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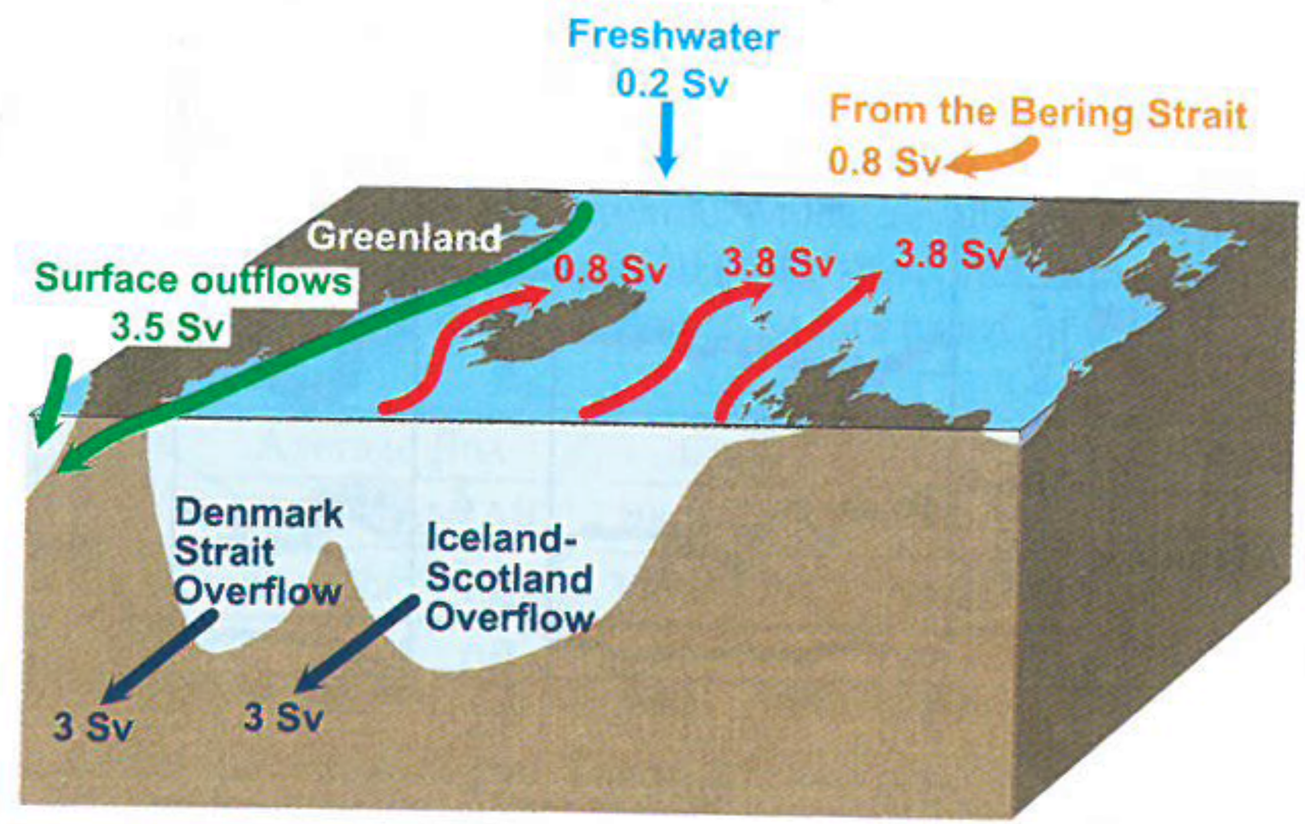
Increased ocean heat transport into the Nordic Seas and Arctic Ocean over the period 1993-2016

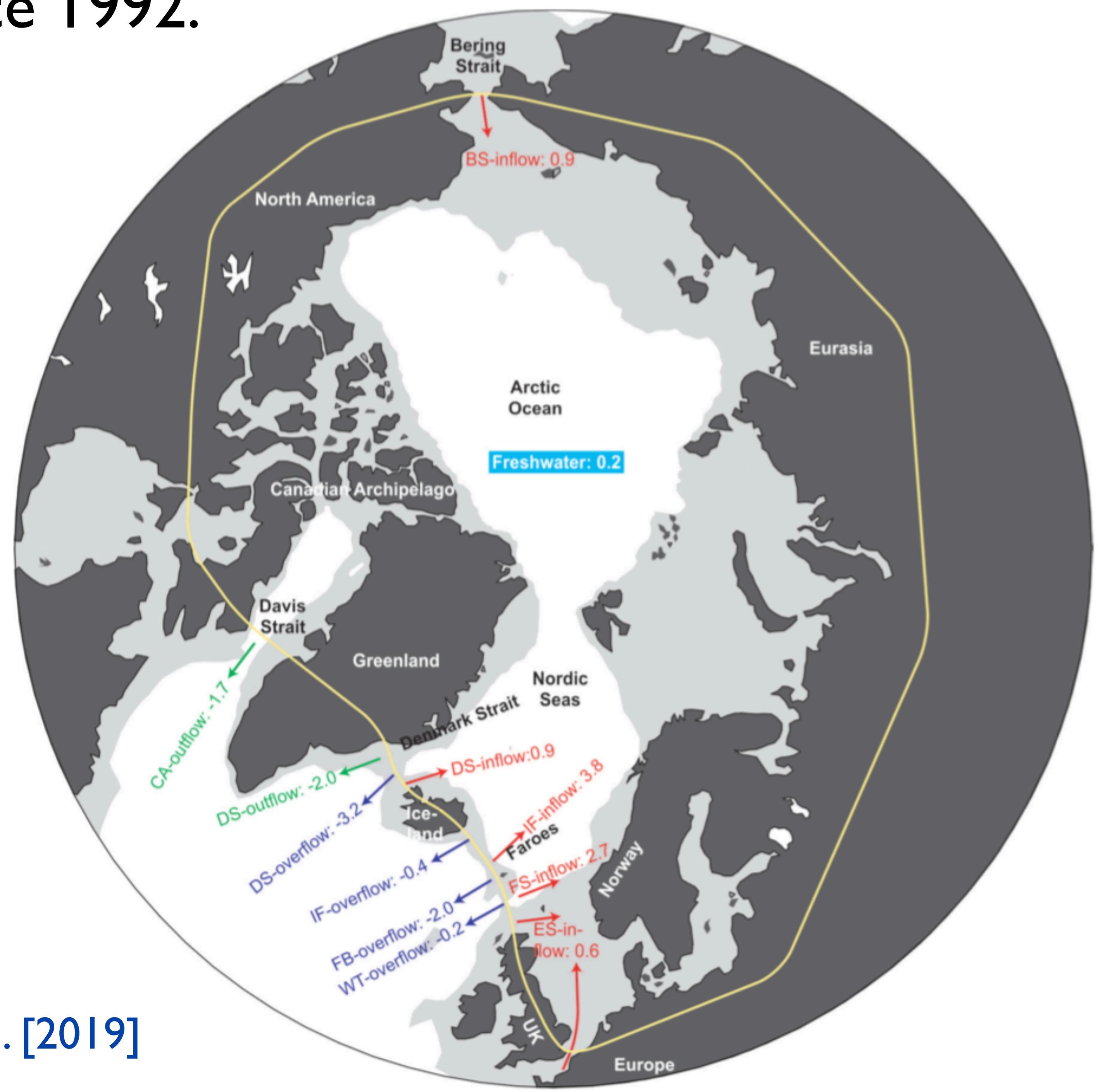
Tsubouchi, T., Våge, K., Hansen, B., Larsen, K., Østerhus, S., Johnson, C., Jónsson, S., and Valdimarsson, H



B. Hansen et al [2008, ASOF book]

The Arctic Mediterranean

- Key gateways: The Greenland-Scotland Ridge, Bering Strait, Davis Strait.
- Long-term measurements since 1992.



Østerhus et al. [2019]

Challenge and approach

Little is known about temporal variability, or even long-term mean of the ocean heat transport.

- Challenge
  - Mass needs to be conserved to estimate ocean heat transport [Schauer and Beszczynska-Moller 2009].
- Approach
  - Consider Arctic Mediterranean as a closed box.
  - Apply box inverse model to constrain mass conservation.

Focus period is from January 1993 to April 2017.

Data

- Volume and temperature transport estimates for the 11 major currents
- PIOMAS sea ice thickness & velocity data [Zhang and Rothrock, 2003].

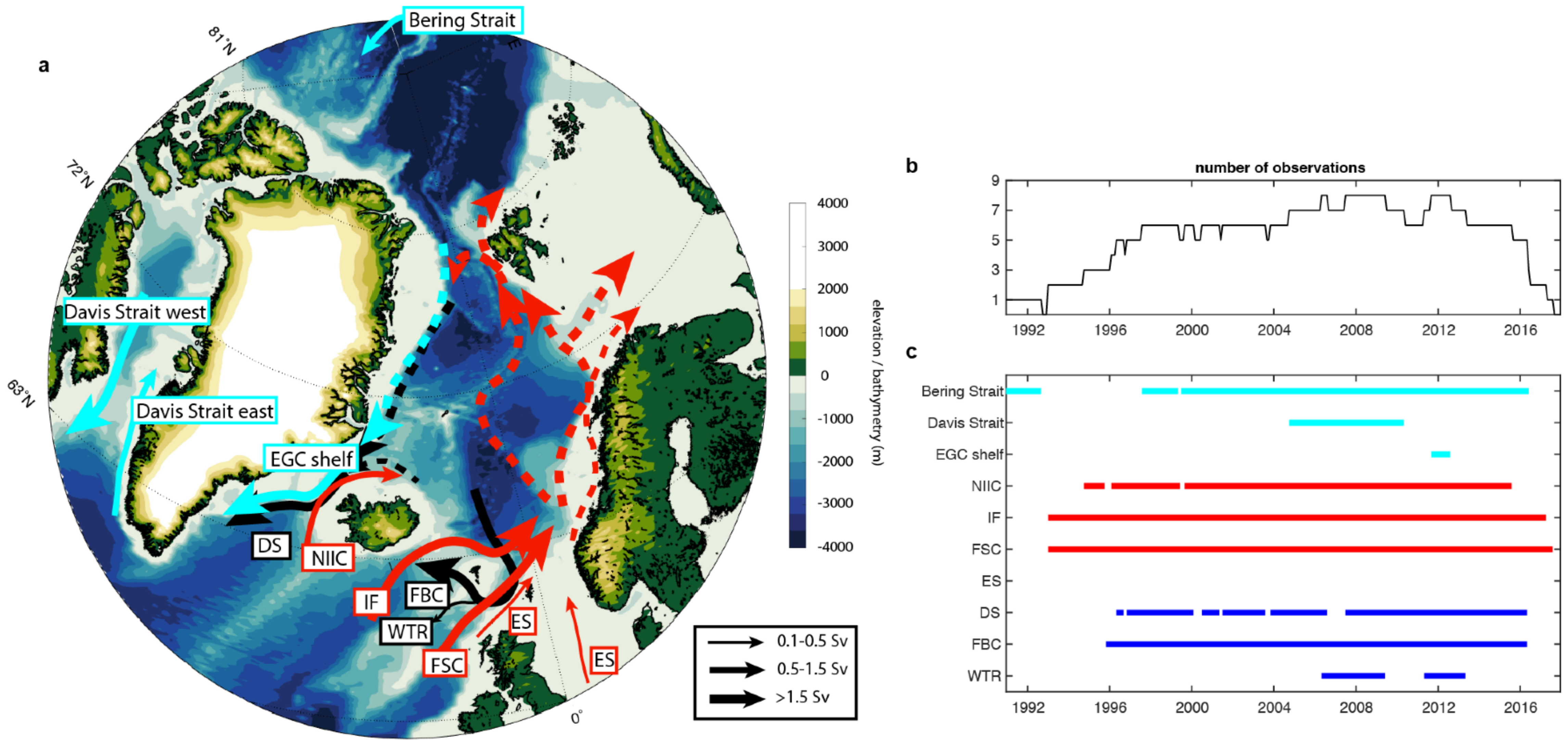


Fig. Major ocean currents of the study region and data coverage.

Ocean heat transport calculation

$$F_{\mathrm{H}}^{\mathrm{o}} = \sum_{j=1}^{N} \rho_{\mathrm{o}} c_{\mathrm{p}}^{\mathrm{o}} V_j \left(\Theta_j - \Theta_{\mathrm{ref}}\right)$$

Vj: inverted volume transport for branch j.

Θ_j : transport weighted potential temperature for branch j.

Θ_{ref} : reference temperature set as 0˚C.

For Θ_j

- We use published temperature transport time series for NIIC, IF, Davis Strait west, Davis Strait east, Bering Strait.
- We use annual mean temperature (González-Pola et al., 2018) with repeat seasonal cycle (Hátún et al., 2004) for FSC, ES.
- We use observed bottom temperature for Denmark Strait, FBC.
- We use constant temperature for WTR, EGCshelf.

Results

Mass-balanced volume transports between 1993-2016

- Continuous mass-closed transports.
- Seasonality in PW and AW.
- Good agreement with Østerhus et al. [2019].

(Sv)	Mean ± uncertainty
PW	-2.7±1.3
AW	+8.1±0.7
OW	-5.6±0.4

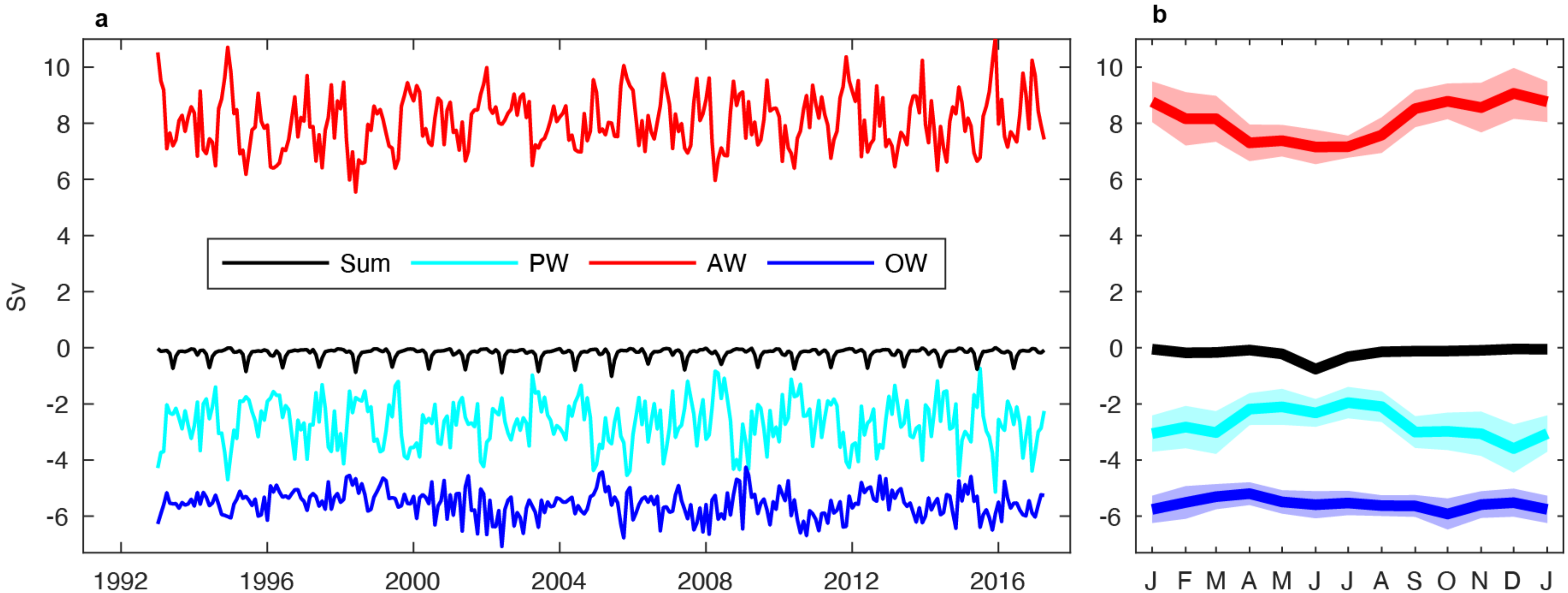


Fig. Mass-balanced volume transport time series in different water masses.

Ocean heat transports between 1993-2016

- The ocean heat transport is 305±26 TW (mean ± uncertainty).
- Seasonality: ~260 TW in AMJ, ~380 TW in SON.
- Increase of 21 TW around 2001 (1.5 Wm^{-2} across the Arctic Mediterranean).

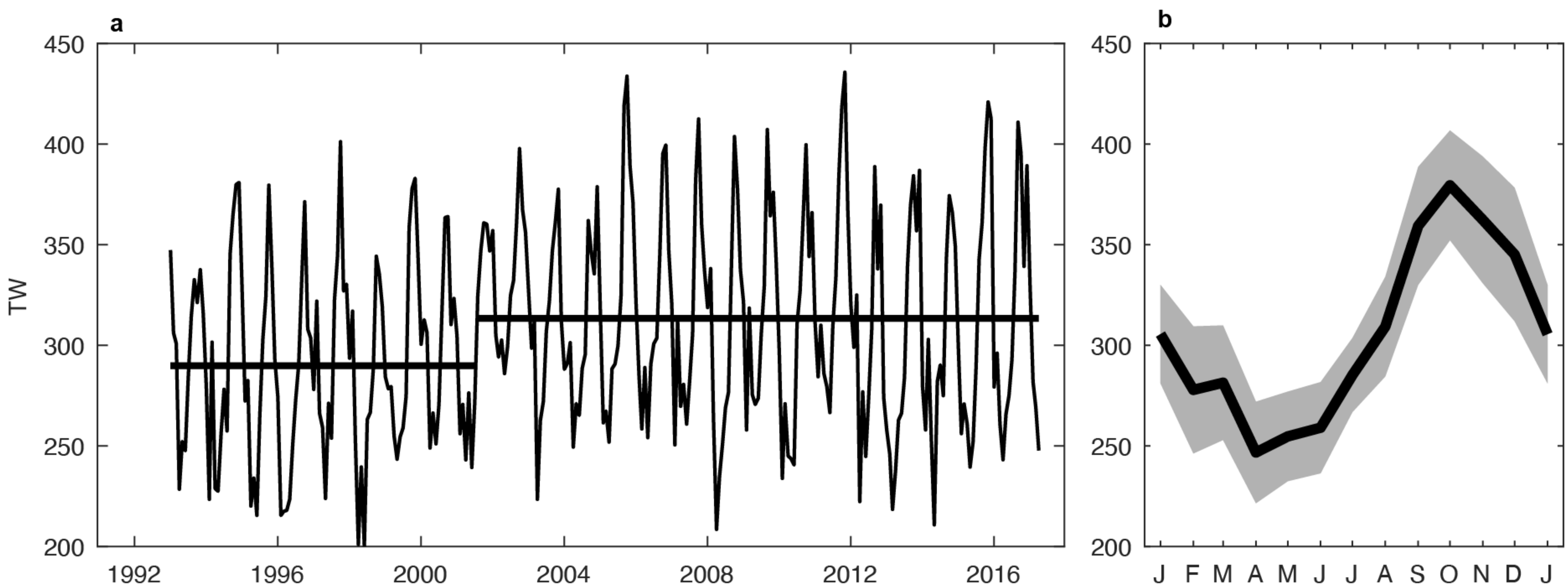


Fig. Ocean heat transport time series with 61 months Hanning filter.

Shift in the ocean heat transport around 2001

- Extra 21 TW heat transport in 2002-2016 reference to 1993-2000.
- The change originates from AW.

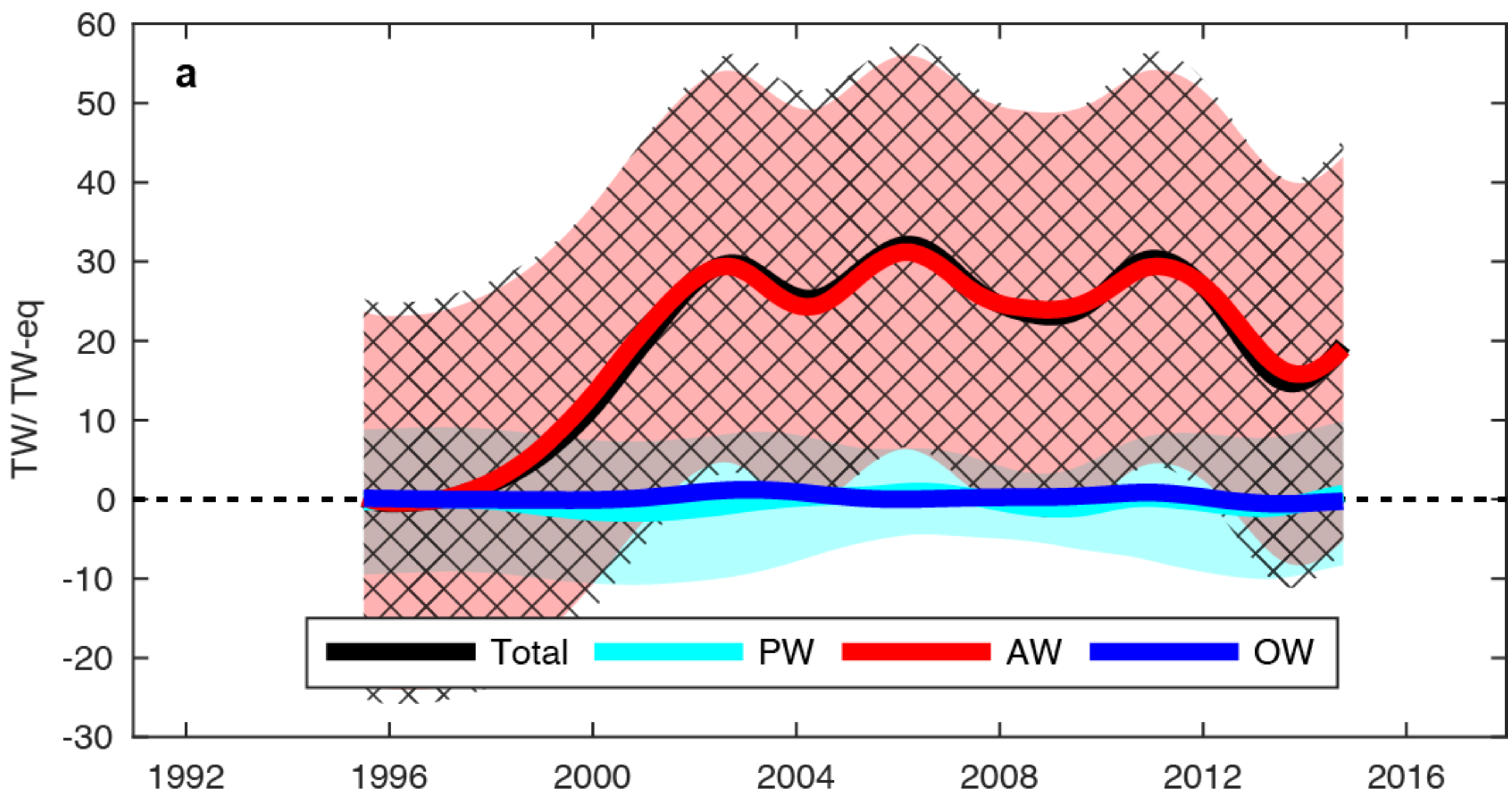


Fig. Filtered ocean heat and temperature transport changes reference to January 1997.

Decomposition of the AW temperature transport

- Initially from FSC branch, then some contributions from NIIC and IF branches.

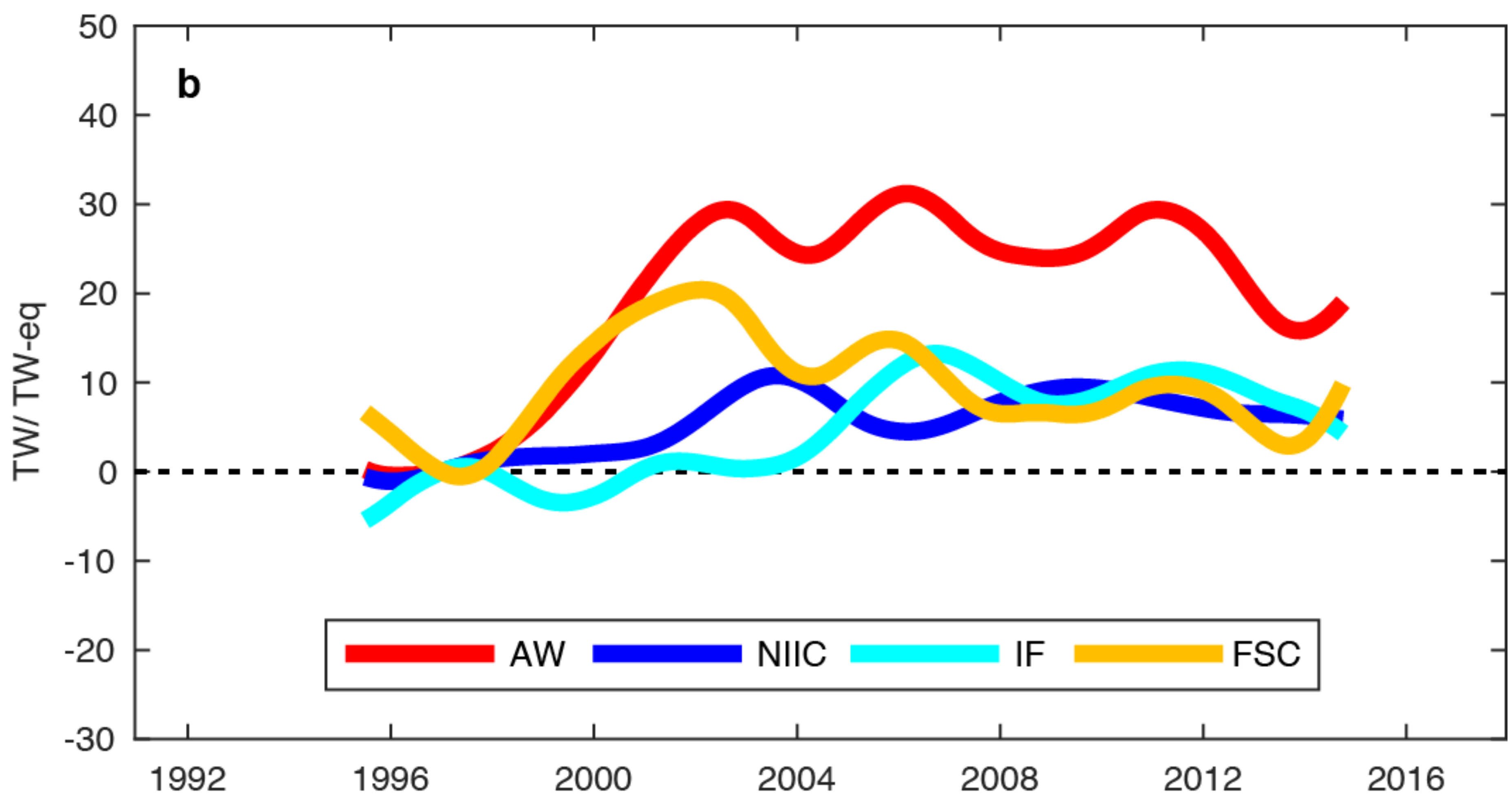


Fig. Contributions to the heat transport change by the temperature transport changes of the three AW branches.

Dominant causes of the ocean heat transport variability

- Both increased volume transport and increased temperature contribute to the change.

$$F_H^o\{V,\Theta\} = F_H^o\{\bar{V},\bar{\Theta}\} + \boxed{F_H^o\{\bar{V},\Theta'\}} + \boxed{F_H^o\{V',\bar{\Theta}\}} + \boxed{F_H^o\{V',\Theta'\}}$$

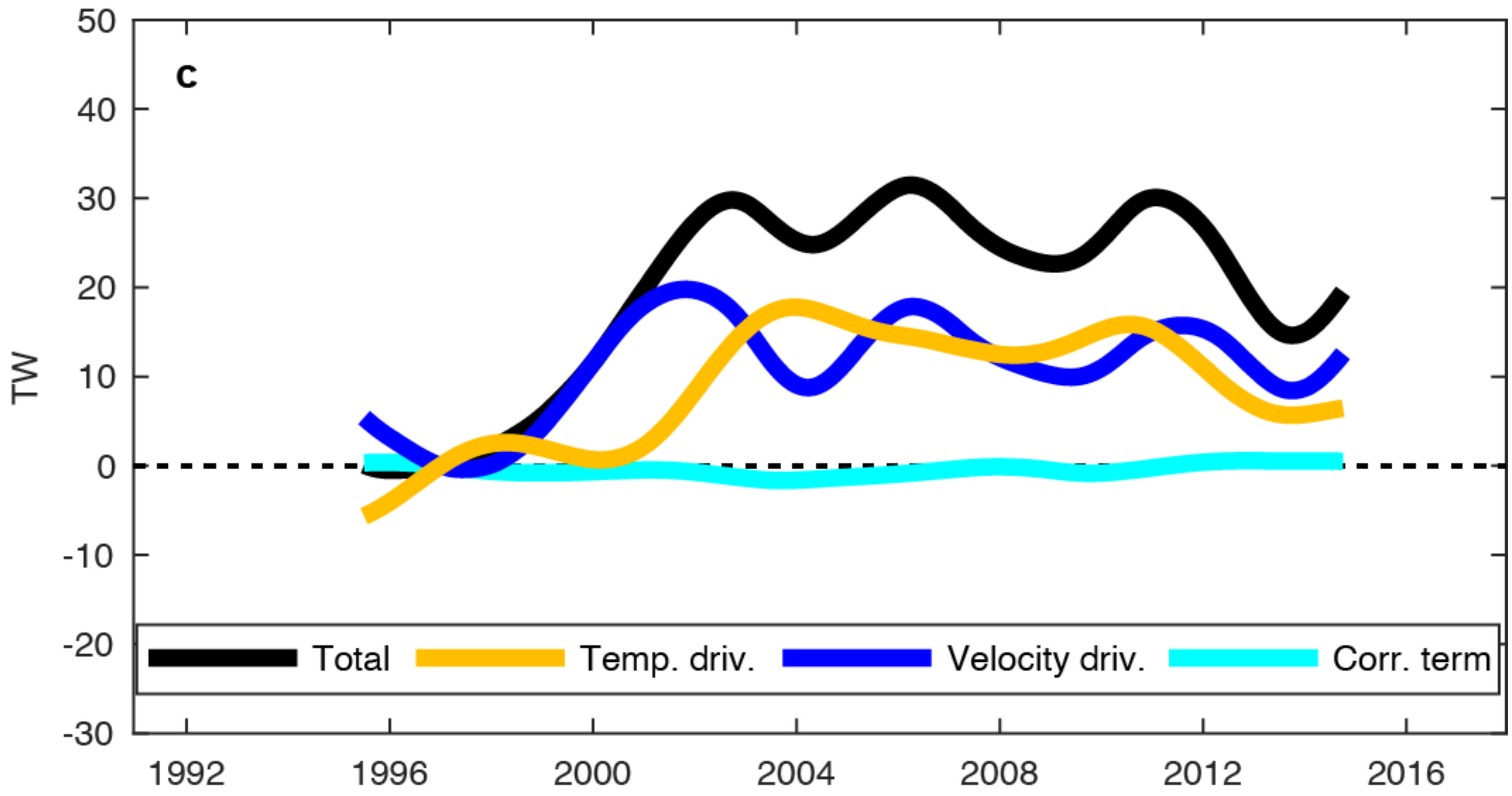


Fig. Decompositions of the heat transport change.

Its role on heat accumulation in the Arctic Mediterranean

- The additional 21 TW heat transport is sufficient to account for the recent accumulation of heat during 2000-2015 [Mayer et al., 2016].
- Ocean heat transport may have played a significant role on heat accumulation in the Arctic Mediterranean since 2000.

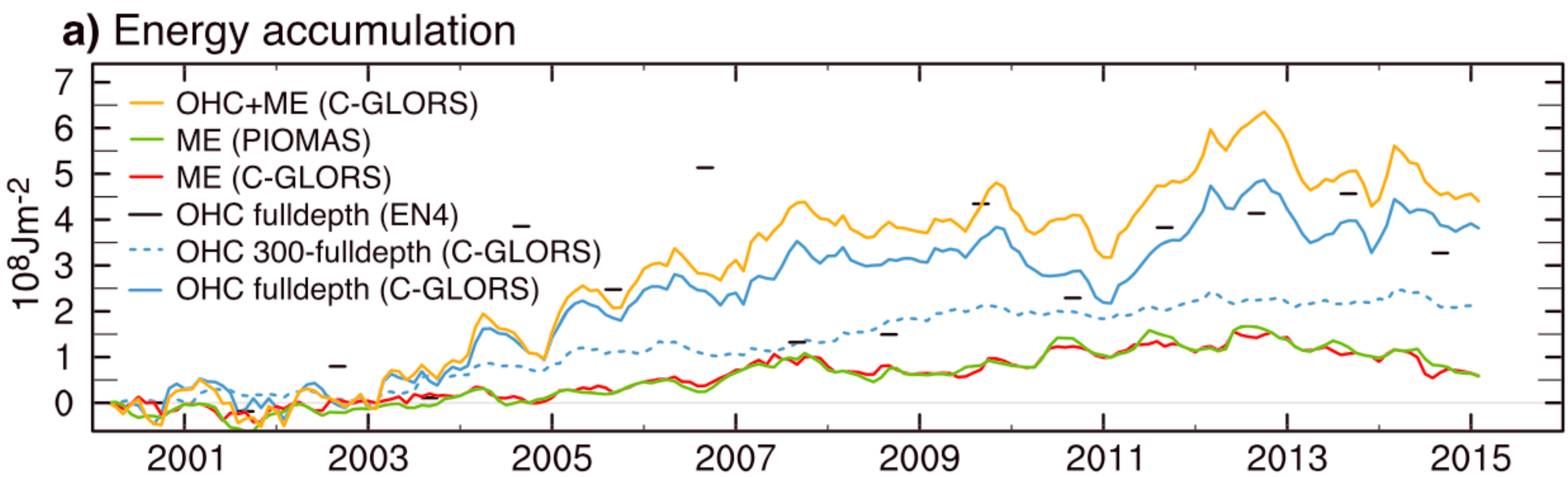


Fig. Energy accumulation north of 70˚N [Mayer et al., 2016].

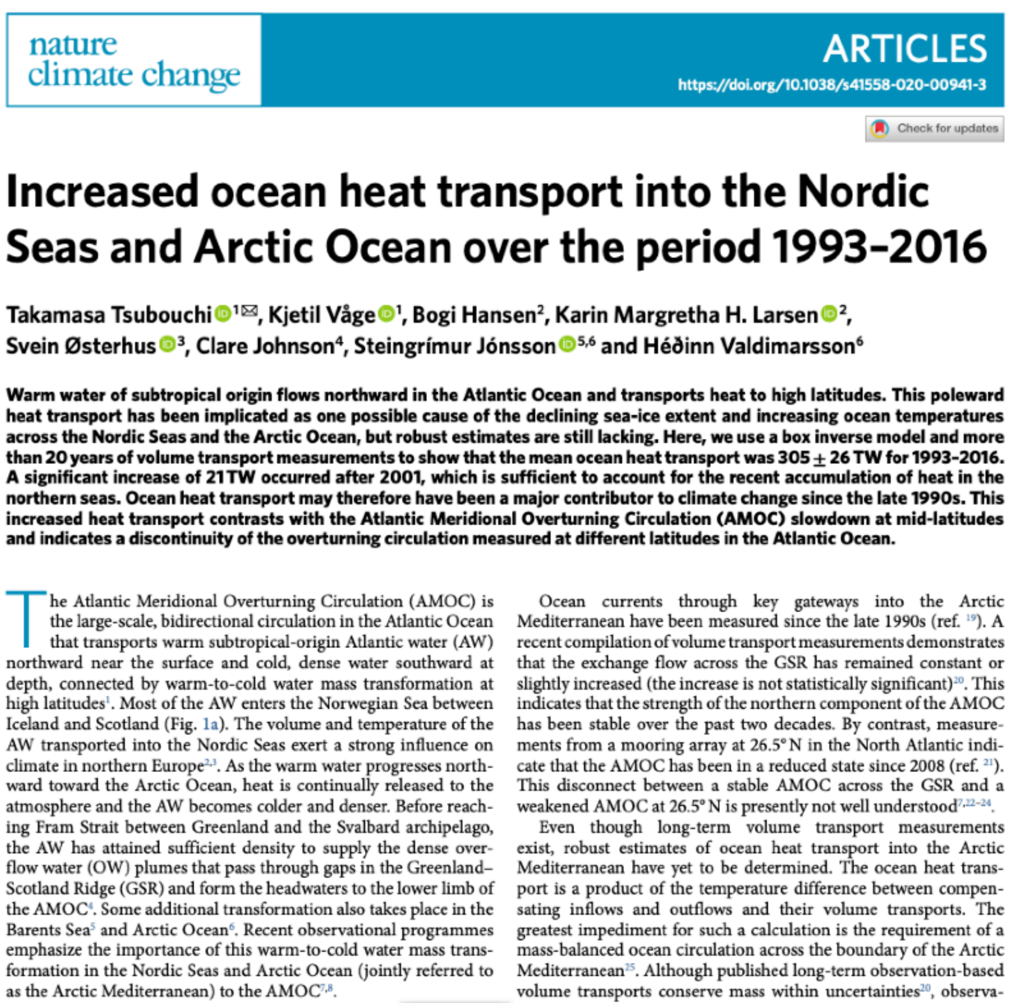
Summary

- This study quantifies time variability of the ocean heat transport using the box inverse model.
- The ocean heat transport is 305±26 TW (mean ± uncertainty).
- Additional 21 TW heat transport in 2002-2016 reference to 1993-2000.
- The additional heat transport is caused by increased temperature and volume transports in AW.

Credits

- T. Tsubouchi, K. Våge, B. Hansen, K. M. H. Larsen, S. Østerhus, C. Johnson, S. Jónsson, H. Valdimarsson (2020): Increased ocean heat transport into the Nordic Seas and Arctic Ocean over the period 1993-2016, Nature Climate Change, https://doi.org/10.1038/s41558-020-00941-3.

- Dataset at Norwegian Maritime Data Centre at http://metadata.nmdc.no/metadata-api/landingpage/0a2ae0e42ef7af767a920811e83784b1



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Increased ocean heat transport into the Nordic Seas and Arctic Ocean over the period 1993–2016

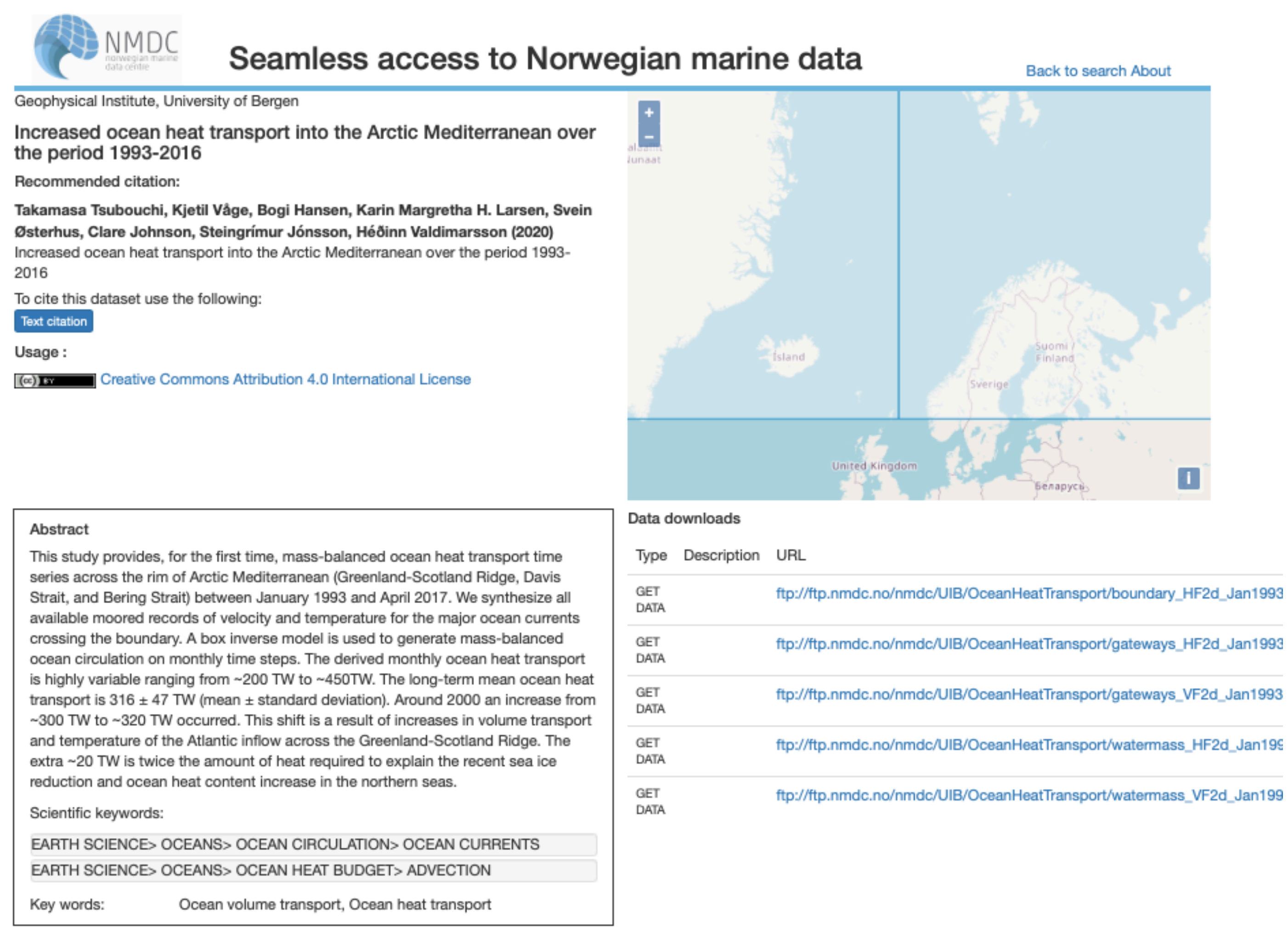
Takamasa Tsubouchi[1✉], Kjetil Våge[1], Bogi Hansen[2], Karin Margretha H. Larsen[2], Svein Østerhus[3], Clare Johnson[4], Steingrímur Jónsson[5,6] and Héðinn Valdimarsson[6]

Warm water of subtropical origin flows northward in the Atlantic Ocean and transports heat to high latitudes. This poleward heat transport has been implicated as one possible cause of the declining sea-ice extent and increasing ocean temperatures across the Nordic Seas and the Arctic Ocean, but robust estimates are still lacking. Here, we use a box inverse model and more than 20 years of volume transport measurements to show that the mean ocean heat transport was 305 ± 26 TW for 1993–2016. A significant increase of 21 TW occurred after 2001, which is sufficient to account for the recent accumulation of heat in the northern seas. Ocean heat transport may therefore have been a major contributor to climate change since the late 1990s. This increased heat transport contrasts with the Atlantic Meridional Overturning Circulation (AMOC) slowdown at mid-latitudes and indicates a discontinuity of the overturning circulation measured at different latitudes in the Atlantic Ocean.

The Atlantic Meridional Overturning Circulation (AMOC) is the large-scale, bidirectional circulation in the Atlantic Ocean that transports warm subtropical-origin Atlantic water (AW) northward near the surface and cold, dense water southward at depth, connected by warm-to-cold water mass transformation at high latitudes[1]. Most of the AW enters the Norwegian Sea between Iceland and Scotland (Fig. 1a). The volume and temperature of the AW transported into the Nordic Seas exert a strong influence on climate in northern Europe[2,3]. As the warm water progresses northward toward the Arctic Ocean, heat is continually released to the atmosphere and the AW becomes colder and denser. Before reaching Fram Strait between Greenland and the Svalbard archipelago, the AW has attained sufficient density to supply the dense overflow water (OW) plumes that pass through gaps in the Greenland–Scotland Ridge (GSR) and form the headwaters to the lower limb of the AMOC[4]. Some additional transformation also takes place in the Barents Sea[5] and Arctic Ocean[6]. Recent observational programmes emphasize the importance of this warm-to-cold water mass transformation in the Nordic Seas and Arctic Ocean (jointly referred to as the Arctic Mediterranean) to the AMOC[7,8].

Ocean currents through key gateways into the Arctic Mediterranean have been measured since the late 1990s (ref. [19]). A recent compilation of volume transport measurements demonstrates that the exchange flow across the GSR has remained constant or slightly increased (the increase is not statistically significant)[20]. This indicates that the strength of the northern component of the AMOC has been stable over the past two decades. By contrast, measurements from a mooring array at 26.5° N in the North Atlantic indicate that the AMOC has been in a reduced state since 2008 (ref. [21]). This disconnect between a stable AMOC across the GSR and a weakened AMOC at 26.5° N is presently not well understood[7,22–24].

Even though long-term volume transport measurements exist, robust estimates of ocean heat transport into the Arctic Mediterranean have yet to be determined. The ocean heat transport is a product of the temperature difference between compensating inflows and outflows and their volume transports. The greatest impediment for such a calculation is the requirement of a mass-balanced ocean circulation across the boundary of the Arctic Mediterranean[25]. Although published long-term observation-based volume transports conserve mass within uncertainties[20], observa-



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Abstract

This study provides, for the first time, mass-balanced ocean heat transport time series across the rim of Arctic Mediterranean (Greenland-Scotland Ridge, Davis Strait, and Bering Strait) between January 1993 and April 2017. We synthesize all available moored records of velocity and temperature for the major ocean currents crossing the boundary. A box inverse model is used to generate mass-balanced ocean circulation on monthly time steps. The derived monthly ocean heat transport is highly variable ranging from ~200 TW to ~450TW. The long-term mean ocean heat transport is 316 ± 47 TW (mean ± standard deviation). Around 2000 an increase from ~300 TW to ~320 TW occurred. This shift is a result of increases in volume transport and temperature of the Atlantic inflow across the Greenland-Scotland Ridge. The extra ~20 TW is twice the amount of heat required to explain the recent sea ice reduction and ocean heat content increase in the northern seas.

Scientific keywords:

EARTH SCIENCE> OCEANS> OCEAN CIRCULATION> OCEAN CURRENTS

EARTH SCIENCE> OCEANS> OCEAN HEAT BUDGET> ADVECTION

Key words: Ocean volume transport, Ocean heat transport

Data downloads

Type	Description	URL
GET DATA		ftp://ftp.nmdc.no/nmdc/UIB/OceanHeatTransport/boundary_HF2d_Jan1993
GET DATA		ftp://ftp.nmdc.no/nmdc/UIB/OceanHeatTransport/gateways_HF2d_Jan1993
GET DATA		ftp://ftp.nmdc.no/nmdc/UIB/OceanHeatTransport/gateways_VF2d_Jan1993
GET DATA		ftp://ftp.nmdc.no/nmdc/UIB/OceanHeatTransport/watermass_HF2d_Jan199
GET DATA		ftp://ftp.nmdc.no/nmdc/UIB/OceanHeatTransport/watermass_VF2d_Jan199

Acknowledgement

- The mooring arrays in key gateways has been maintained by several PIs
  - The Greenland-Scotland Ridge
    - NIIC: Valdimarsson, Jónsson.
    - Faroe - Scotland: Hansen, Østerhus, Larsen, Hatun, Berx.
    - Denmark Strait: Quadfasel, Jochumsen, Moritz.
    - EGC shelf: de Steuer.
    - Wyville Thomson Ridge: Sherwin, Johnson.
  - The Arctic boundary
    - Bering Strait: Woodgate, Weingartner.
    - Davis Strait: Lee.