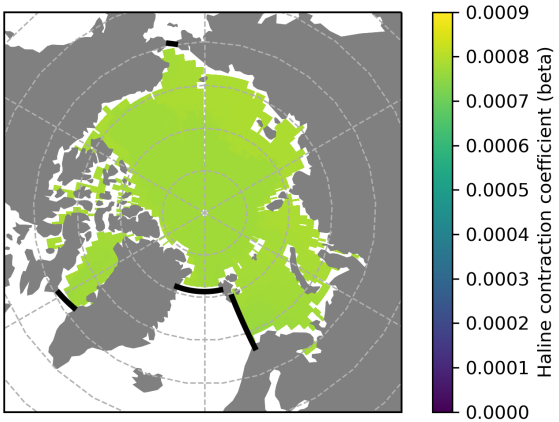


Tsubouchi et al. 2018,2019

Oceanic transport equation of state

Arctic-wide equation of state





Conclusions and next steps

- Observations are consistent with some combination of the following
  - small net oceanic divergence over the Arctic
  - overestimation of freshwater sources
  - underestimation of volume (and mass) storage
- This closed budget can be used to approximate freshwater budgets using a linear equation of state and diagnose relative roles of budget terms
- Ultimately will also quantify the amount of compensation between the Beaufort Gyre and Eurasian basin (or how well we can know it)