Duyck, E. & de Jong, M.F. (2021). Circulation over the South-East Greenland Shelf and potential for liquid freshwater export: a drifter study. *Geophysical Research Letters,* 48: e2020JB020886.

Published version: https://doi.org/10.1029/2020gl091948

NIOZ Repository: http://imis.nioz.nl/imis.php?module=ref&refid=334005

Research data: https://doi.org/10.25850/nioz/7b.b.4

Circulation over the South-East Greenland Shelf and Potential for Liquid Freshwater Export: a Drifter Study

E. Duyck[1], M.F. De Jong[1]

[1] NIOZ, Royal Netherlands Institute for Sea Research, Department of Ocean Systems, Texel, The Netherlands

Corresponding author: Elodie Duyck elodie.duyck@nioz.nl

Key Points:

- Drifter tracks show steering from shelfbreak towards the EGCC at Sermilik Trough and exchanges between the EGC and EGCC downstream.
- West of Cape Farewell, drifters in the EGC and EGCC are redistributed into a shelfbreak core and a slow, eddying inner-shelf flow.
- Five of 15 shallow drifters were exported, mainly near Cape Farewell. Cold water leakage is observed from SST data in the same area.

Abstract

Freshwater input into deep convection regions could affect the overturning circulation. With a set of 15 CARTHE and 15 SVP drifters, we investigate the circulation over the south-east Greenland shelf and the potential for off-shelf freshwater export. Part of the East Greenland Current flow is steered into the East Greenland Coastal Current immediately upstream of Sermilik Trough. Between the trough and Cape Farewell, two separate cores are visible. Just past Cape Farewell drifters are redistributed into a shelfbreak core and a slow eddying shelf flow. A coastal core is reestablished downstream. Exchanges between the shelfbreak and coastal flows take place both on the east and west Greenland shelf, allowing fresher water to be diverted away from the coast. Five of 15 shallower CARTHE drifters were exported, mainly at Cape Farewell. CARTHE motion shows a higher correlation with local winds, which are more favorable for off-shelf transport in this area.

Plain Language Summary

The Atlantic Meridional Overturning Circulation is a key element of the climate system. Global warming causes an influx of freshwater over the east Greenland shelf, that could affect the Atlantic circulation if it is exported into areas where deep water is formed. We deployed 30 surface drifters in August 2019, which we combine here with existing drifter and satellite data to describe the circulation over the south-east Greenland shelf. The export of five shallow water drifters into the Irminger Sea suggests that wind could be a driver for freshwater export away from the shelf.

1 Introduction

Atmospheric and oceanic warming of the Arctic and Subarctic regions results in enhanced Greenland Ice Sheet melt and freshening of the Arctic Ocean, leading to increased discharge of freshwater into the East Greenland Current (EGC) (Bamber et al., 2018; Haine et al., 2015). Additional freshwater input into the convective regions of the Subpolar North Atlantic could strengthen watercolumn stratification and weaken deep mixing (Aagaard & Carmack, 1989), in turn affecting the strength of the Atlantic Meridional Overturning Circulation (Bakker et al., 2016; Böning et al., 2016; Manabe & Stouffer, 1994). Recent findings argue for a more important role of the overturning east of Greenland (Lozier et al., 2019), highlighting the particular climatic importance of freshwater export from the east Greenland Shelf. This study investigates the fate of liquid freshwater from the EGC system, notably potential export into the deep convection region of the central Irminger Sea (de Jong et al., 2018).

South of Denmark Strait (DS), the EGC system (Figure 1A) consists of a main branch located at the shelf-break (EGC), and a coastal branch referred to as the East Greenland Coastal Current (EGCC). The EGC is found at the front between the colder, fresher waters flowing south from Fram Strait and the warmer, saltier Irminger Current waters. The EGCC (Malmberg, 1967; Bacon, 2002) is a fresh (practical salinity < 34), 20 km-wide, surface-intensified current, with a high-velocity core (speeds > 1 m s^{-1}) carrying arctic waters and Greenland runoff equatorwards (Bacon et al., 2014; le Bras et al., 2018). Recent work (Foukal et al, 2020) showed that the EGCC extends along the whole east Greenland coast, while confirming that deep troughs south of Denmark strait divert part of the EGC into the coastal current (Sutherland & Pickart, 2008; Sutherland & Cenedese, 2009). Past Cape Farewell (CF), the EGC and EGCC were first thought to merge into the West Greenland Current (WGC) (Bacon, 2002), but more recent studies argue that the EGCC keeps its identity as a coastal core to become the West Greenland Coastal Current (WGCC) (Lin et al., 2018).

The cold and fresh Polar Surface Water found over most of the east Greenland shelf (Rudels et al., 2002) is isolated from interior seas by the sharp hydrographic front associated with the EGC. It is pushed towards the coast by the onshore Ekman transport caused by south-westward barrier winds (Moore & Renfrew, 2005). However, the complex bathymetry of the shelf, meandering of the front, wind strength and variability, create opportunities for export of surface waters towards the interior seas, notably at CF (Holliday et al., 2007). While export of fresh waters from the west Greenland shelf into the Labrador Sea is already well documented (Schulze Chretien & Frajka-Williams, 2018; Wolfe & Cenedese, 2006), there is still little insight into surface water export from the east Greenland shelf into the Irminger Sea.

Despite renewed interest in the EGC system, our understanding of the liquid freshwater circulation over the east Greenland shelf remains sparse. Insight into the properties and structure of the EGC is provided by synoptic sections, mooring arrays in select locations and isolated drifters (Bacon 2002, Reverdin 2003). In this study, we present a set of 30 drifters deployed at the east Greenland continental shelf-break at approximately 65°N. Drifter deployments and data processing are described in Section 2. Drifter trajectories and insights from additional datasets are presented in Section 3. Section 4 discusses the results and possible implications for liquid freshwater export.

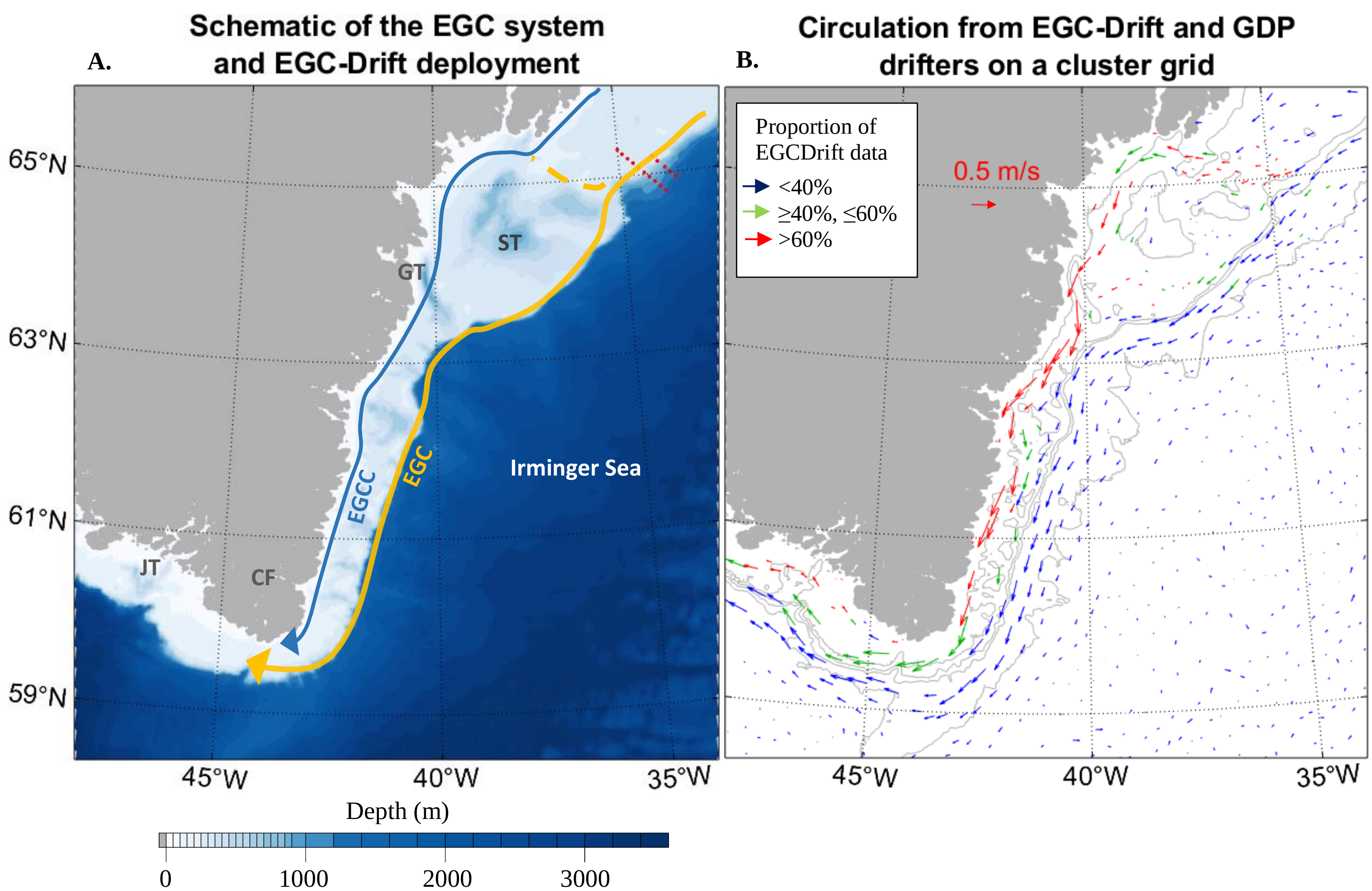

Figure 1:
Schematic of the surface circulation over the east Greenland shelf with drifter deployment location and drifter data overview: **A.** EGC System, and main topographic features. EGC: East Greenland Current, EGCC: East Greenland Coastal Current, ST: Sermilik Trough, GT: Gyldenlove Trough, CF: Cape Farewell, JT: Julianehåb Trough; Drifters were deployed at two shelfbreak sections at 65°N (red dots). **B.** Circulation inferred from the Global Drifter Program and our EGC-DrIFT datasets combined on a cluster grid (see methods in Section 2). Arrows are colored depending on the percentage of EGC-DrIFT data in each cluster as defined in the legend. Isobaths (in grey) are drawn at 2000, 1000, 500 and 200 m depth.

2 Materials and Methods

We present the first results from the East Greenland Current Drifter Investigation of Freshwater Transport (EGC-DrIFT) campaign. This study aims to elucidate possible pathways for freshwater exchanges east of Greenland with surface drifter deployments planned in the summers of 2019, 2020 and 2021. The dataset discussed here consists of two types of drifters. Surface Velocity Program (SVP) drifters are composed of a spherical buoy and a holey sock drogue centred at 15 m below sea level (Lumpkin et al., 2017). Two models of SVP drifters are used: SVP-T, fitted with a temperature sensor measuring sea surface temperature (SST) at 0.5 m depth, and SVP-S fitted with an additional conductivity sensor to measure salinity. GPS positions and data are transmitted to shore via iridium at hourly intervals for SVP-T drifters and 3-hourly intervals for SVP-S drifters. CARTHE drifters (Consortium for Advanced Research for the Transport of Hydrocarbon in the Environment, Novelli et al., 2017) are shallower drifters, composed of a floating torus sitting low above water and a drogue at 0.4 m depth. They provide GPS tracking at 3-hourly intervals.

In total, 15 CARTHEs and 15 SVPs (seven SVP-Ts, eight SVP-Ss) were deployed along two lines perpendicular to the shelf-break and 40 km apart (Figure 1A) on the 14th August 2019. The southern line extended from 1200 to 250 m depth and the northern line from 1300 to 250 m depth. Drifters were released 9 km apart, in pairs of one SVP and one CARTHE drifter, as to elucidate the behaviour of different extents of the surface water layer. We present here their trajectories until 1st December 2019 and up to 48°W.

One SVP drifter stopped working upon launch, but the remaining 14 functioned properly. By the 1st December 2019, 12 SVPs and four CARTHEs (that have a shorter expected lifetime) were still active. SVP-Ts occasionally (4% of dataset) display repeated positions, mostly corresponding to one to two hours GPS gaps. SVP-Ss do not experience similar issues. CARTHEs display GPS gaps that can last for several days. Temperature and conductivity timeseries are despiked and other hydrographic properties, such as absolute salinity and density are derived using the TEOS10 toolbox (Mc Dougall and Barker, 2011). Drifter velocities, computed from displacement, are filtered with a 25-hour centered Butterworth filter to remove high-frequency components. The presence of the drogues on SVP drifters is monitored from a submergence sensor and the time to first GPS fix, both of which exhibit drastic changes when a drogue is lost. No SVP drifter seems to have lost its drogue before 1st December 2019. Finally, the dataset is resampled using linear interpolation on a 3-hour regular grid, not interpolating data gaps longer than 12h.

We use the Global Drifter Program (GDP) quality-controlled 6-hour interpolated dataset (Lumpkin & Centurioni, 2019) to contextualize our results. GDP and EGC-DrIFT data are non-uniformly distributed in the region, and therefore less suitable for regular spatial gridding. Instead, we combine EGC-DrIFT and GDP drifter data on an irregular grid built with a clustering method using a k-mean algorithm. This algorithm groups neighboring observations in clusters with an iterative assignment/update mechanism, in order to find a solution minimizing the distance between observations and cluster centers. See McKay (2003) for more details on the algorithm, or Koszalka and LaCasce (2010) for an example of its application to drifter data. We choose a k number of clusters so that the mean amount of observations per cluster is 80, and do not take into account clusters with less than 20 data points

Surface winds from 1993 to 2020 are retrieved from the ERA5 atmospheric reanalysis hourly data on single levels (Copernicus Climate Change Service, 2017). Wind data are used to compute the correlation coefficient between wind and drifter motion. This coefficient is the magnitude of the complex correlation between wind and drifter velocities (u(t)+i·v(t)) (Poulain 2009). Wind data are also used to evaluate potential for off-shelf Ekman transport along the east greenland shelf. Wind components are interpolated along the shelfbreak, defined as the 500 m isobath, and Ekman transport is computed from wind stress as:

$$\begin{cases} U_{ek} = \dfrac{T_y}{f * \rho} \\ V_{ek} = \dfrac{-T_x}{f * \rho} \end{cases}$$

Tx, Ty being wind stress components, ρ=1027 kg m^{-3} and f=10^{-4} s^{-1}. Along and across shelf Ekman transports are then derived using the local angle of the 500 m isobath, and used to compute the proportion of days with positive off-shelf Ekman transport along the shelf.

SST is retrieved from the GHRSST Level 4 MUR Global Foundation SST Analysis (JPL MUR MEaSUREs Project, 2015), a data blend of microwave, infrared, ice fraction and in situ measurements, with a very high resolution (1 km) in cloudless conditions (Chin et al., 2017). Cloud cover sometimes diminishes the real resolution of the MUR dataset and can cause artifacts. The quality of the MUR SST data at times of interest is verified by comparing it to the GHRSST Level 4 OSTIA Global Foundation SST Analysis (UK MetOffice, 2012).

3 Results

The trajectories of the EGC-DrIFT SVP buoys are consistent with existing GDP trajectories, while providing extended coverage close to the coast and a denser sampling of the circulation over the shelf (Figure 1B). Although the EGC-DrIFT drifters are limited in numbers they close an important data gap in the inner shelf region and provide coverage of the EGC and EGCC simultaneously, allowing comparison of properties and insight into exchanges taking place between these two cores.

The drifters take one to two months to reach the southern tip of Greenland. They quickly separate into three groups after deployment (figures 2B and 2C): 1) following the EGC, 2) steering around Sermilik Trough (ST) into the EGCC, and 3) entering the trough before joining the EGCC.

The first group follows the EGC and is composed of 12 drifters, among those deployed the furthest offshore (seven out of 15 (7/15) CARTHEs and 5/14 SVPs). In the EGC core, SVPs measure temperatures about 10°C and absolute salinities between 34.6 and 35.2 g kg^{-1} (Figures 2E and F). Speeds do not exceed 0.6 m s^{-1} as the EGC is steered around ST (Figure 2D). The three SVP drifters from the northern line first head offshore, but loop around and come back on the inshore side of the EGC. Three SVPs and one CARTHE re-enter the shelf at different points along the trough. Out of the core, their motion becomes very slow (<0.1 m s^{-1}) and inertial. They join the EGCC just downstream of ST, measuring a sharp decrease in temperature as they enter the coastal core.

Ten drifters (2/15 CARTHEs, 8/14 SVP drifters) belong to the second group, which is steered around ST directly towards the EGCC. They are initially slow (<0.1 m s^{-1}) but accelerate as they get closer to the coast, eventually reaching speeds up to 0.8 m s^{-1} as they enter the EGCC core. Inside the core, they measure a large range of salinities (29 to 34 g kg^{-1}) and temperatures between 3 and 5.5°C, the coldest and freshest waters being closest to the coast.

Finally, seven drifters (6/15 CARTHEs and 1/14 SVPs) move across the trough before joining the EGCC. They all follow similar trajectories as they flow from their deployment area, close to the shelf-break, into the trough and later into the EGCC. Their speed inside the trough does not exceed 0.2 m s^{-1}. The SVP drifter measures temperatures around 7°C , and salinities around 34.5 g kg^{-1} in the middle of ST.

South of ST, only two groups are identifiable, associated with the two current cores. As the Greenland shelf narrows downstream of ST, drifters in the EGCC are steered along the Gyldenløve Trough and accelerate, reaching speeds of more than 1 m s^{-1}. The EGCC remains faster than the EGC until they reach CF. The cores are well defined but exchanges take place between them. As was previously observed with a CTD section by Sutherland & Pickart (2008), the two cores come closer together just downstream of ST, at the narrowest part of the shelf. There, four of the CARTHEs are deviated from the EGCC to the EGC. Further downstream, two SVPs and one CARTHE also leave the EGCC for the EGC. As the drifters near CF, seven SVPs and no CARTHE remain in the EGCC, four SVPs and six CARTHEs in the EGC.

Four of these CARTHEs are exported into the Irminger Sea just before rounding CF. The two others round the cape and enter the west Greenland shelf. Another CARTHE drifter had been exported earlier at a bathymetric bend downstream of ST. The others stopped functioning.

West of CF, only one strong (1 m s^{-1}) velocity core is visible, at the shelf-break, with a slower, less laminar flow over the shelf. As illustrated in Figure 2A, SVPs originating from the EGCC (green) spread over the shelf as they round the cape. Two SVPs remain close to the shore, showing slow and eddying motions, while five SVPs approach the shelfbreak, two of which enter the WGC. Similarly, two of the EGC-origin SVPs (red) enter the shelf on the western side of Greenland. Most shelf SVPs are then steered along Julianehåb Trough. This redistribution of coastal and shelfbreak floats suggests that the WGC and WGCC are not as clearly separated as the EGC and EGCC, enhancing potential for freshwater exchange away from the inner shelf west of CF.

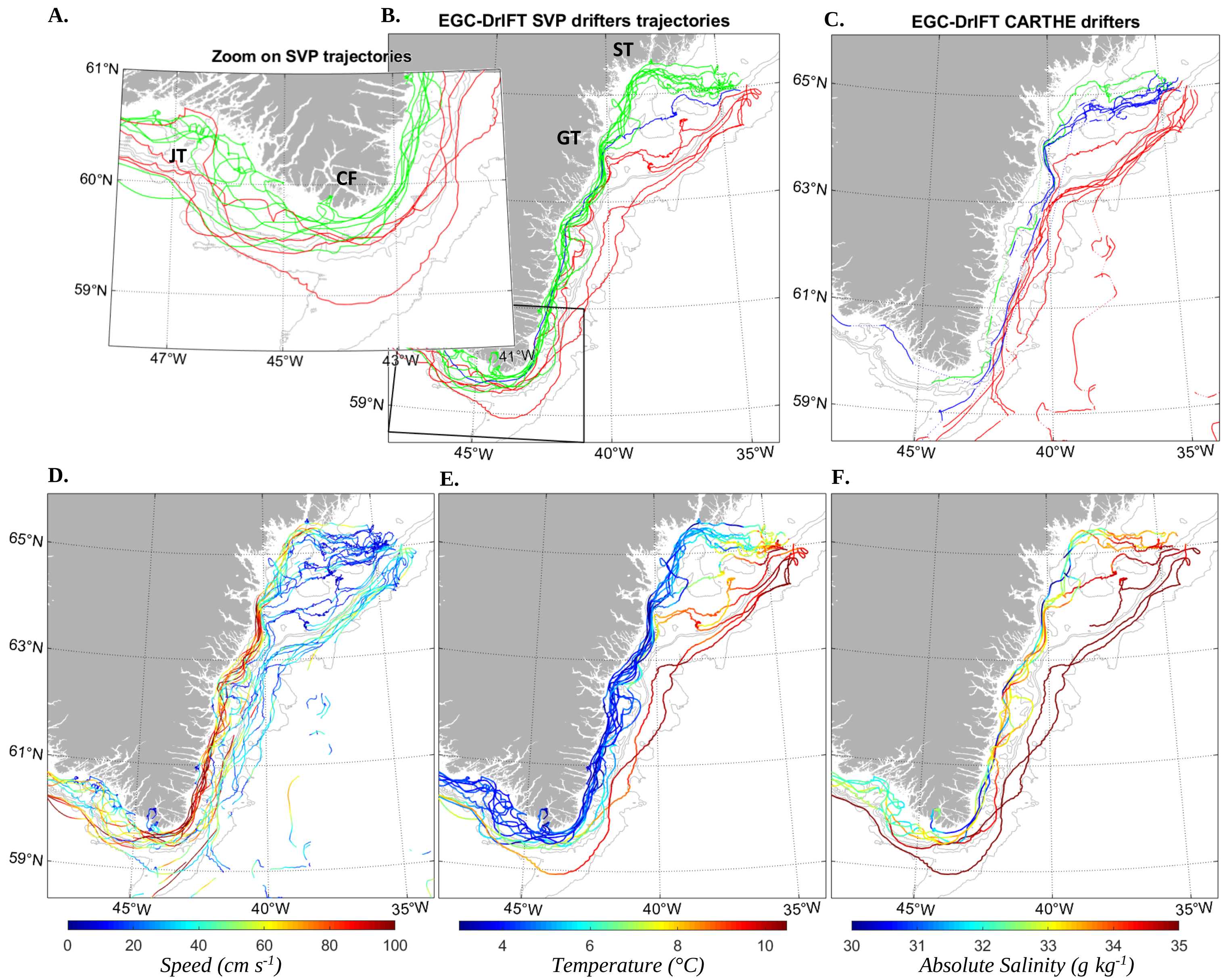

Figure 2:

Overview of drifter trajectories and along-track properties. A. Zoom on SVP trajectories at CF, distinguishing origin from the EGC (red) and EGCC (green) B. SVP trajectories, coloured in three groups (EGCC: green, ST: Blue, EGC: Red); ; C. Same as B for CARTHEs; D. Drifter speed in cm s^{-1}; E. Temperature in °C from SVP-S and SVP-Ts; F. Absolute salinity from SVP-Ss in g kg^{-1}. Isobaths (in grey) are drawn at 2000, 1000, 500 and 200 m depth.

CARTHE and SVP drifters display different behaviours: As they approach ST, nearly all SVPs join either the EGC or the EGCC, when nearly half of the CARTHEs cut across the trough. A majority of CARTHEs remain in or re-enter the EGC when most SVP drifters are part of the EGCC. Most of the exchanges between the EGC and EGCC cores, and all the export into the Irminger Sea, are observed with CARTHE drifters. Though CARTHEs and SVPs are both built to minimize wind drag and have similar water following capabilities (Novelli et al, 2017), CARTHEs have shallower anchors (0.4 m against 15 m), and are therefore more directly influenced by wind forcing. This is confirmed by computing the correlation between drifter and wind velocities, reaching 0.66 for CARTHEs, against 0.23 for SVPs, a value that is consistent with existing studies (Poulain 2009).

Drifter data are limited in space and time and therefore only provide a limited overview of processes at the front. We investigate the correspondence between very-high resolution satellite SST measurements (1 km) and drifter tracks to assess the use of satellite SST as a source of information for surface circulation over the shelf when no drifter data is available. The SST snapshots (Figure 3A-F) show the concurrent evolution of drifter tracks and MUR SST at ST, from deployment until the beginning of September. Two temperature fronts are visible in the snapshots, which coincide well with the EGC and EGCC as inferred from drifter tracks. Drifters that move across ST closely follow warm water entering the trough from the north-east (24th - 27th August). South of the trough, a second warm-water intrusion is visible, coincident with drifters from the EGC re-entering the shelf (4th-11th September). Both SVPs and CARTHEs trajectories are consistent with the MUR SST patterns, suggesting the satellite data reflects the surface circulation well. Looking at the complete MUR (2002-2020) and OSTIA (2007-2020) SST time series, we repetitively find the same patterns in ST suggesting that the circulation observed with the drifters is typical of the area.

The agreement between drifter tracks and SST patterns suggests that high resolution SST data can help infer variability of the location of the front over the East Greenland shelf. We use the MUR SST data to further investigate potential for freshwater export at CF. Figures 3G-I show a cold water tongue exiting the shelf at CF in early September 2019. Similar features are visible at CF at other times and could be markers of an export pathway for fresh and cold surface shelf waters towards the Irminger Sea. Due to cloud cover at the exact time when the CARTHE drifters were exported, it is not possible to investigate that specific event with the MUR SST data. Further observations or model analysis are necessary to verify the link between such cold water signature in the SST data and surface water export.

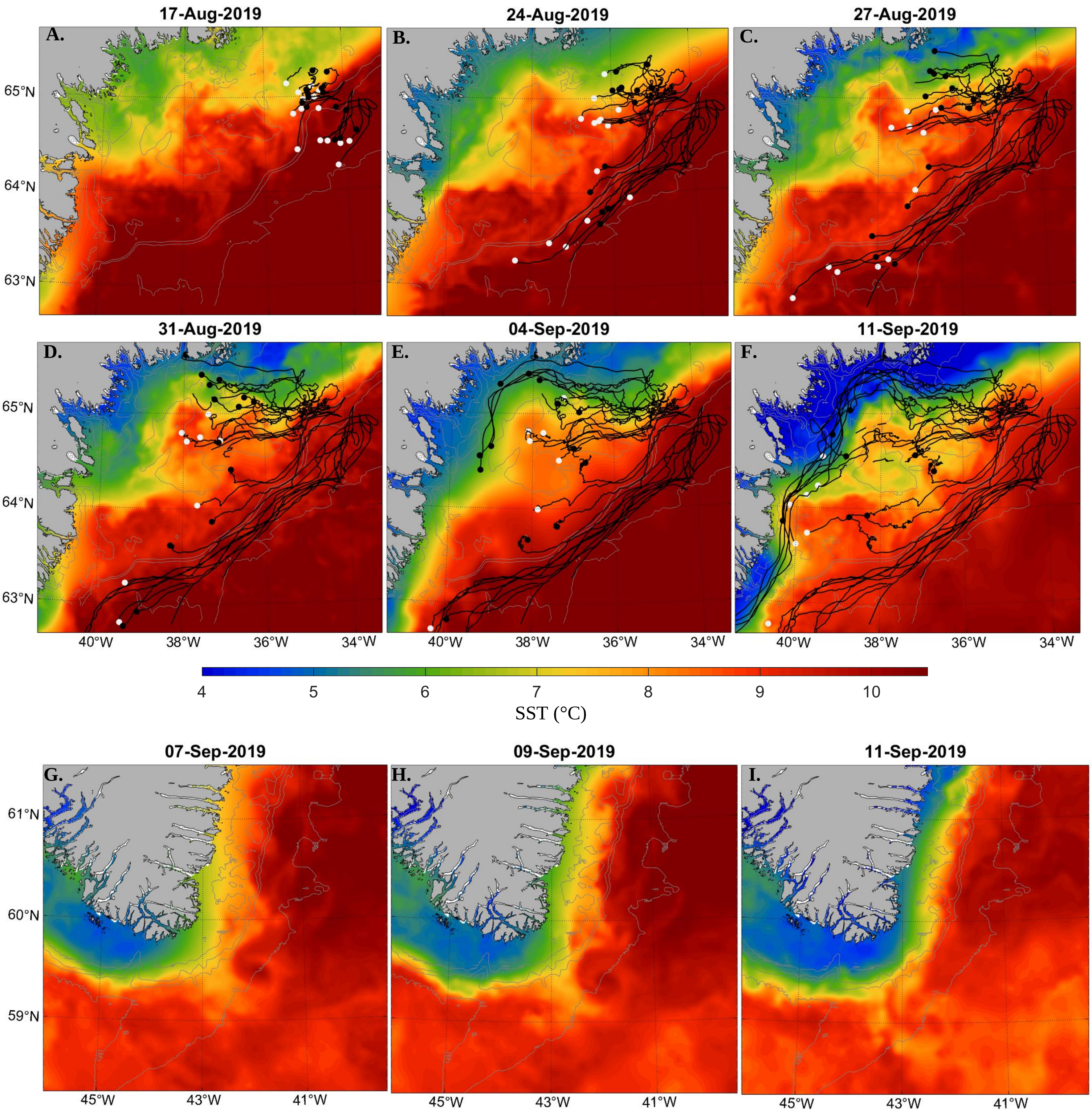

Figure 3: Sea surface temperature snapshots from MUR at ST and CF.
A-F. Co-evolution of SST with SVPs (Black) and CARTHEs (White) drifters from deployment through 11 September. Dots indicate drifter position at the time of the snapshots, with tracks shown since deployment. **G-I.** Instability at the EGC front at CF forming a cold water tongue, likely a marker of shelf water export. Isobaths (in grey) are drawn at 2000, 1000, 500 and 200 m depth.

4 Discussion and conclusion

The circulation of freshwater over the south-east Greenland shelf and its potential export into the Irminger Sea are of particular climatic importance. In this study, we presented observations from drifters deployed during the EGC-DrIFT campaign, in August 2019. Our results generally agree with existing literature regarding the position, speed and properties of the EGC and EGCC cores (Harden et al., 2014; Sutherland & Pickart, 2008), and extend existing drifter coverage closer to the coast.

The new drifter dataset shows exchanges between the East and West Greenland shelf and shelfbreak cores, suggesting that Greenland meltwater is not solely confined to the inner shelf. Past CF, earlier studies suggested that the EGC and EGCC merge into the WGC (Bacon 2002). Recent results (Lin et al 2018) argue that the coastal core keeps its identity to become the WGCC, although local bathymetry does divert part of the flow to the outer shelf, causing loss of freshwater to the WGC. In this study, coastal drifters show a stark behaviour change as they round the cape. While drifters in the EGCC showed fast, nearly straight tracks, no clearly defined coastal velocity core is visible between CF and 46°W. Part of the drifters from the EGCC are deviated towards the outer shelf and the WGC. The drifters that stay on the inner shelf slow down substiantially (Fig. 2D), displaying eddying or meandering motions, likely due to the widening of the shelf in this area. As drifters are steered along Julianehab Trough, a well defined coastal core reappears. The low velocities and meandering tracks on the inner shelf between Cape Farewell and Julianehåb Trough suggest there was no coherent WGCC velocity core in this section of the shelf at the time the drifters were there. Tracks from GDP drifters also do not show a coherent WGCC core in that area, only downstream of Julianehab Trough (Fig. 4A). The location of the WGCC core may be time variable, as could be interpreted from Pacini et al (2020). The combination of EGC-DrIFT and GDP datasets (Fig. 4A) shows that most drifters originating from the EGCC (red) spread over the western shelf, while most EGC-origin drifters (blue) flow along the western shelfbreak, with exchanges taking place between the two. Past 48°W, the position of drifters with respect to the shelfbreak is not indicative of their origin in either the EGCC or EGC. These exchanges contribute to the export of freshwater from the inner shelf to the central Labrador Sea, as a well known eddy shedding region is located shortly downstream (Lilly et al., 2003; Bracco et al., 2008; de Jong et al., 2014).

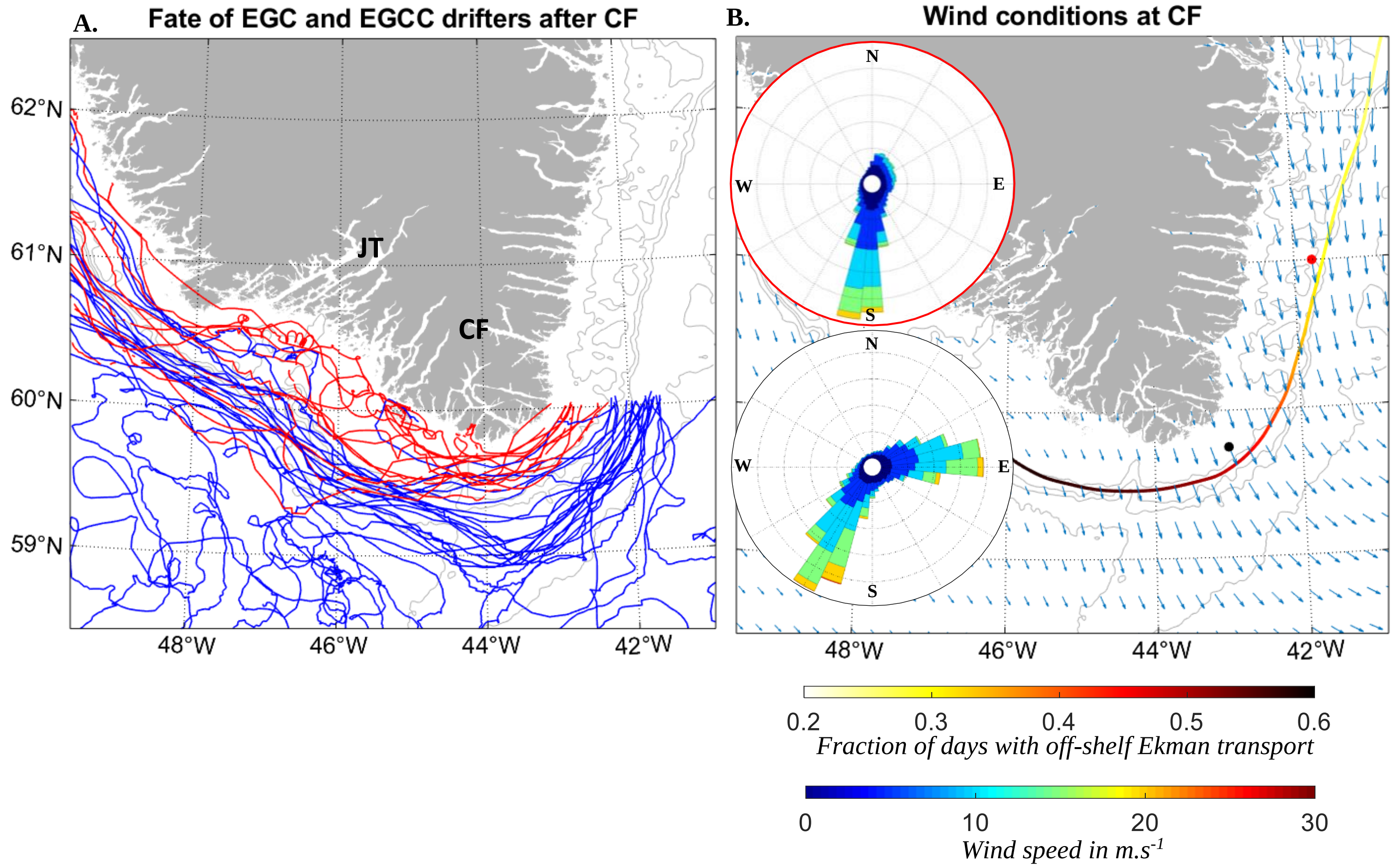

Figure 4

Drifter tracks and wind conditions around CF. A. EGC-Drift (SVPs) and GDP drifter tracks originating from the EGC (blue) and EGCC (red) cores. B. Mean winds and fraction of days with positive off-shelf wind-driven transport (as defined in Methods, section 2). Windroses show speed and direction of winds at the red and black dots during 1993-2020. Isobaths (in grey) are drawn at 2000, 1000, 500 and 200 m depth.

Out of 15 SVP and 15 CARTHE drifters, five CARTHEs were exported into the Irminger Sea, including four at CF. The motion of these shallow drifters is more strongly correlated with wind forcing, suggesting that wind could be a primary driver for export away from the east Greenland shelf into the Irminger Sea, similar to what Schulze Chretien and Frajka-Williams (2018) found for export off the west Greenland shelf. The fraction of days with positive off-shelf Ekman transport (as defined in Methods, section 2), shows a sharp transition to more off-shelf transport favourable conditions near CF (Figure 4B). This is both due to the bend in the shelf and to strong eastward wind events such as tip jets (Moore & Renfrew, 2005), opposed to the dominance of strong and persistent barrier winds along the eastern shelf, as shown by the wind-roses in Figure 4B. Satellite SST snapshots at CF (Figure 3G-I) confirm that CF could be an enhanced export area for cold and fresh surface shelf waters. These export events could contribute to the low salinity surface waters extending away from the shelf as found by Sutherland and Pickart (2008). Whether bathymetry driven instabilities, possibly related to the subsurface retroflection of the EGC (Holliday et al, 2007), contribute these surface features is currently not clear. A more quantitative study of the wind driven cross-shelf freshwater export east of Greenland is ongoing.

Acknowledgments and Data

The EGC-DrIFT project is financially supported by the Innovational Research Incentives Scheme of the Netherlands Organisation for Scientific Research (NWO) under grant agreement nos. 016.Vidi.189.130.
The drifter dataset presented in this study is available at : Duyck, E., & de Jong, M.F. (2020), EGC-DrIFT drifter dataset Kulusuk deployment 2019, doi:10.25850/nioz/7b.b.4
We thank the captain and crew of the M/V Adolph Jansen, from which drifters were deployed.

References

Aagaard, K., & Carmack, E. C. (1989). The role of sea ice and other fresh water in the Arctic circulation. *Journal of Geophysical Research*, *94*(C10), 14485. https://doi.org/10.1029/JC094iC10p14485

Bacon, S. (2002). A freshwater jet on the east Greenland shelf. *Journal of Geophysical Research*, *107*(C7). https://doi.org/10.1029/2001jc000935

Bacon, S., Marshall, A., Holliday, N. P., Aksenov, Y., & Dye, S. R. (2014). Seasonal variability of the East Greenland Coastal Current. *Journal of Geophysical Research: Oceans*, *119*(6), 3967–3987. https://doi.org/10.1002/2013JC009279

Bakker, P., Schmittner, A., Lenaerts, J. T. M., Abe-Ouchi, A., Bi, D., van den Broeke, M. R., Chan, W. L., Hu, A., Beadling, R. L., Marsland, S. J., Mernild, S. H., Saenko, O. A., Swingedouw, D., Sullivan, A., & Yin, J. (2016). Fate of the Atlantic Meridional Overturning Circulation: Strong decline under continued warming and Greenland melting. *Geophysical Research Letters*, *43*(23), 12,252-12,260. https://doi.org/10.1002/2016GL070457

Bamber, J. L., Tedstone, A. J., King, M. D., Howat, I. M., Enderlin, E. M., van den Broeke, M. R., & Noel, B. (2018). Land Ice Freshwater Budget of the Arctic and North Atlantic Oceans: 1. Data, Methods, and Results. *Journal of Geophysical Research: Oceans*, *123*(3), 1827–1837. https://doi.org/10.1002/2017JC013605

Böning, C. W., Behrens, E., Biastoch, A., Getzlaff, K., & Bamber, J. L. (2016). Emerging impact of Greenland meltwater on deepwater formation in the North Atlantic Ocean. *Nature Geoscience*, *9*(7), 523–527. https://doi.org/10.1038/ngeo2740

Bracco, A., J.Pedlosky, and R. S.Pickart, 2008: Eddy formation near the west coast of Greenland. *J. Phys. Oceanogr*., 38, 1992–2002. https://doi.org/10.1175/2008JPO3669.1

Chin, T. M., Vazquez-Cuervo, J., & Armstrong, E. M. (2017). A multi-scale high-resolution analysis of global sea surface temperature. *Remote Sensing of Environment*, *200* (December 2016), 154–169. https://doi.org/10.1016/j.rse.2017.07.029

Copernicus Climate Change Service (C3S) (2017): ERA5: Fifth generation of ECMWF atmospheric reanalyses of the global climate . Copernicus Climate Change Service Climate Data Store (CDS), [2020-03-31], https://cds.climate.copernicus.eu/cdsapp#!/home

de Jong, M. F., Oltmanns, M., Karstensen, J., & de Steur, L. (2018). Deep Convection in the Irminger Sea Observed with a Dense Mooring Array. *Oceanography*, 31(1), 50–59. https://doi.org/10.5670/oceanog.2018.109

de Jong, M. F., Bower, A. S., & Furey, H. H. (2014). Two Years of Observations of Warm-Core Anticyclones in the Labrador Sea and Their Seasonal Cycle in Heat and Salt Stratification, *Journal of Physical Oceanography*, *44*(2), 427-444. https://doi.org/10.1175/JPO-D-13-070.1

Foukal, N. P., Gelderloos, R., Pickart, R. S., A continuous pathway for fresh water along the East Greenland shelf (2020). *Science Advances,* 43(6), eabc4254. https://doi.org/10.1126/sciadv.abc4254

Haine, T. W. N., Curry, B., Gerdes, R., Hansen, E., Karcher, M., Lee, C., Rudels, B., Spreen, G., de Steur, L., Stewart, K. D., & Woodgate, R. (2015). Arctic freshwater export: Status, mechanisms, and prospects. *Global and Planetary Change,* 125, 13–35. https://doi.org/10.1016/j.gloplacha.2014.11.013

Harden, B. E., Straneo, F., & Sutherland, D. A. (2014). Moored observations of synoptic and seasonal variability in the East Greenland Coastal Current. *Journal of Geophysical Research: Oceans*, *119*(12), 8838–8857. https://doi.org/10.1002/2014JC010134

Holliday, N. P., Meyer, A., Bacon, S., Alderson, S. G., & de Cuevas, B. (2007). Retroflection of part of the east Greenland current at Cape Farewell. *Geophysical Research Letters*, *34*(7), L07609. https://doi.org/10.1029/2006GL029085

JPL MUR MEaSUREs Project. 2015. GHRSST Level 4 MUR Global Foundation Sea Surface Temperature Analysis (v4.1). Ver. 4.1. PO.DAAC, CA, USA. Dataset accessed [2020-03-31] at https://doi.org/10.5067/GHGMR-4FJ04.

Koszalka, I. M., & Lacasce, J. H. (2010). Lagrangian analysis by clustering. *Ocean Dynamics*, *60*(4), 957–972. https://doi.org/10.1007/s10236-010-0306-2

le Bras, I. A.-A., Straneo, F., Holte, J., & Holliday, N. P. (2018). Seasonality of Freshwater in the East Greenland Current System From 2014 to 2016. *Journal of Geophysical Research: Oceans*, *123*(12), 8828–8848. https://doi.org/10.1029/2018JC014511

Lilly, J. M., P. B.Rhines, R.Schott, K.Lavender, J.Lazier, U.Send, and E.D'Asaro, 2003: Observations of the Labrador Sea eddy field. Prog. Oceanogr., 59, 75–176. https://doi.org/10.1016/j.pocean.2003.08.013

Lin, P., Pickart, R. S., Torres, D. J., & Pacini, A. (2018). Evolution of the Freshwater Coastal Current at the Southern Tip of Greenland. *Journal of Physical Oceanography*, *48*(9), 2127–2140. https://doi.org/10.1175/jpo-d-18-0035.1

Lozier, M. S., Li, F., Bacon, S., Bahr, F., Bower, A. S., Cunningham, S. A., de Jong, M. F., de Steur, L., deYoung, B., Fischer, J., Gary, S. F., Greenan, B. J. W., Holliday, N. P., Houk, A., Houpert, L., Inall, M. E., Johns, W. E., Johnson, H. L., Johnson, C., … Zhao, J. (2019). A sea change in our view of overturning in the subpolar North Atlantic. *Science*, *363*(6426), 516–521. https://doi.org/10.1126/science.aau6592

Lumpkin, R., Özgökmen, T., & Centurioni, L. (2017). Advances in the Application of Surface Drifters. *Annual Review of Marine Science*, *9*(1), 59–81. https://doi.org/10.1146/annurev-marine-010816-060641

Lumpkin, Rick; Centurioni, Luca (2019). Global Drifter Program quality-controlled 6-hour interpolated data from ocean surface drifting buoys. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/7ntx-z961. Accessed [2020-03-31]

MacKay DJC (2003) Information theory, inference, and learning algorithms. Cambridge University Press, Cambridge

Malmberg, S.-A., Gade, H.G., Sweers, H.E., 1967. Report on the second joint Icelandic–Norwegian expedition to the area between Iceland and Greenland in August–September 1965. *NATO Subcommittee on Oceanographic Research, Technical Report* No. 41, Irminger Sea Project, 44 pp

Manabe, S., & Stouffer, R. J. (1994). Multiple-Century Response of a Coupled Ocean-Atmosphere Model to an Increase of Atmospheric Carbon Dioxide. *Journal of Climate*, *7*(1), 5–23. https://doi.org/10.1175/1520-0442(1994)007

McDougall, T. J., & Barker, P. M. (2011). *Getting started with TEOS-10 and the Gibbs Seawater (GSW) Oceanographic Toolbox*, 28pp., SCOR/IAPSO WG127, ISBN 978-0-646-55621-5.

Moore, G. W. K., & Renfrew, I. A. (2005). Tip jets and barrier winds: A QuikSCAT climatology of high wind speed events around Greenland. *Journal of Climate*, *18*(18), 3713–3725. https://doi.org/10.1175/JCLI3455.1

Novelli, G., Guigand, C. M., Cousin, C., Ryan, E. H., Laxague, N. J. M., Dai, H., Haus, B. K., & Özgökmen, T. M. (2017). A biodegradable surface drifter for ocean sampling on a massive scale. *Journal of Atmospheric and Oceanic Technology*, *34*(11), 2509–2532. https://doi.org/10.1175/JTECH-D-17-0055.1

Pacini, A., and Coauthors, 2020: Mean Conditions and Seasonality of the West Greenland Boundary Current System near Cape Farewell. *J. Phys. Oceanogr.*, **50**, 2849–2871, https://doi.org/10.1175/JPO-D-20-0086.1

Poulain, P. M., Gerin, R., Mauri, E., & Pennel, R. (2009). Wind effects on drogued and undrogued drifters in the eastern Mediterranean. Journal of Atmospheric and Oceanic Technology, 26(6), 1144–1156. https://doi.org/10.1175/2008JTECHO618.1

Reverdin, G., Niiler, P. P., and Valdimarsson, H., North Atlantic Ocean surface currents, *J. Geophys. Res.*, 108(C1), 3002, doi:10.1029/2001JC001020, 2003.

Rudels, B., Fahrbach, E., Meincke, J., Budéus, G., & Eriksson, P. (2002). The East Greenland Current and its contribution to the Denmark Strait overflow. *ICES Journal of Marine Science*, *59*(6), 1133–1154. https://doi.org/10.1006/jmsc.2002.1284

Schulze Chretien, L. M., & Frajka-Williams, E. (2018). Wind-driven transport of fresh shelf water into the upper 30m of the Labrador Sea. *Ocean Science*, *14*(5), 1247–1264. https://doi.org/10.5194/os-14-1247-2018

Sutherland, D. A., & Cenedese, C. (2009). Laboratory Experiments on the Interaction of a Buoyant Coastal Current with a Canyon: Application to the East Greenland Current. *Journal of Physical Oceanography*, *39*(5), 1258–1271. https://doi.org/10.1175/2008jpo4028.1

Sutherland, D. A., & Pickart, R. S. (2008). The East Greenland Coastal Current: Structure, variability, and forcing. *Progress in Oceanography*, *78*(1), 58–77. https://doi.org/10.1016/j.pocean.2007.09.006

UK Met Office. 2012. GHRSST Level 4 OSTIA Global Foundation Sea Surface Temperature Analysis (GDS version 2). Ver. 2.0. PO.DAAC, CA, USA. Dataset accessed [2020-06-10] at https://doi.org/10.5067/GHOST-4FK02

Wolfe, C. L., & Cenedese, C. (2006). Laboratory experiments on eddy generation by a buoyant coastal current flowing over variable bathymetry. *Journal of Physical Oceanography*, *36*(3), 395–411. https://doi.org/10.1175/JPO2857.1