Arctic Ocean freshwater observations and implications

by Benjamin Rabe

Collaborators: Michael Karcher, Frank Kauker, Ursula Schauer, Rüdiger Gerdes

Alfred Wegener Institute), Bremerhaven, Germany

John Toole, Rick Krishfield

Woods Hole Oceanographic Institution, Woods Hole, USA

Sergey Pisarev

Shirshov Institute of Oceanology, Moscow, Russia

Takashi Kikuchi

JAMSTEC, Yokosuka, Japan

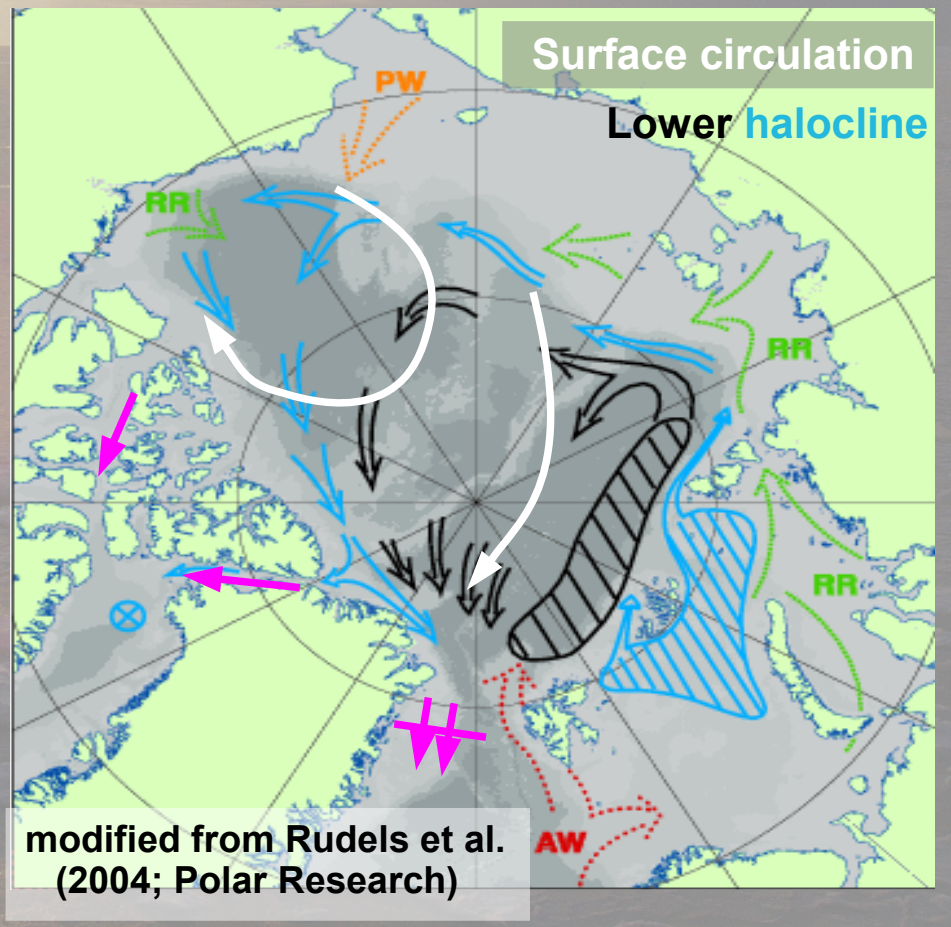
Jie Su

Ocean University of China, Qingdao, China

Backround and motivation

- 10% of worldwide river runoff goes into the Arctic Ocean
- Liquid freshwater determines upper ocean stratification (Rudels et al., 2004; Polar Res.) and plays a major role in Arctic Ocean dynamics, and the formation of water masses and sea ice (MacDonald, 2000; NATO book).
- Changes in freshwater distribution differ between forced high resolution ice-ocean general circulation model hindcasts (Jahn et al., 2012; JGR) and coupled climate model scenarios for this century (Holland et al., 2007; JGR).

→ Improve understanding of processes inside and around the Arctic Ocean !



modified from Rudels et al. (2004; Polar Research)

Arctic Ocean liquid freshwater (LFW) sources and sinks

- ***LFW reference:***

  Salty inflow Atlantic water (AW)

- *LFW sources:*

  Pacific Water (PW)

  River Runoff (RR)

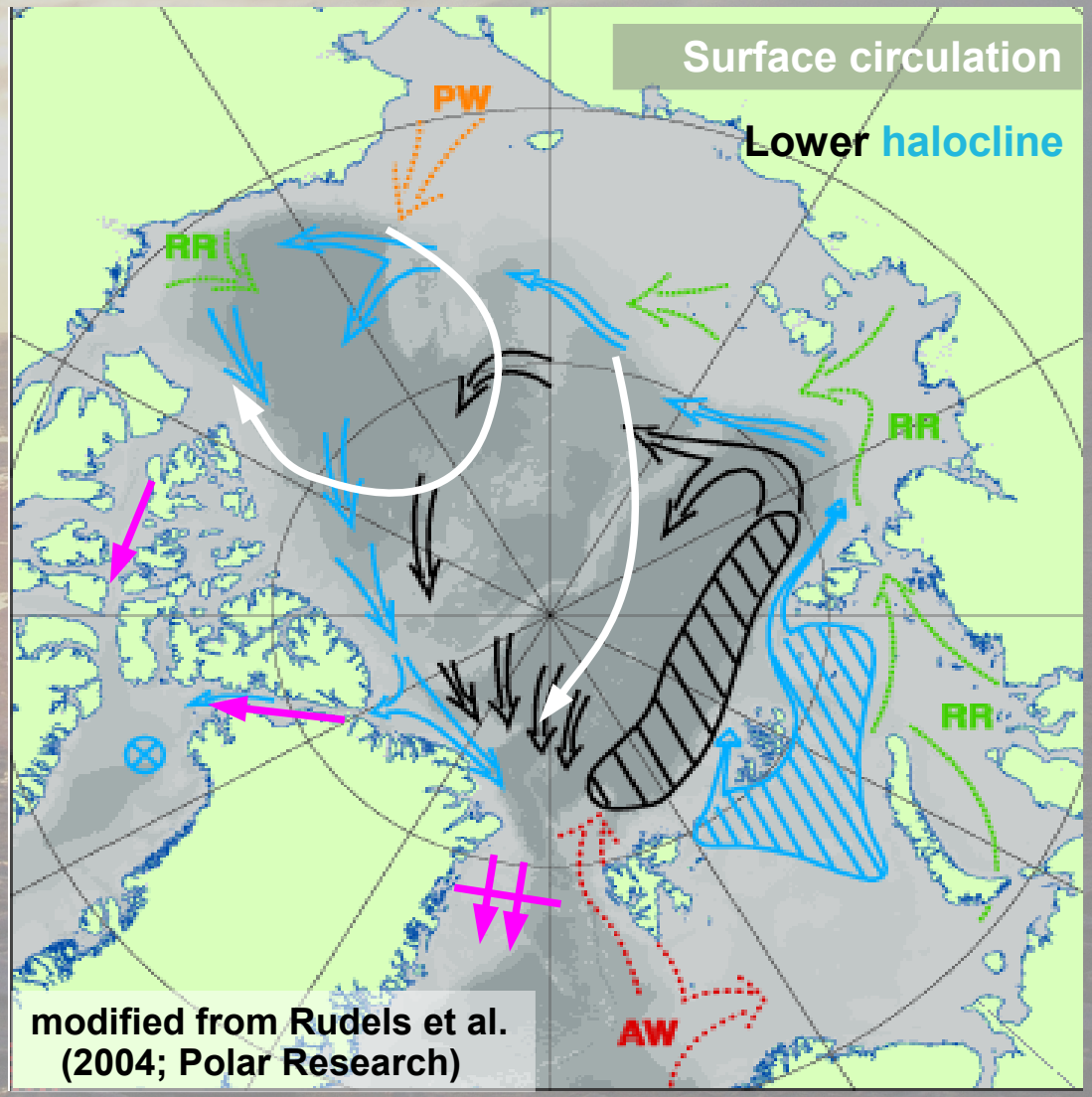
  Precipitation

  Ice melt

- *LFW sinks:*

  Export to North Atlantic

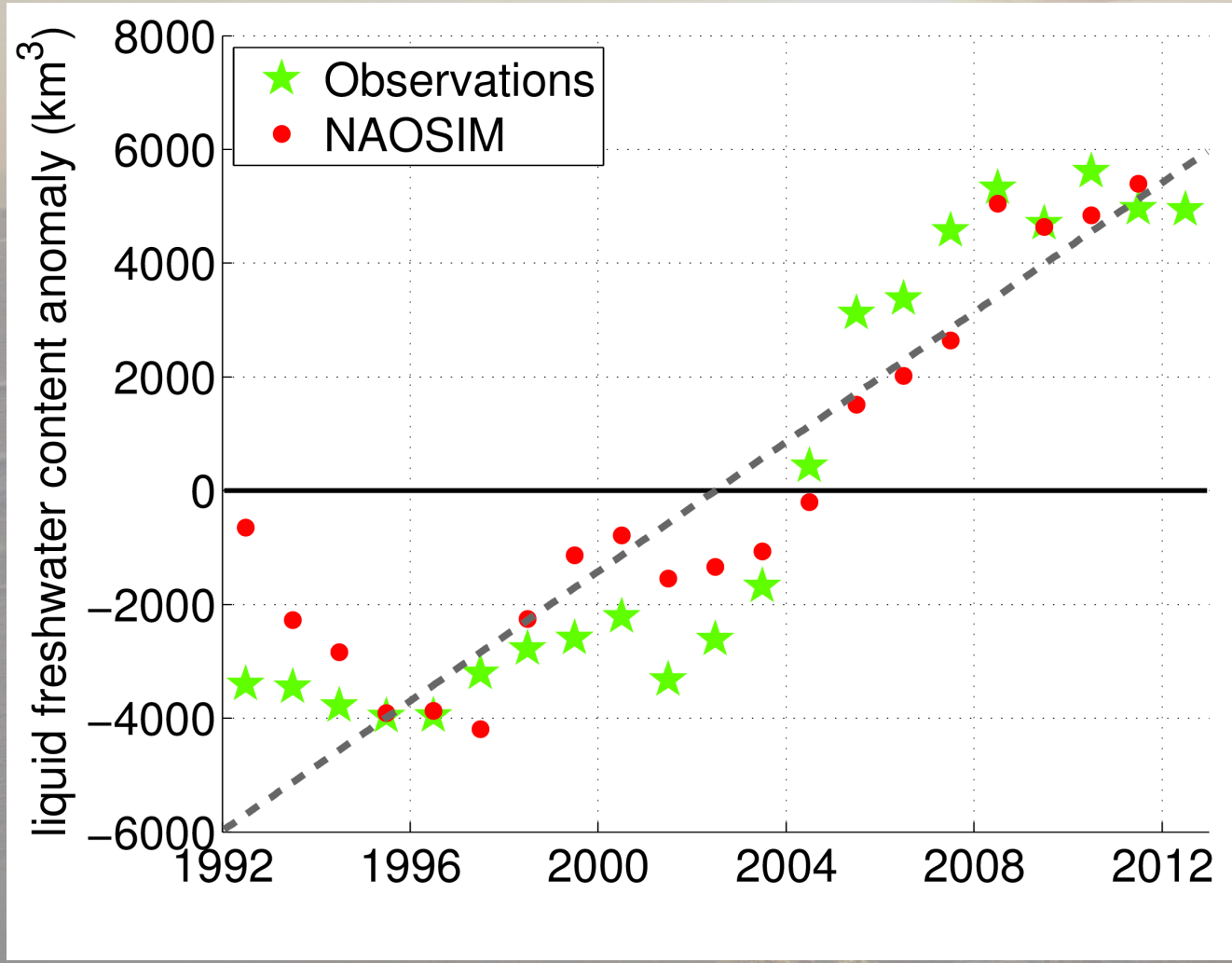
  Ice formation



→ **Arctic Ocean basins (no shelves), layer between surface and 34 isohaline**

Liquid freshwater storage trend from observation and simulation

Upper Arctic Ocean Basins

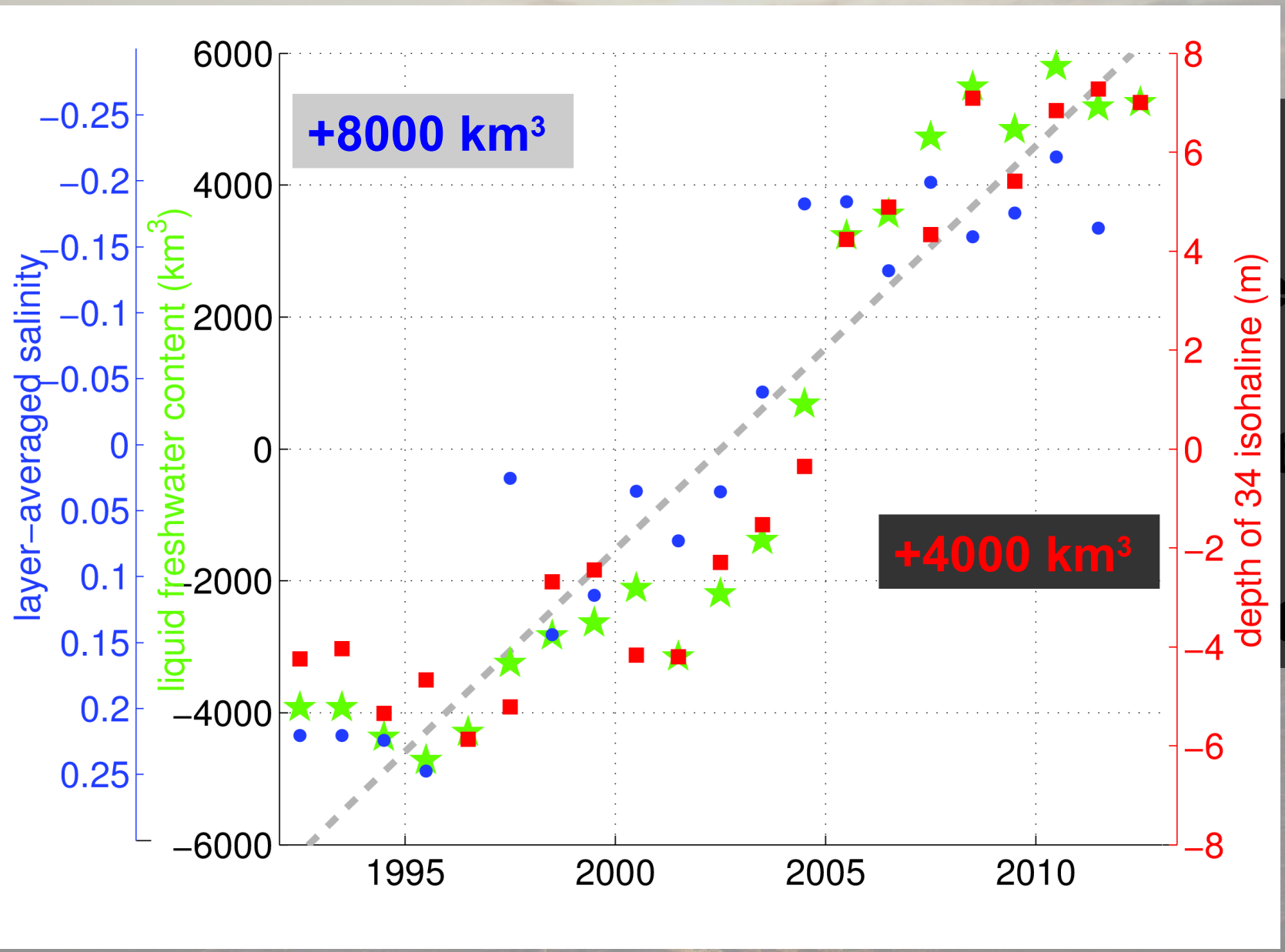


600±300 km^3 yr^{-1} increase over 21 yrs, equivalent to about 12000 km^3 or a 3 m layer of freshwater (S_{ref}=35).

NAOSIM is a high resolution sea ice – ocean model of the Arctic and North Atlantic

Rabe et al. (in revision)

Liquid freshwater storage trend contributors



km³ yr⁻¹
over
equivalent
12000 km³
m layer of
ter (S_{ref}=35).

Rabe et al.
(in revision)

Liquid freshwater storage trend

Fluxes likely to contribute to the trend:

Increase in Bering Strait inflow (Woodgate et al., 2012; GRL)

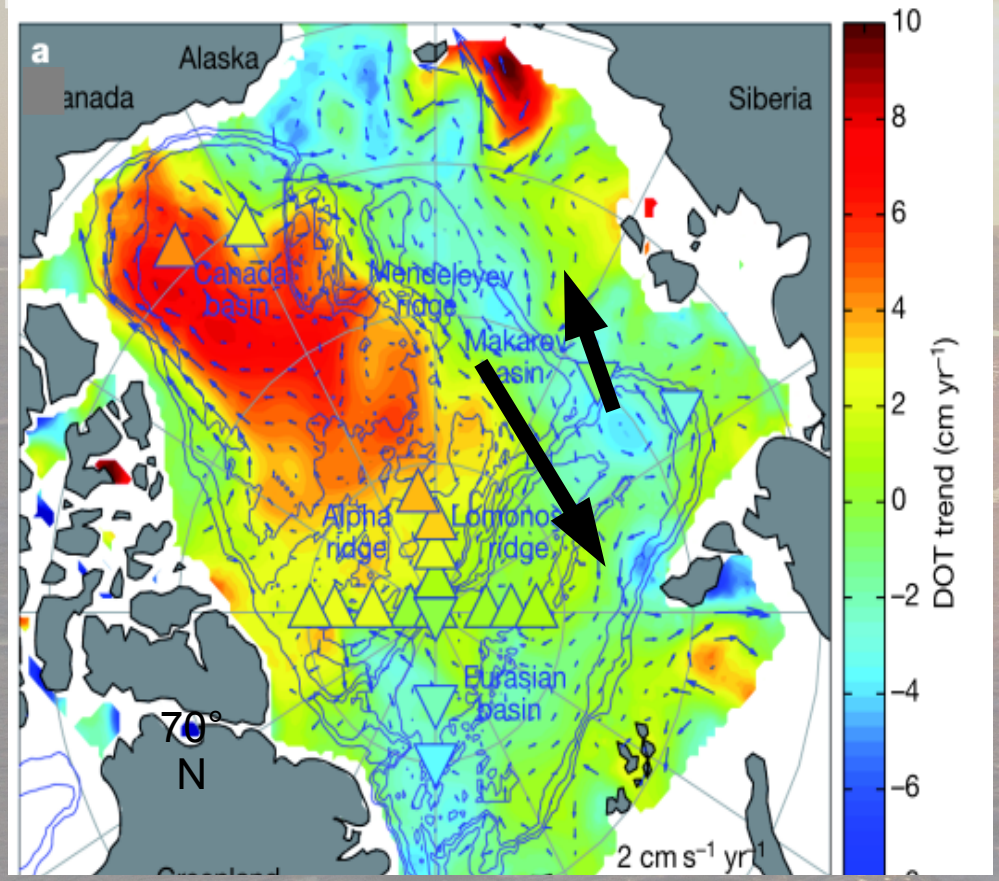
Increase in (net) sea-ice melt (e.g. Yamamoto-Kawai et al., 2009, JGR; Korhonen et al., 2012; OSD)

Reduction in sea-ice volume / reduction in export (Kwok et al., 2009, JGR; Hansen et al., 2013, GRL) → *Sinhead Farrell talk ...*

Not increased continental runoff (Overeem and Syvitski, 2010; Geogr. Ann.)

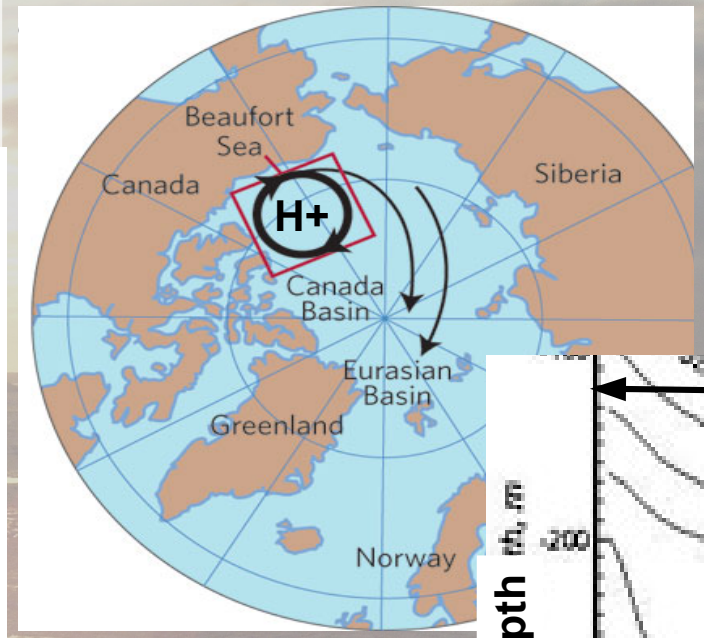
Not decreased export through Fram Strait (de Steur et al., 2009; GRL; Rabe et al., 2013; OS) ONLY since 1998 !

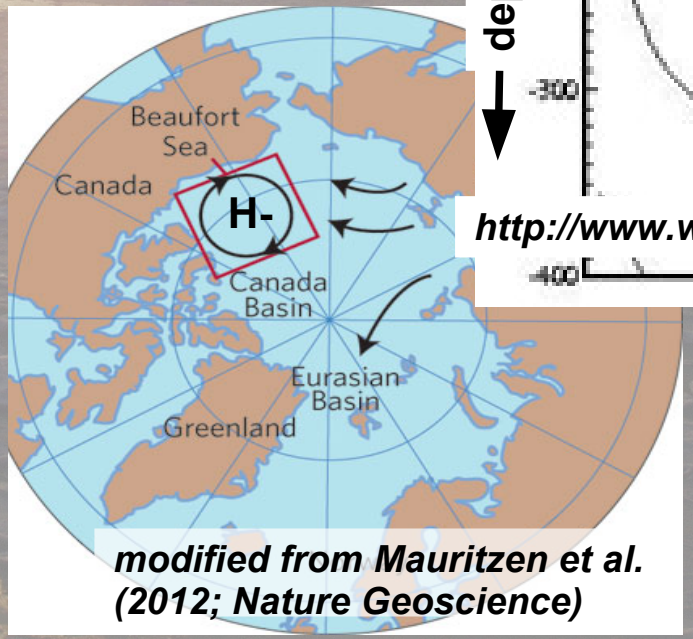
Liquid freshwater changes and geostrophic velocity (satellite observations: 2003-2008)

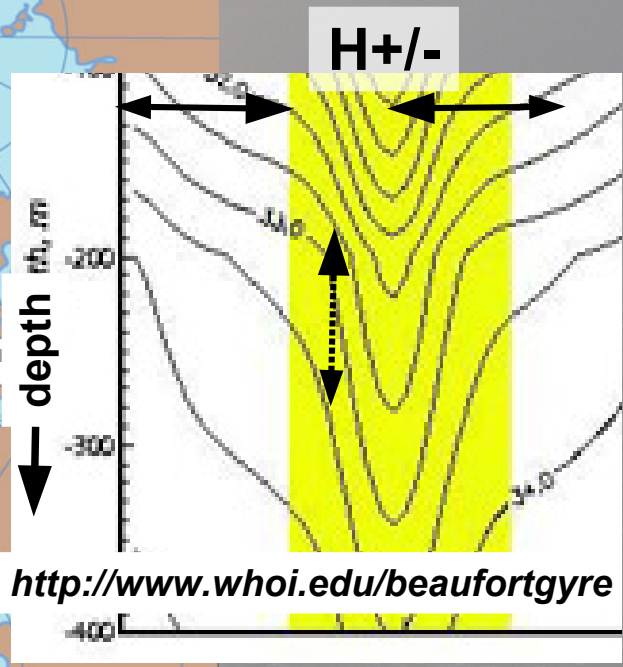


Modified from Morison et al. (2012; Nature)

Background and motivation

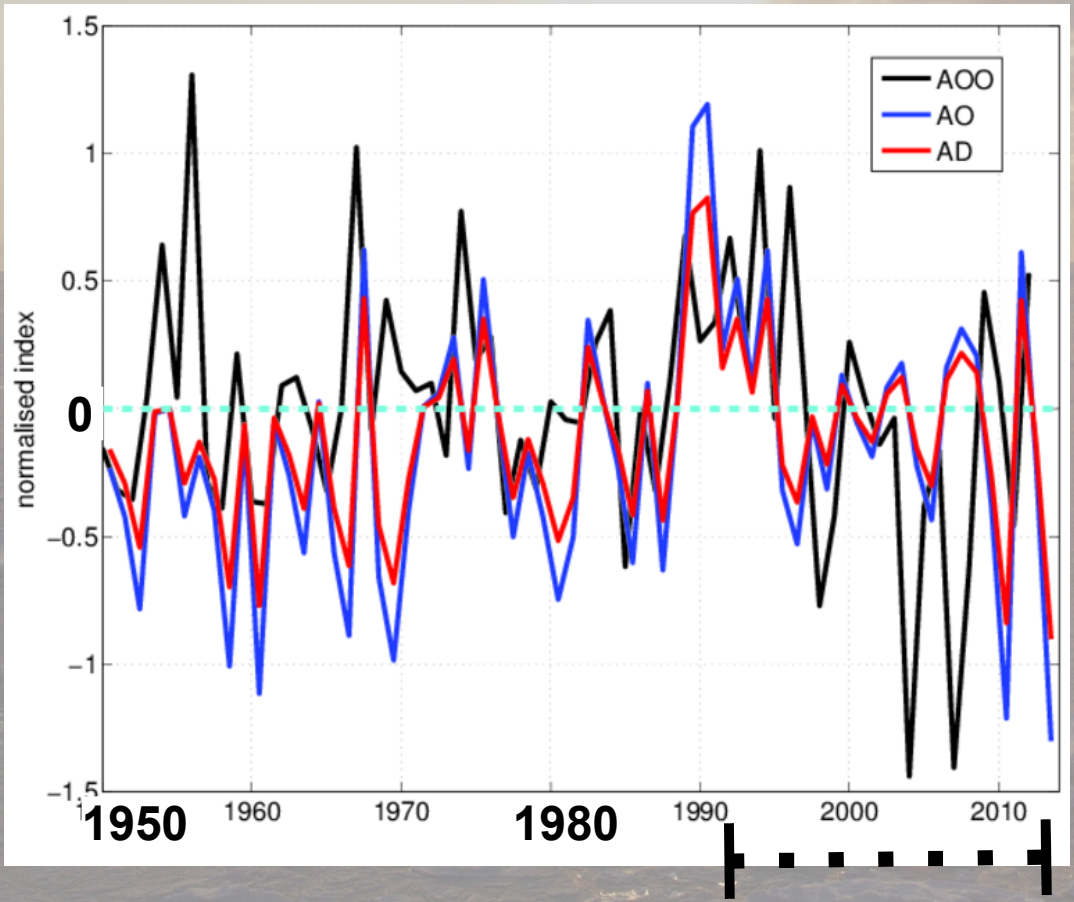


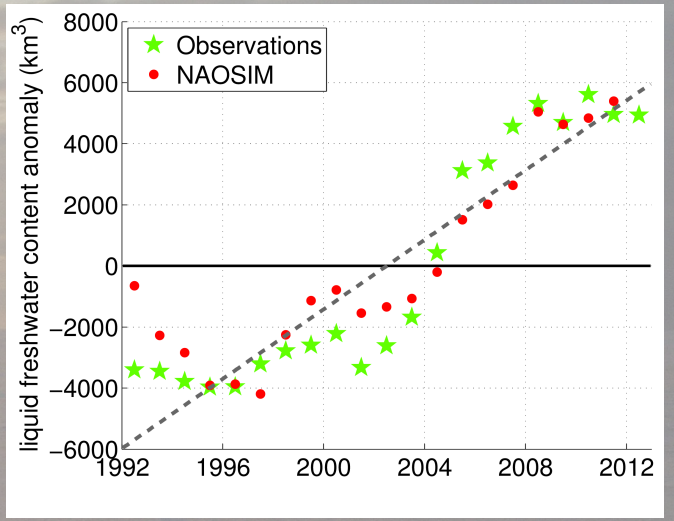




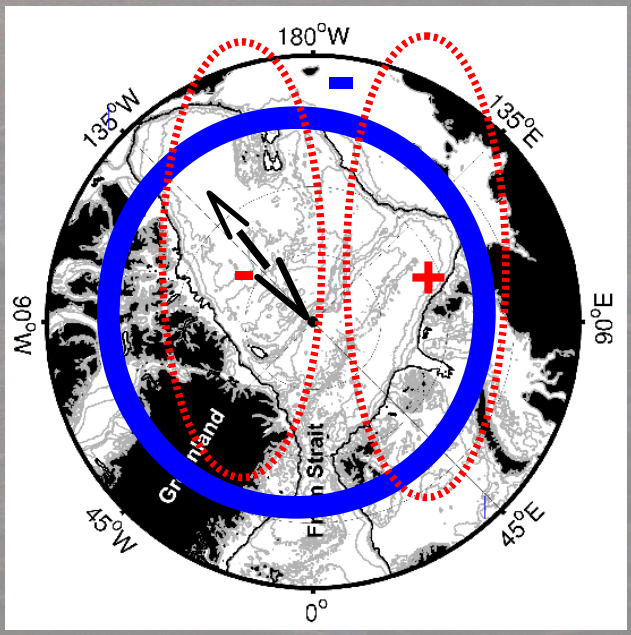
modified from Mauritzen et al. (2012; Nature Geoscience)

Upper Arctic Ocean liquid freshwater storage trend – drivers?





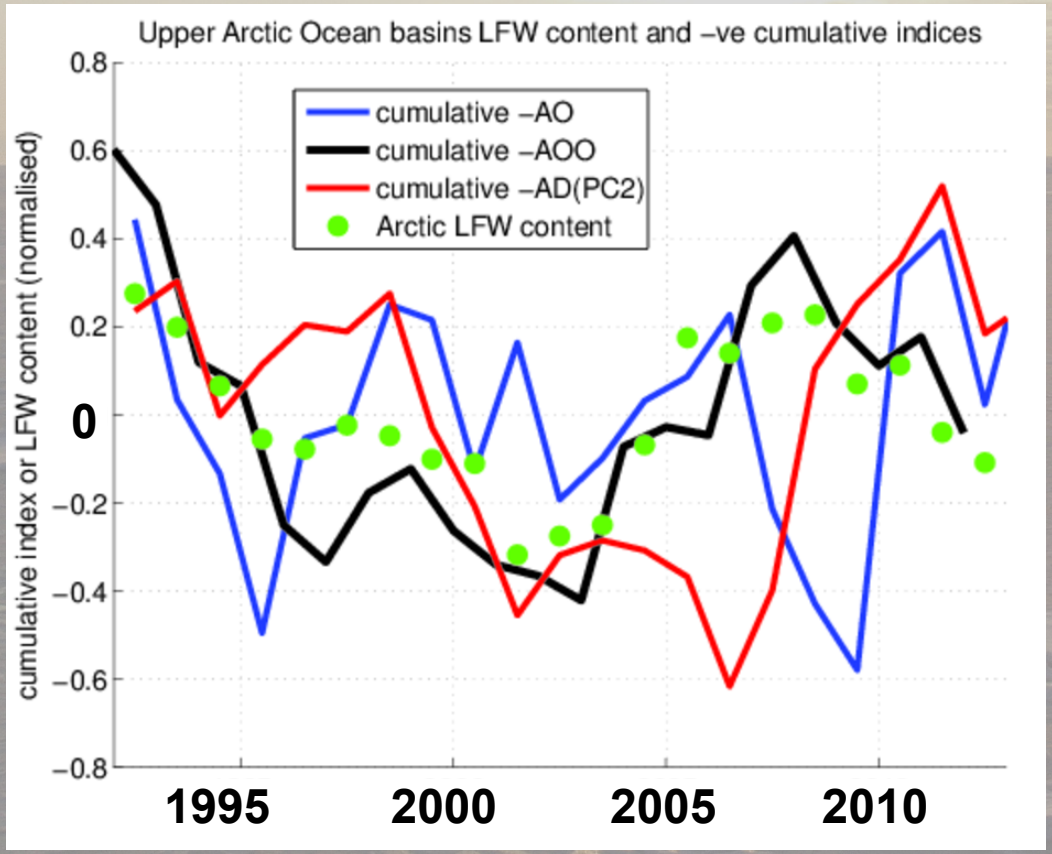
Patterns of indices

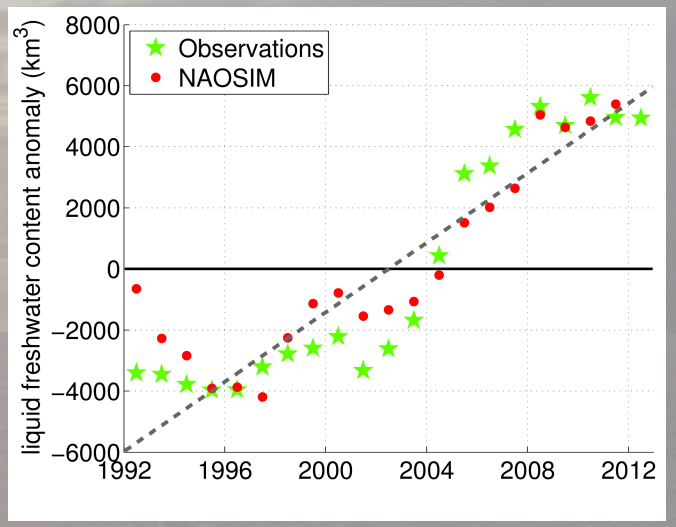


AO: Arctic Oscillation (Thompson and Wallace, 1998)
AD: Arctic Dipole (Overland et al., 2010; 2012)
AOO: Arctic Ocean Oscillation (Proshutinsky and Johnson, 1997)

Upper Arctic Ocean liquid freshwater storage trend – drivers?

Cumulative timeseries (annual means, demeaned, detrended)





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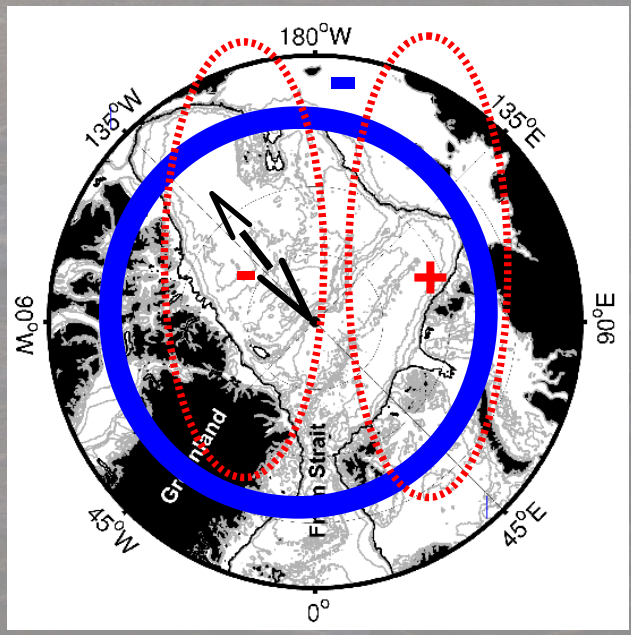

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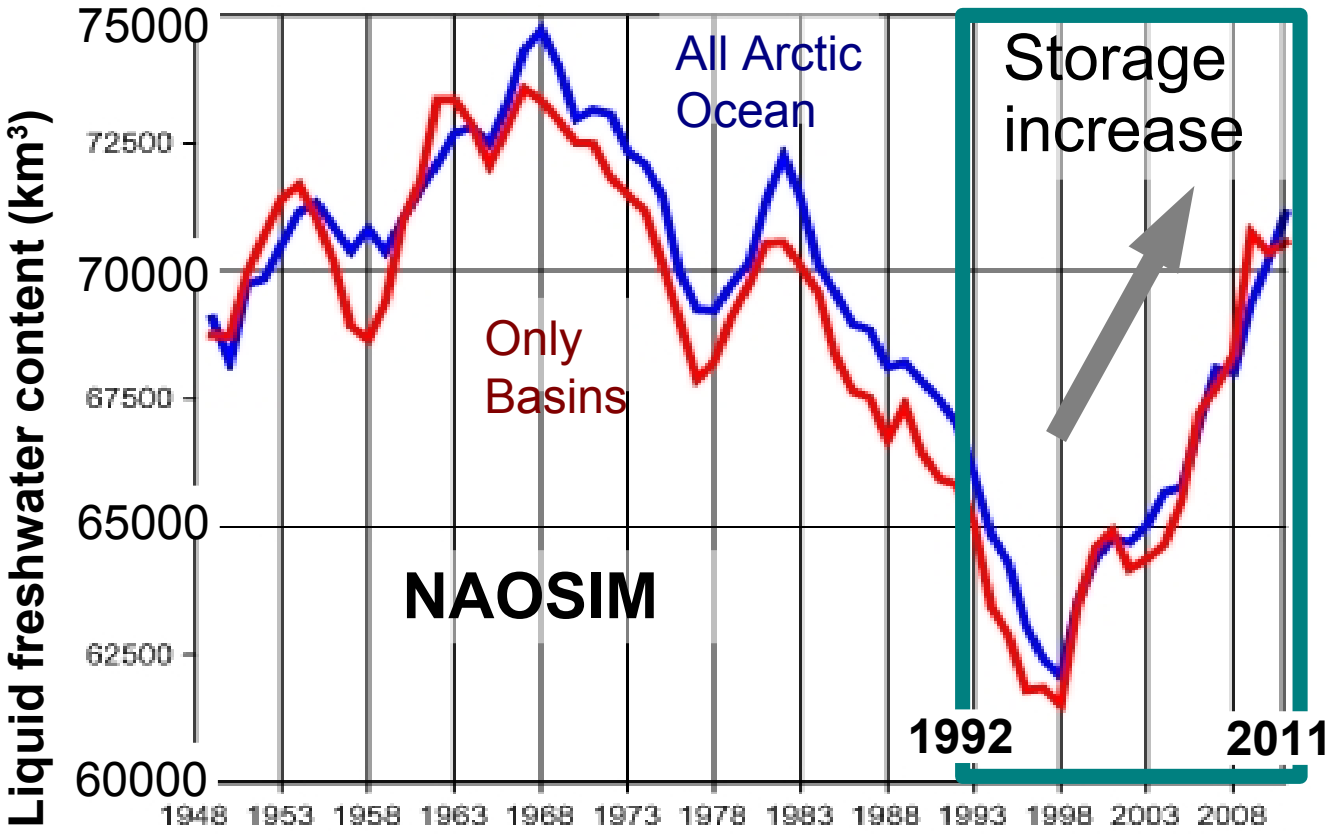
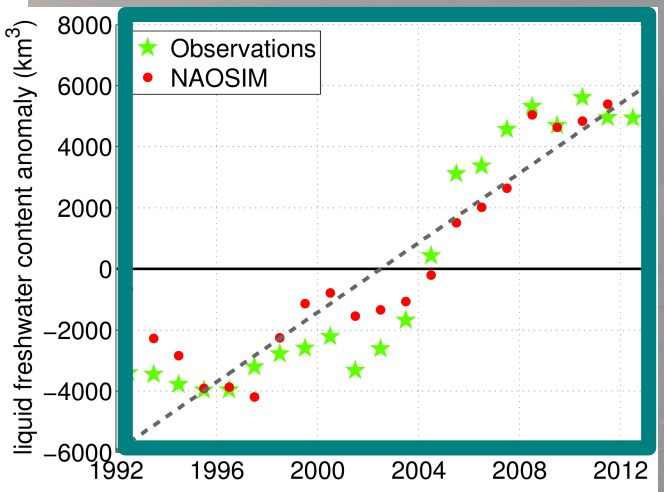
Simulated liquid freshwater: processes and long-term context





Liquid freshwater content (relative to a salinity of 35) in the layer above the 34 isohaline in the NAOSIM model (blue: whole Arctic Ocean; red: only basins without shelves, offset by +23000 km³).

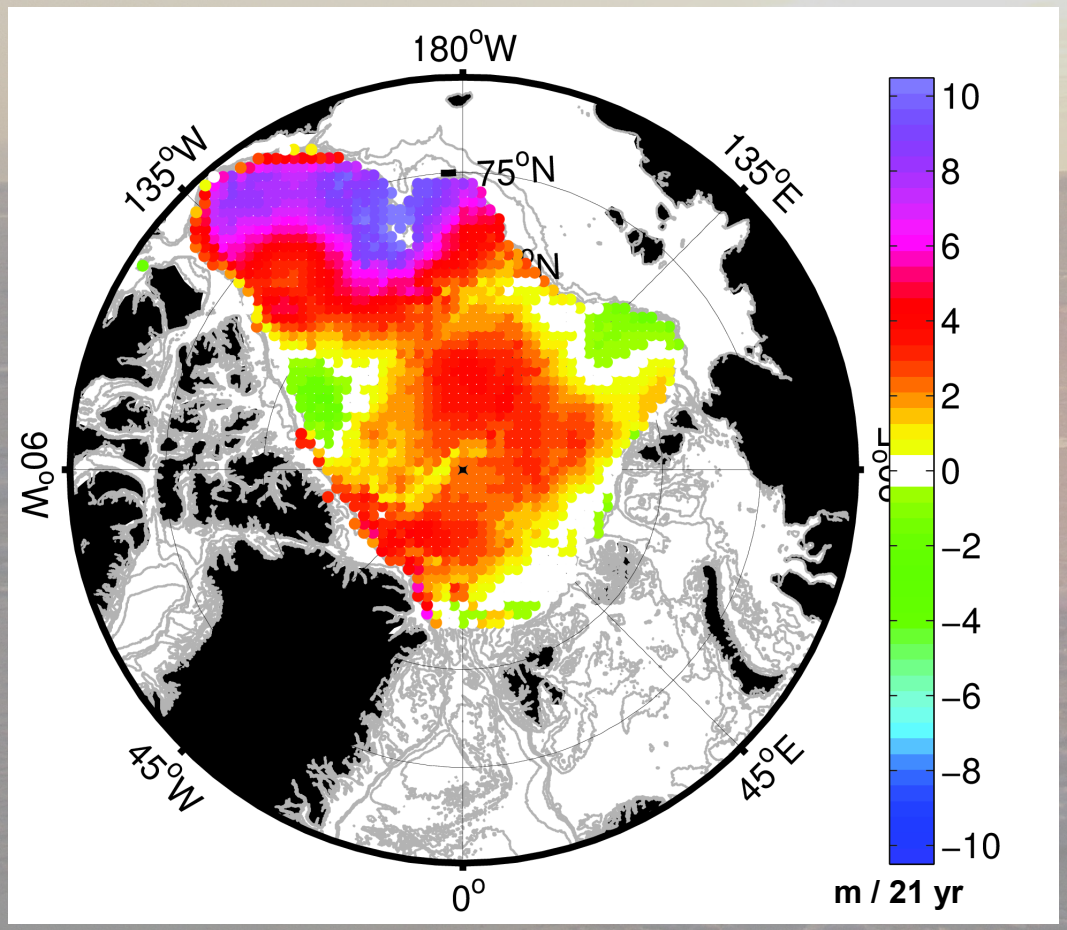
→ Net export decrease (jump ~1998)

→ Surface flux increase (~1/3 of total freshwater change)

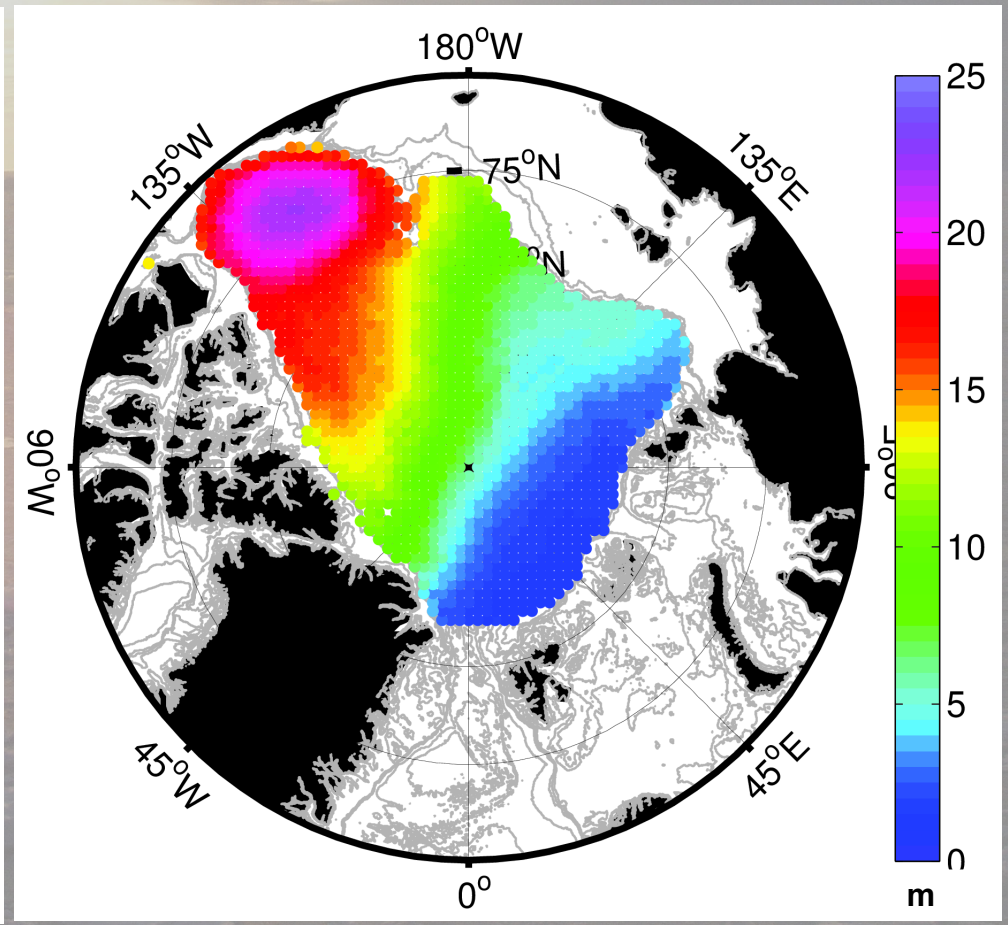
→ Increasing Ekman pumping (Amerasian Basin)

Distribution of Liquid Freshwater inventories 1992-2012

Trend



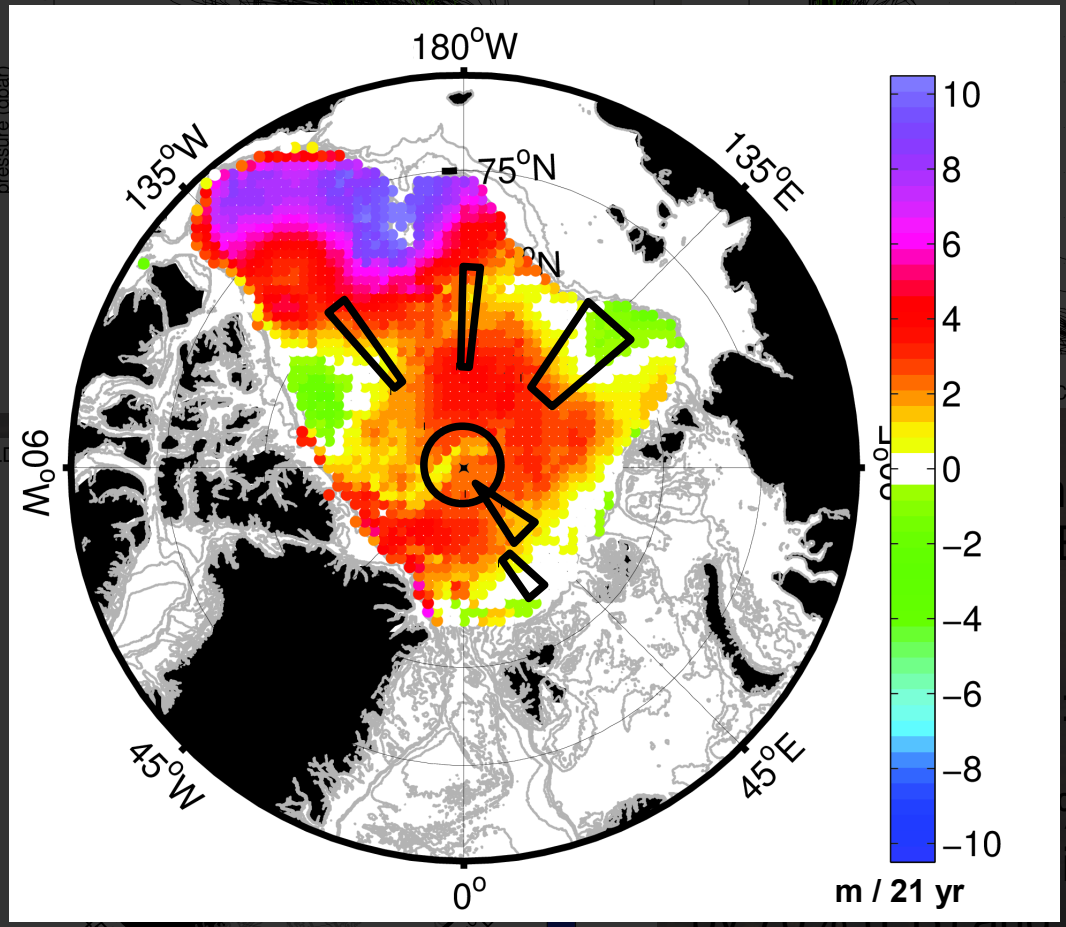
Mean field



c.f.: 1992-1999 to 2006-2008: Rabe et al. (2011, DSR-I)

Implications of freshwater content change: stratification

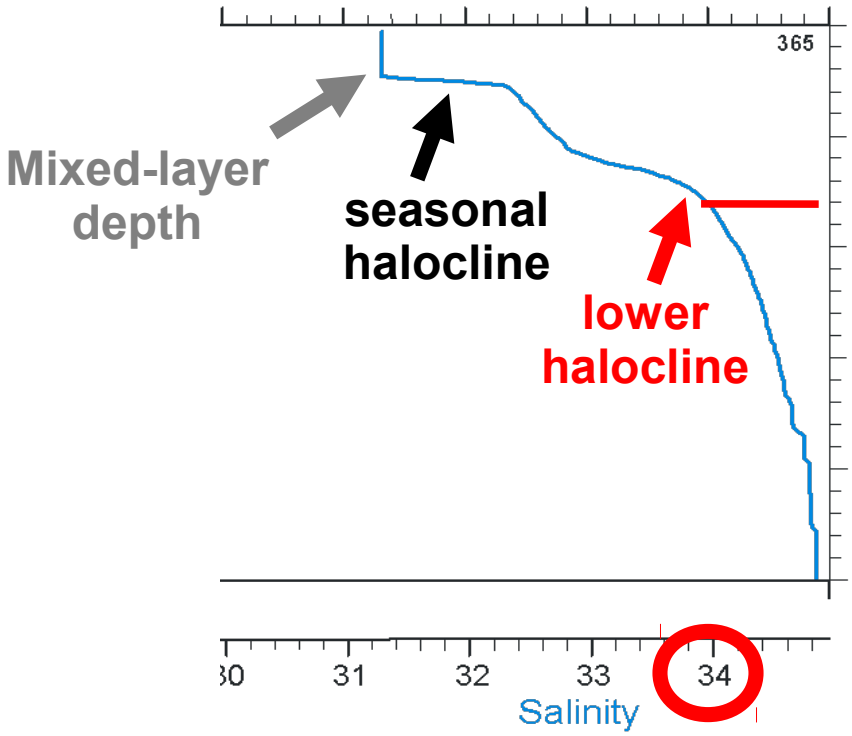
Stratification changes in all regions (median)



→ affects winter mixing, nutrients and primary production !

Mixed-layer depth decreased by 40% (10 m)

Density gradients increased by
→ mixed-layer to 34 isohaline 60%
→ 5 m below ML 20%

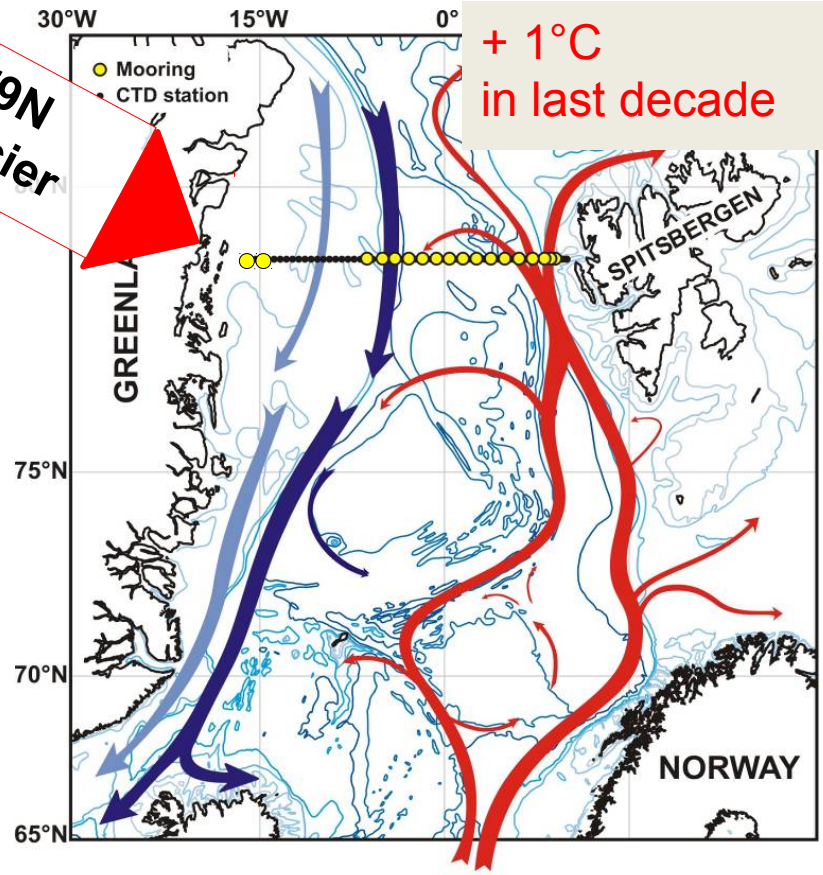


Summary: liquid freshwater content above the 34 isohaline

- Positive trend of about 600±300 km^3 yr^{-1} (12000 km^3) between 1992 and 2012
- Change 30% of liquid freshwater reservoir, larger than average annual export of freshwater (liquid and solid).
- Freshwater storage and trend in a high resolution ice-ocean simulation (NAOSIM) agree very well with our observational estimates.
- Likely contributors to freshwater increase in upper Arctic Ocean basins are increased inflow through the Bering Strait and increased (net) sea ice melt.
- Liquid freshwater content covaries with Arctic Ocean Oscillation.
- Arctic Oscillation or Arctic Dipole indices do not appear to be drivers.
- Ice-ocean simulation indicates:
  increased Ekman Pumping (mainly Amerasian Basin), reduced export from 1998 and, to a lesser extent, increased net sea ice melt.
- Additional freshwater enhanced stratification and reduced mixed-layer depth.

79N Glacier

Polarstern expedition Fram Strait 2014



Thanks to all contributing observational efforts