Online Supplemental Material

Temporal Variability of the overturning Circulation in the Arctic Ocean and the Associated Heat and Freshwater Transports during 2004–10

Journal of Physical Oceanography
https://doi.org/10.1175/JPO-D-23-0056.1

Takamasa Tsubouchi*, Wilken-Jon von Appen, Torsten Kanzow
Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Laura de Steur
Norwegian Polar Institute, Tromsø, Norway

Contents

Support information A: Construction and major features of the monthly gridded fields
Fig. S1 to Fig. S5 are included.

*Corresponding author: t.tsubouchi@met.kishou.go.jp

Support information A

Construction and major features of the monthly gridded fields

a. Mooring data treatment and gridding procedure

Figure S1 shows an overview of mooring current records analysed in this study. Total of 1,165 observed temperature, salinity and velocity moored instrumental records are converted into the 261 continuous monthly time series with no data gap. They consist of 104 temperature, 62 salinity and 95 velocity time series at 109 moored instrument locations across the Arctic four main gateways. The actual procedure is as follows. After a quality control (see detail for supplemental material in T2018), in situ individual temperature, salinity and velocity time series from a single deployment are subsampled at hourly, detided (velocity data only), and smoothed with 27 days cut off Butterworth filter. The individual smooth time series are aligned onto the common daily time axis using 1-day boxcar averaging. Gaussian filter with 5 days e-folding scale and 15 days window is further applied to fill data gaps less than 30 days. Data gaps longer than 30 days are filled by its mean seasonal cycle. Finally, 30 days boxcar averaging is applied to obtain monthly time series. Note that even if ADCP measures velocity profile above the instrument, only point velocity measurement just above the instrument is analysed.

The 261 monthly time series are then used to construct coast to coast and surface to bottom gridded fields. For Davis Strait and Fram Strait, vertical profiles of temperature, salinity and velocity at each mooring site are obtained with vertical linear interpolation using the continuous point measurement of temperature, salinity and velocity time series. This procedure is simpler than that of T2018 because we now deal with a time series with no data gap. No stratification is assumed above the shallowest instruments at each mooring site. They are above ~100 m in the central part of Davis Strait and above ~75 m in Fram Strait. For Bering Strait, only bottom mooring records of temperature, salinity and velocity at each mooring site are used to obtain vertically uniform profiles (Figure S1). Then, vertical profiles at each mooring site in Davis, Fram and Bering Straits are interpolated horizontally with a linear interpolation to obtain the gridded fields. In the BSO, bottom velocity records at 5 mooring sites (FB1-FB5) and nearly bi-monthly CTD profiles are analysed. Geostrophic velocity profiles from CTD profiles and bottom velocity records at the mooring sites are combined to obtain the gridded fields. Finally, in the unobserved parts of the section, zero velocity is applied. They are west of 9.0˚W in Fram Strait (Belgica bank in Fram Strait) and north of 74.5˚N in BSO (north of Bear Island).

b. major features of the monthly gridded fields

Figure S2 shows constructed monthly-mean temperature, salinity and velocity variability at 50 m depth across the pan-Arctic boundary. It captures the major water mass distributions and directions of currents across the pan-Arctic boundary, such as cold and fresh polar water outflow from the Arctic Ocean in the western side of the Davis Strait and East Greenland Current (EGC) region in the Fram Strait, in contrast to warm and salty AW inflow into the Arctic Ocean through the West Spitsbergen Current (WSC) region in the Fram Strait and the BSO. In the Bering Strait, temperature, salinity and velocity are highly variable with a range of 10˚C in temperature, 2.0 in salinity and 0.5 ms^{-1} in velocity. Generally, AW in BSO is 2-3˚C warmer than that of WSC in Fram Strait. Note that there is no spatial variability over Belgica bank on the east Greenland shelf and north of Bear Island in the BSO as a result of the lack of moored observations there.

Figure S3 shows initial volume transport imbalances from October 2004 to May 2010. Full depth initial volume transport imbalance in black line is -3.0±2.2 Sv (mean ± standard deviation (std)), meaning that the Arctic Ocean is losing its volume. In contrast, initial volume transport imbalance above 1,500 m in grey line is -0.5±1.9 Sv (mean ± std). This means that above the 1,500 m, where most of the water mass transformation happens, the inflow transports and outflow transports are almost balanced on long-term average. Most of the imbalance comes from the deep central passage of the Fram Strait. Note that there are still month-to-month imbalances ranging from -6 Sv to 2 Sv above 1,500 m, which will be constrained by the inverse model.

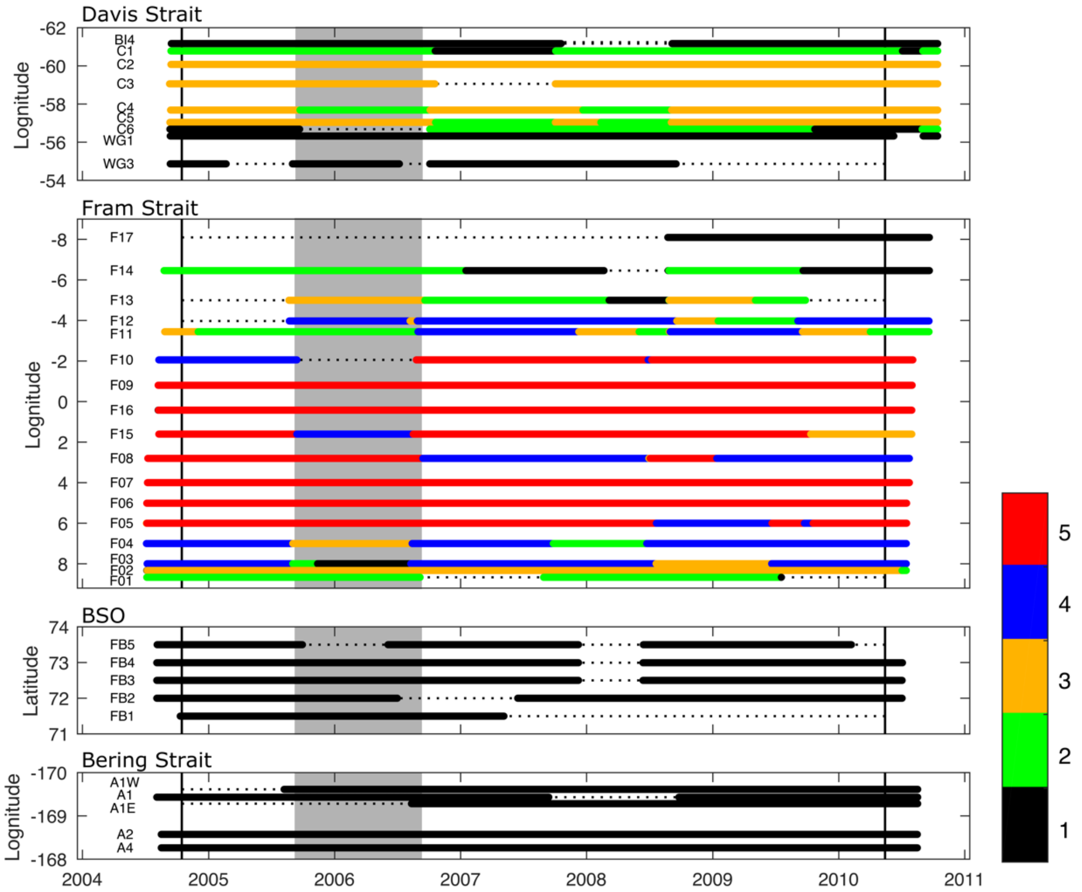

Fig. S1: Number of current records in the vertical at each mooring site analysed in this study in colour. When there is no data available at a particular time, it is shown in dotted lines. The T2018's study period of September 2005 to August 2006 are shaded.

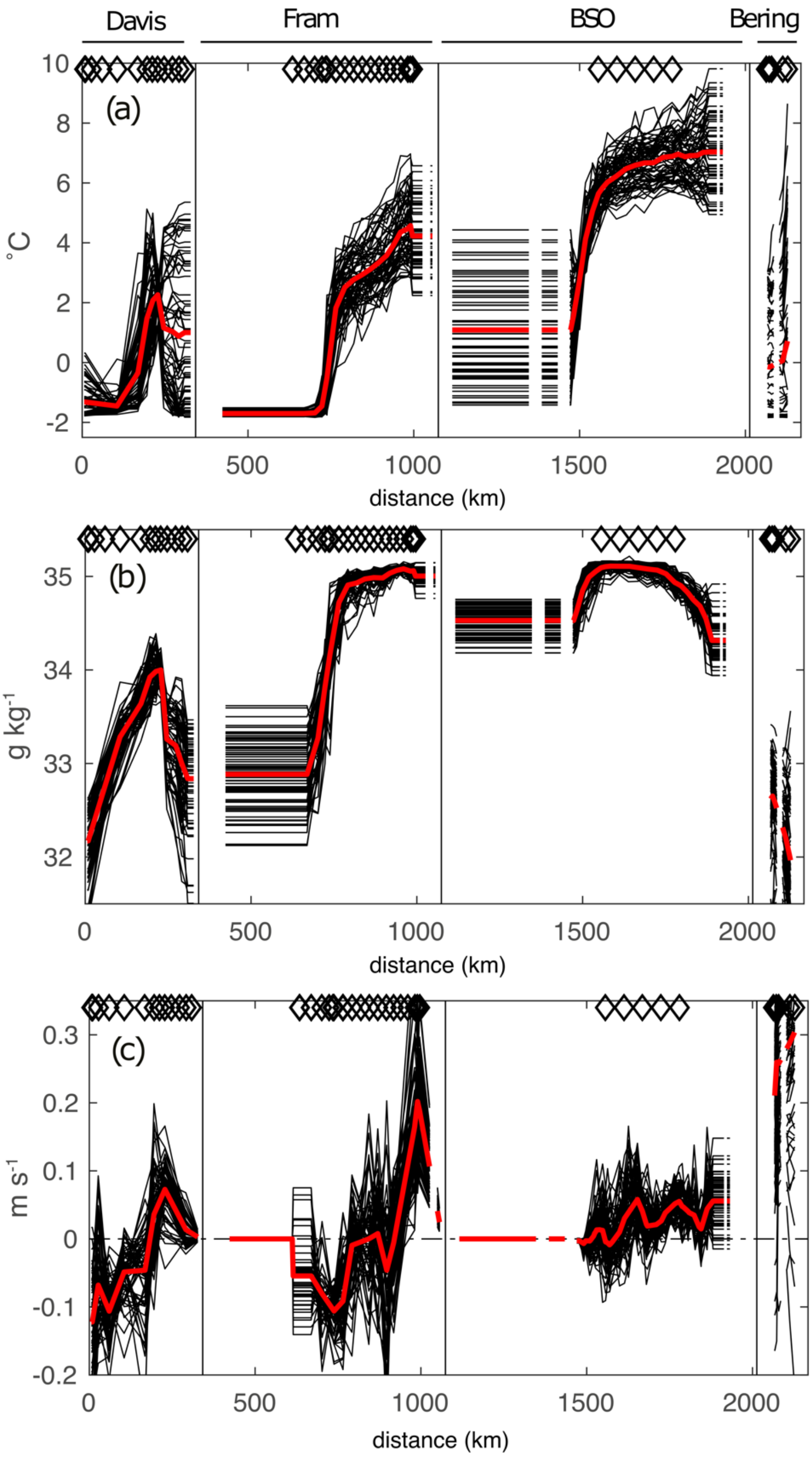

Fig. S2: (a) Temperature variability at 50 m depth across the four Arctic main gateways. Red line shows the mean value and black lines show the individual monthly temperature. Black diamonds show the location of mooring sites. (b) same as (a), but for salinity variability at 50 m depth. (c) same as (a), but for velocity variability at 50 m depth (m s^{-1}). Positive indicates inflow and negative indicates outflow. Zero velocity values are shown in a dashed black line.

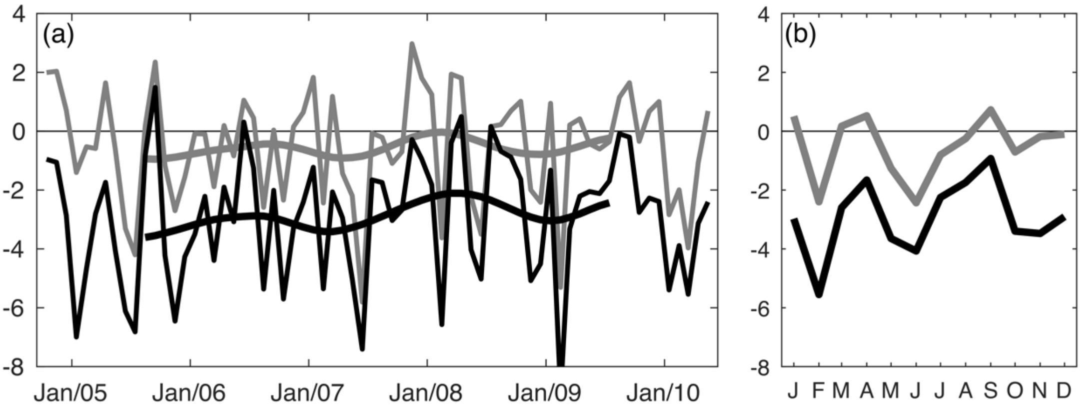

Fig. S3: (a) Time series of initial unbalanced volume transport (Sv) calculated as sum of initial ocean transport, sea ice transport and surface FW input. Negative indicates deficit of volume transport to the Arctic Ocean, meaning that the Arctic Ocean is losing its volume. The black lines show full depth unbalanced volume transports and the grey lines show the corresponding transports above Deep Water (i.e. above 1,500 metres). Bold lines show smooth time series using a 21-point Hanning filter. (b) mean seasonal cycles of the time series. Zero volume transports are shown in horizontal solid lines.

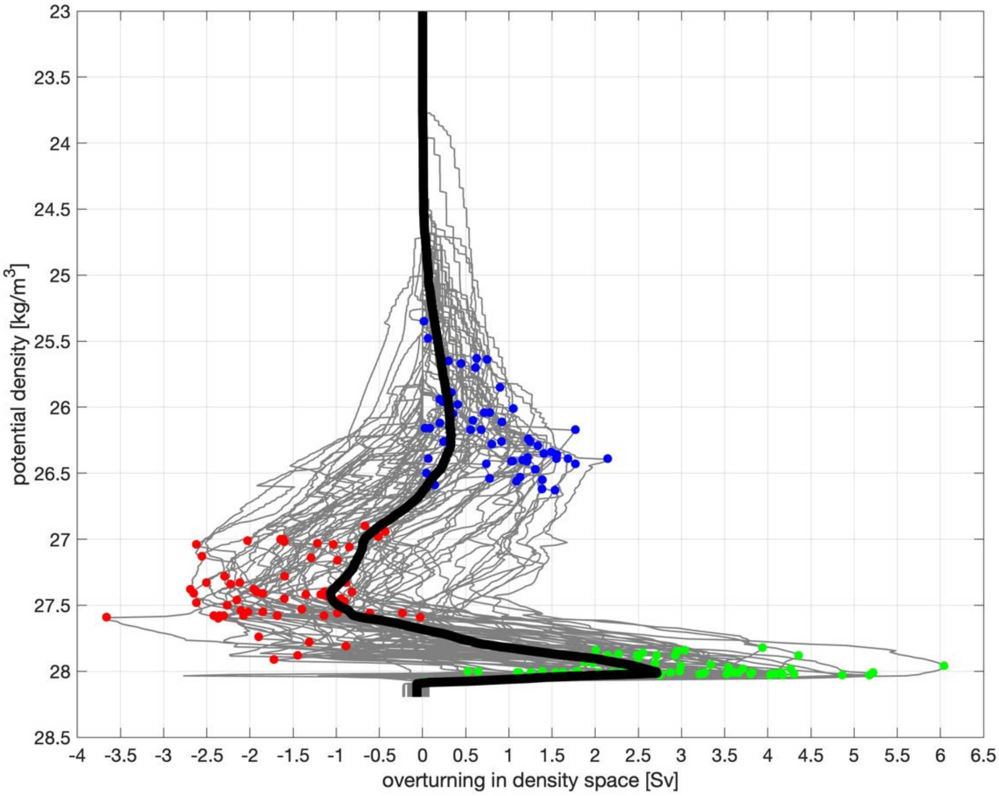

Fig. S4: The overturning stream function in the Arctic Ocean. The 68 months average is shown in a bold black line (same as Fig. 4b) and individual months are shown in grey lines. Green dots show the AW to IW/DW cell defined as maxima denser than 27.683 kgm^{-3}. Red dots show the AW to Polar Water cell defined as minima lighter than the density of the green dot of the same month. Blue dots show the Pacific Water to Polar Water cell defined as maxima lighter than the density of the red dot of the same month. Since the density of these maxima and minima changes from month to month, the 68 months averages of the three overturing cells in the second column of Table 2 are higher than the two maxima and the one minimum of the 68 months mean overturning stream function in Fig. 4b.

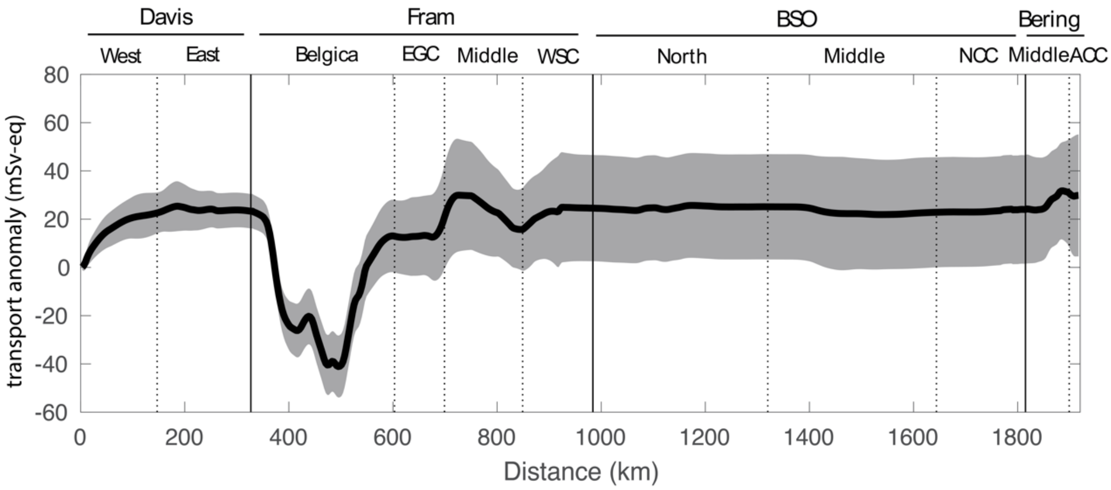

Fig. S5: Integrated FWT anomaly (mSv-eq) across the Arctic boundary compared to T2018 during September 2005 to August 2006 (FWT estimate in T2018 minus that in this study). Twelve months mean in black line and that of standard deviation in grey shading are shown. Vertical solid lines show the boundary of the Arctic four gateways and vertical black dot lines show sections of each gateway.