# Inter-annual Variability of the Current System off the West Greenland Coast from a very high-resolution numerical model

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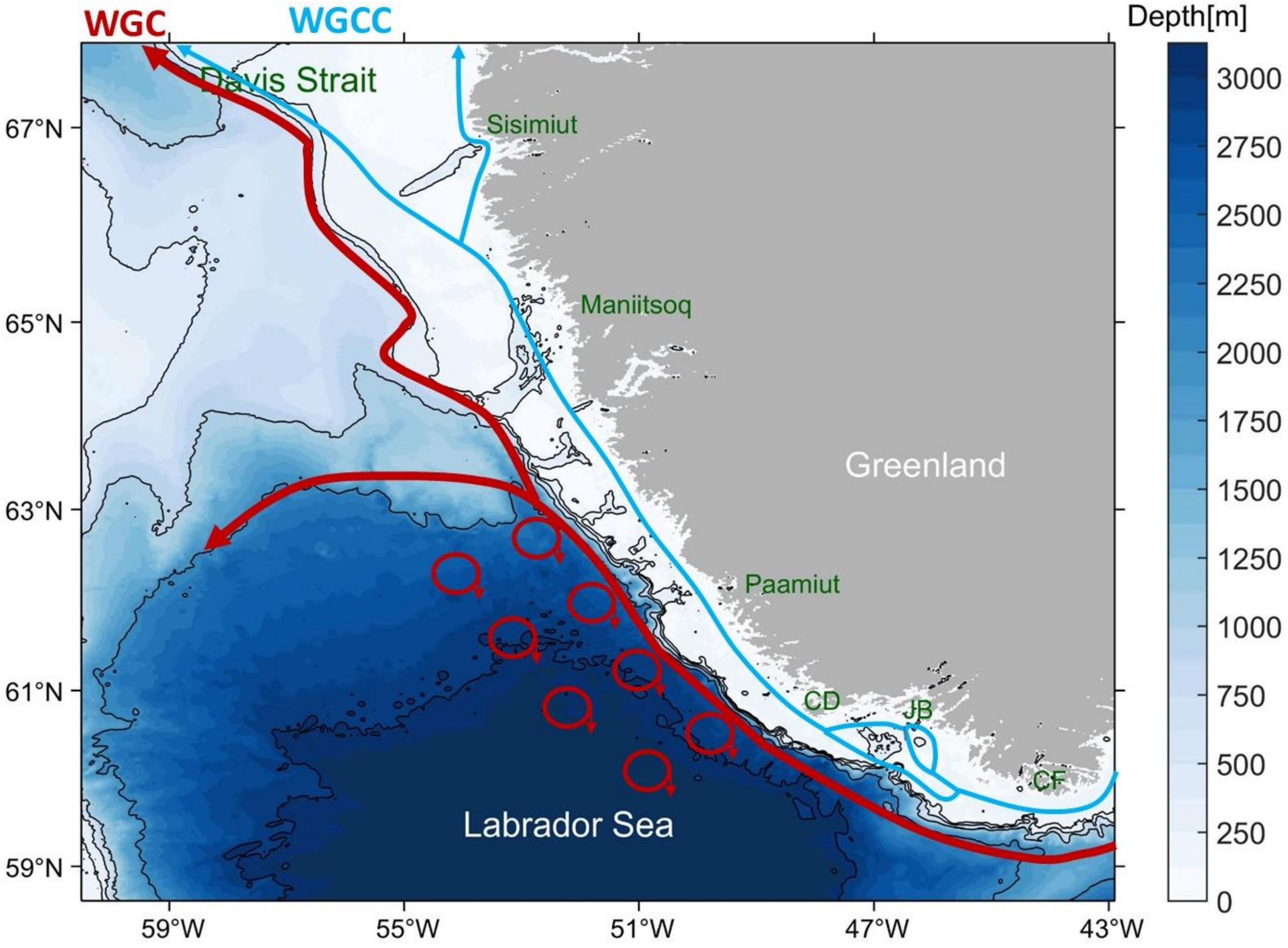
# Background

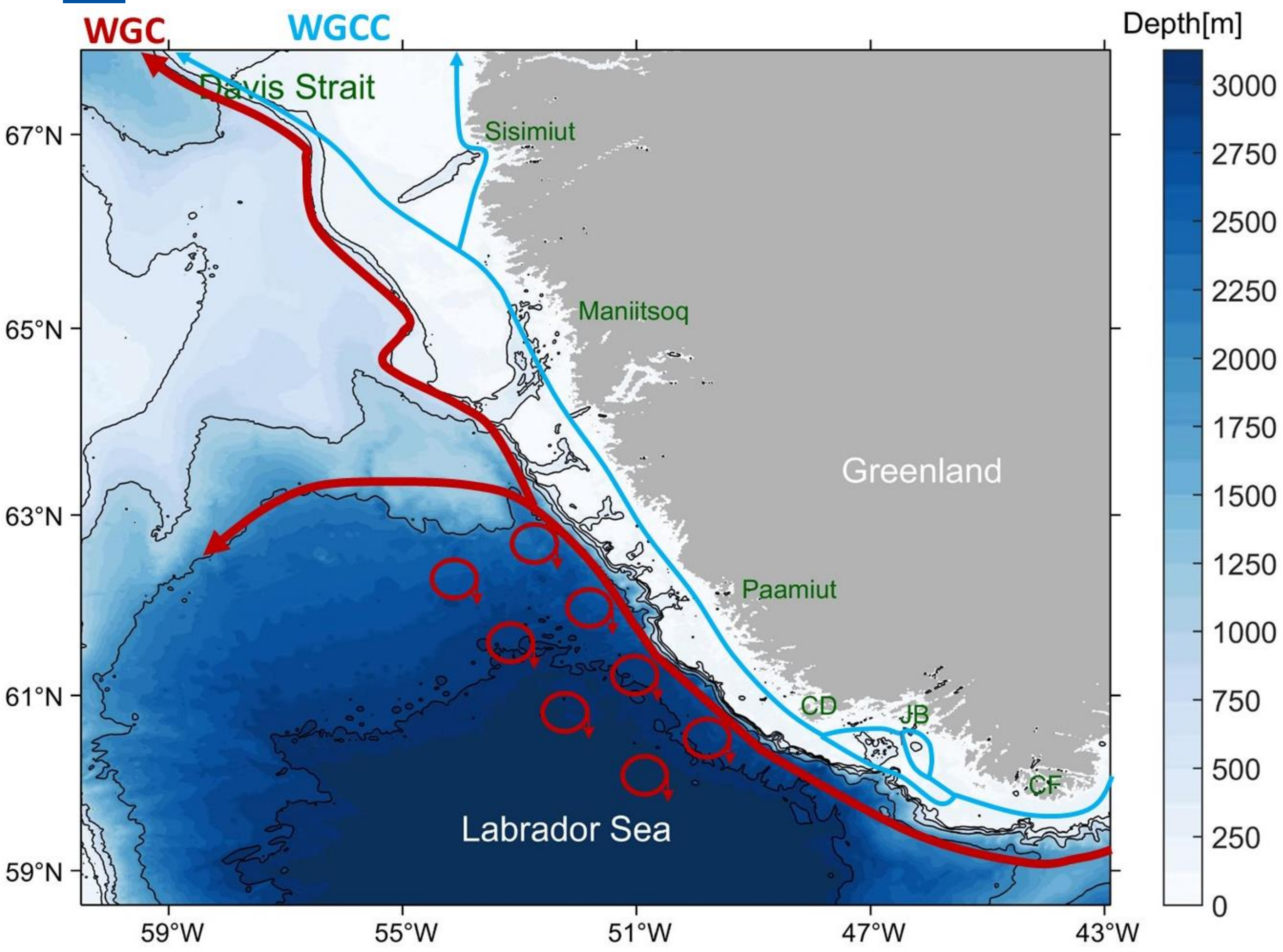



*CF, JB, CD denotes Cape Farewell, Juliannehaab Bight, Cape Desolation respectively. Black contours denote the 250, 500, 1,000, 2,000, 3,000 m isobaths. Red circles denote Irminger Rings shed by the WGC.

**About the current system**

- It consists of West Greenland Coastal Current (**WGCC**; Lin et al., 2018) on the shelf and West Greenland Current (**WGC**) at shelf break
- It carries the **coldest and freshest water** from the Arctic/Fram Strait and Greenland (Pacini et al., 2020).
- Via eddy (e.g., de Jong et al., 2014) and Ekman exchanges (Schulze-Chretien & Frajka-Williams, 2018), its transport to the interior could strengthen the stratification and thus **impact the deep convection**.

## Background

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**Reasons for using a high-resolution model to study its inter-annual variability**

1. Observations are insufficient: Short time span (2014-2018) of OSNAP and the mainly summertime occupations of the sections

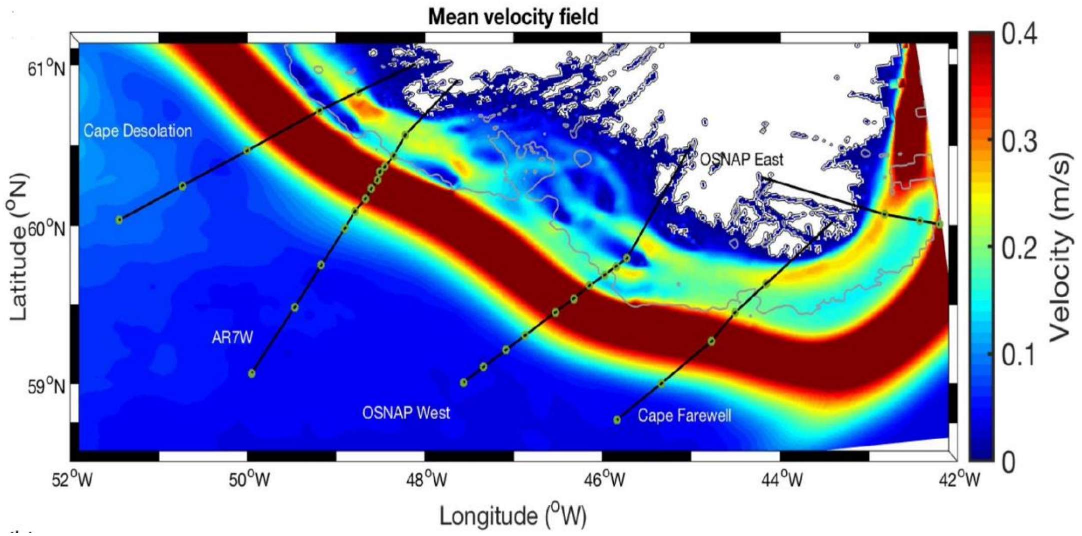
2. Low resolution is incapable of resolving the WGCC: WGCC is rather narrow with a core width of 10-20km and has complicated pathways (Benetti et al., 2019)。

3. Our model corresponds well with observations, in terms of the behavior on the shelf and the offshore exchange (Gou et al., 2021; Pennelly & Myers, 2021).

# Former work - the seasonality of the WGCC in the vicinity of south Greenland (Gou et al., JGR, 2021)

**Key Points:**

- A shelf break WGCC exists about half a year between Cape Farewell and Cape Desolation, with a three current system at the Overturning in the Subpolar North Atlantic Program (OSNAP) West section
- The shelf system is strongest in fall, with largest freshwater transport (25–40 mSv), with a transport minimum in spring (15–25 mSv)
- The transport decreases as water is lost offshore, decreasing from OSNAP East (0.61 Sv) to Cape Desolation (0.41 Sv)



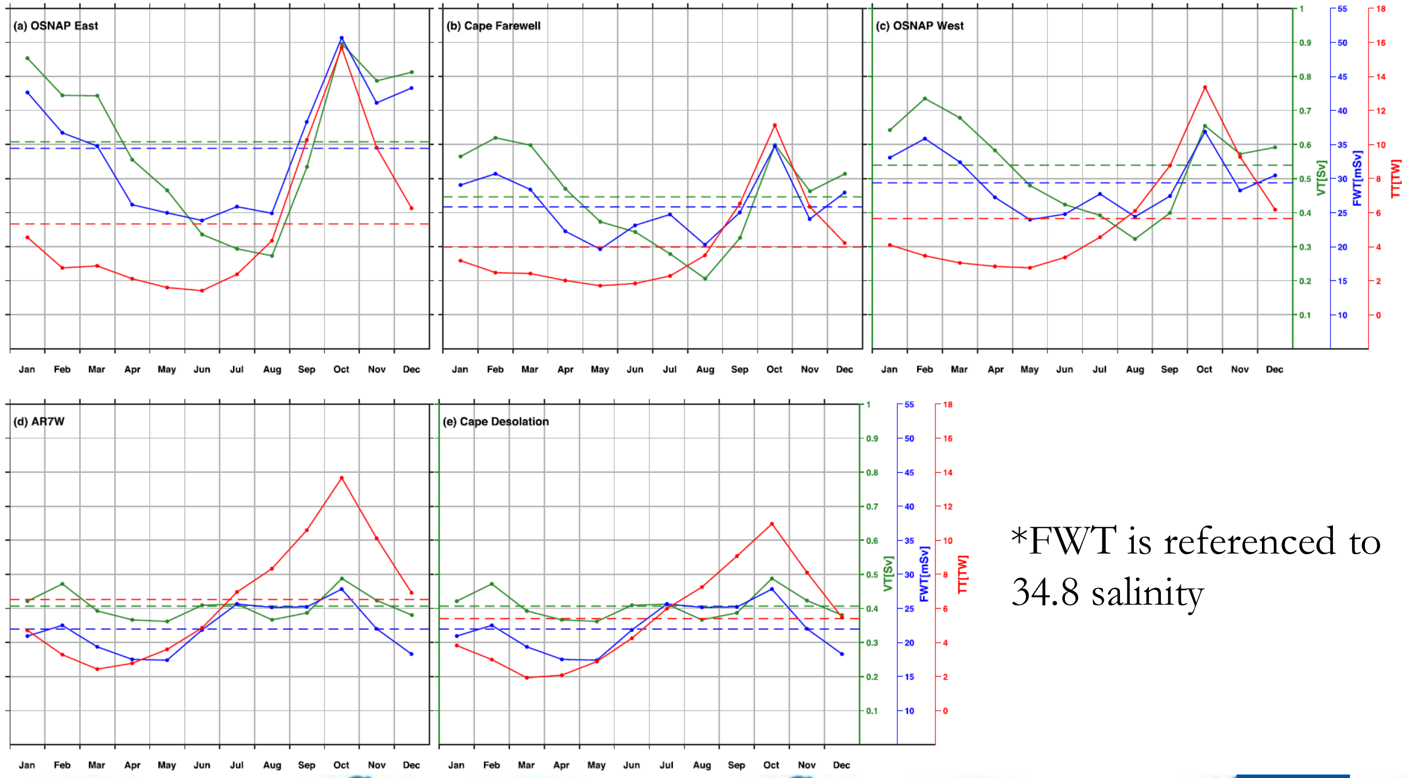
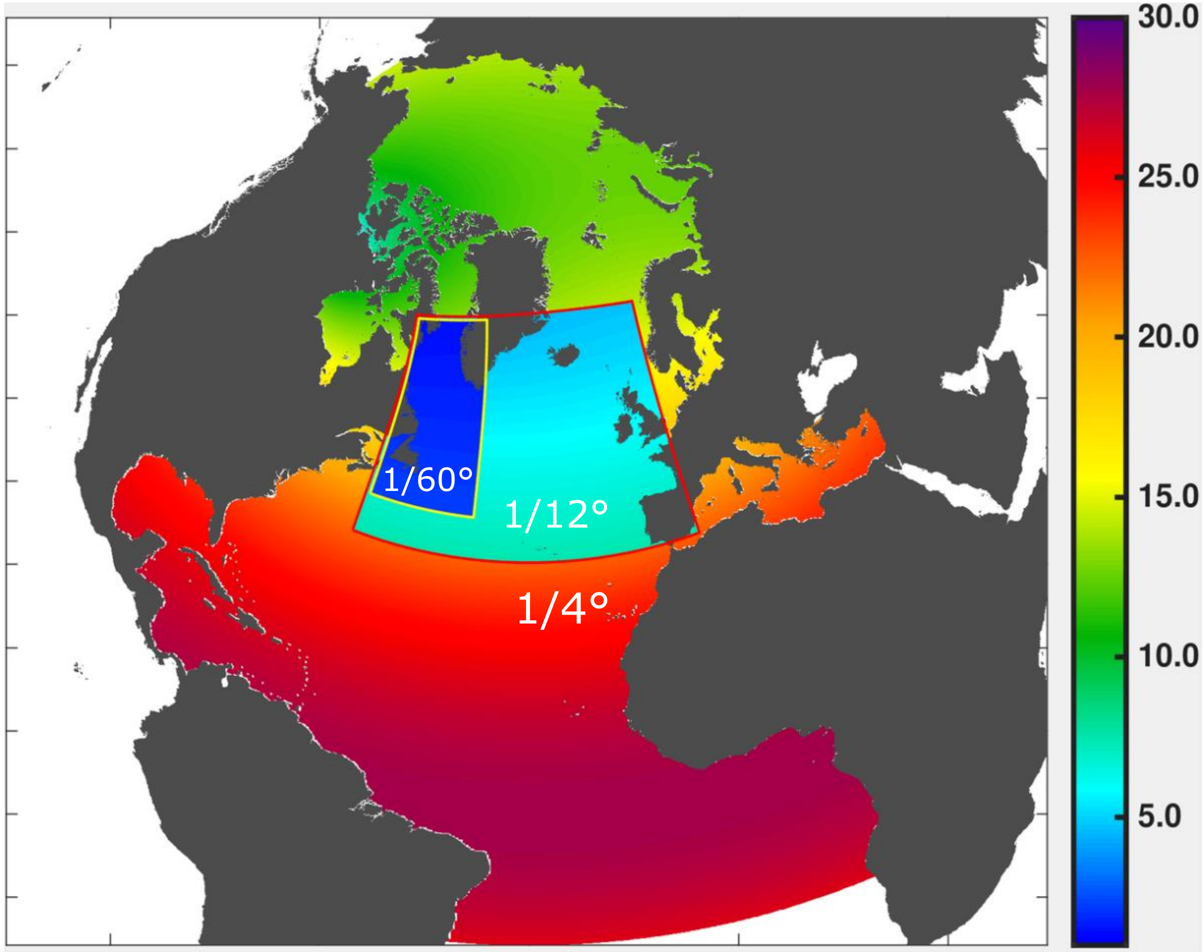




**Table 1**
*Annual Means (2005–2014) of Greenland Coastal Current Transports for Each Section*

| Section | OSNAP East | Cape Farewell | OSNAP West | AR7W | Cape Desolation |
|---|---|---|---|---|---|
| VT (Sv) | 0.61 | 0.45 | 0.54 | 0.50 | 0.41 |
| FWT (mSv) | 34.4 | 25.8 | 29.4 | 27.1 | 22.0 |
| TT(TW) | 5.3 | 4.0 | 5.7 | 6.5 | 5.4 |

*FWT is referenced to 34.8 salinity

# Model details



ANHA4-SPG12-LAB60 (color shows the resolution in kilometers)

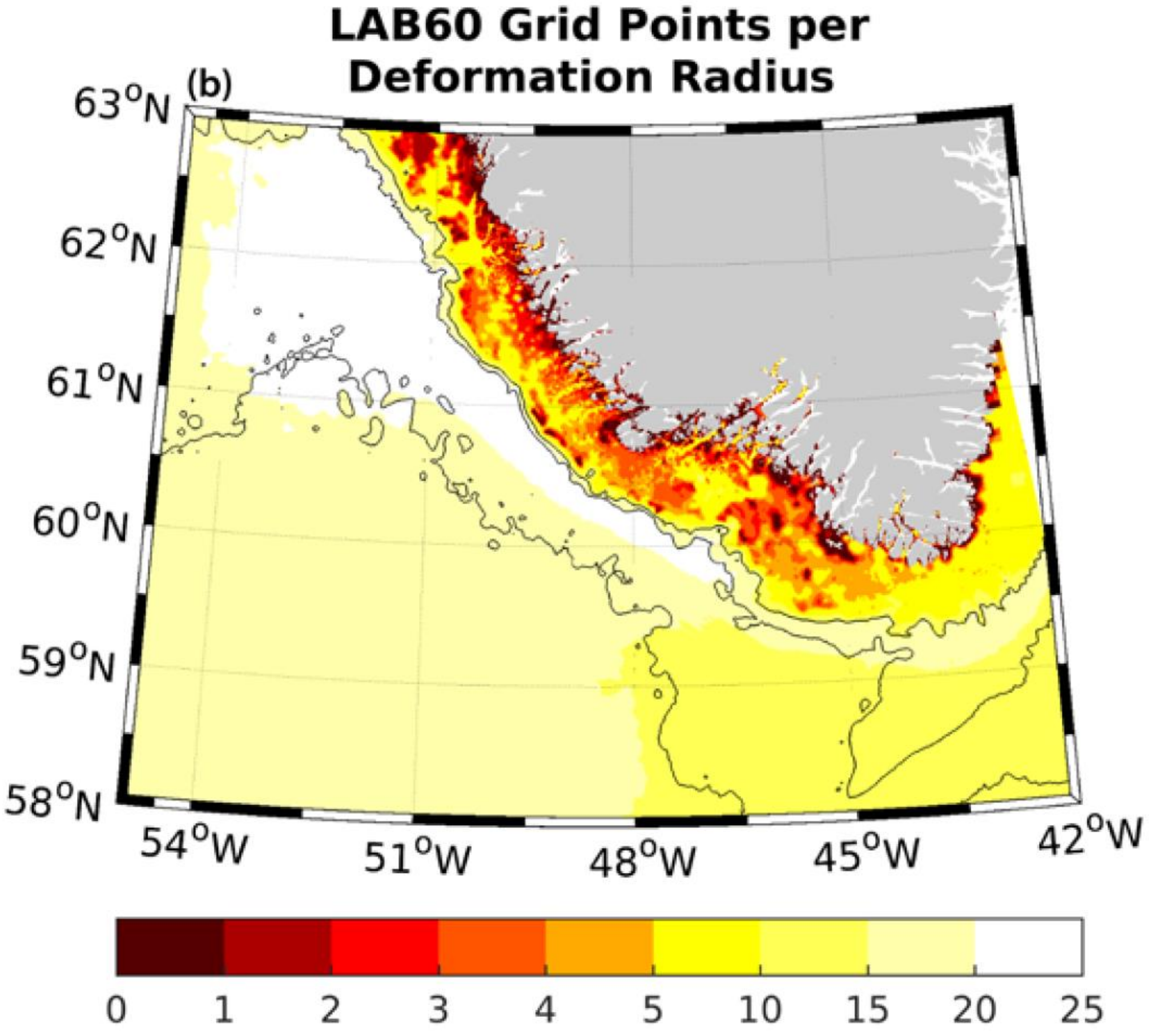
## Basics

- **Model Name:** Nucleus for European Modelling of the Ocean (NEMO) version 3.6
- **Regional Configuration:** ANHA4-SPG12-LAB60 (**1/60°** horizontal resolution)
- 2 way AGRIF nesting, **800-900 m** resolution in LAB Sea
- daily averaged data for 2008-2018, 75 vertical levels

## Other Details

- Atmospheric forcing：DFS5.2—wind, precipitation, temperature, humidity, radiation (short and long wave)
- Sea Ice Module：LIM2
- Initial Conditions：GLORYS1v1—SSH， sea ice, T, S, U, V

# Model details




Pennelly & Myers, 2021, submitted

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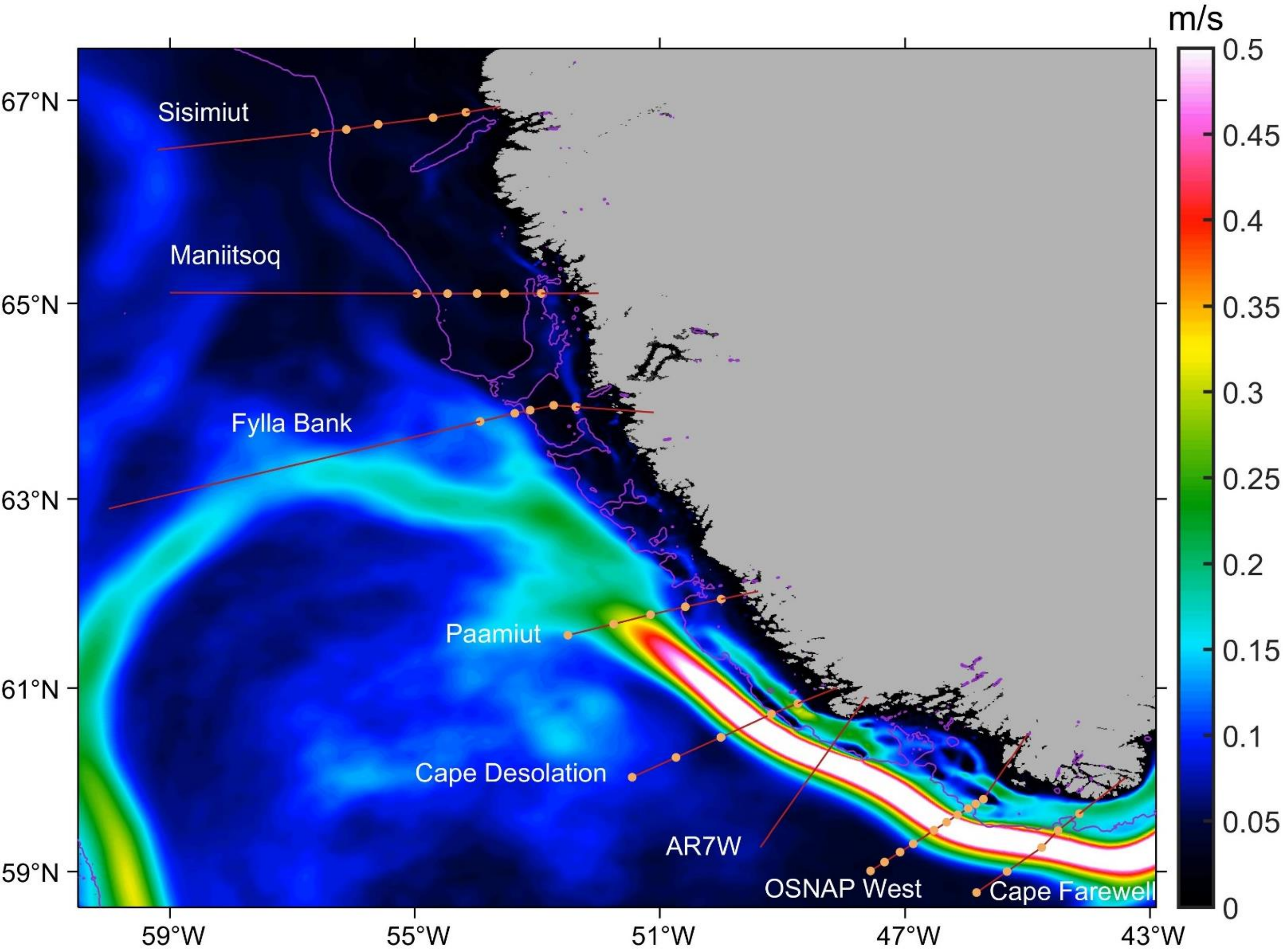
# Results - top-50m annual mean speed




*Sections used in this study are denoted with dots representing actual stations, and the purple lines denote the 250m isobath.

**WGCC structure north of Cape Desolation**

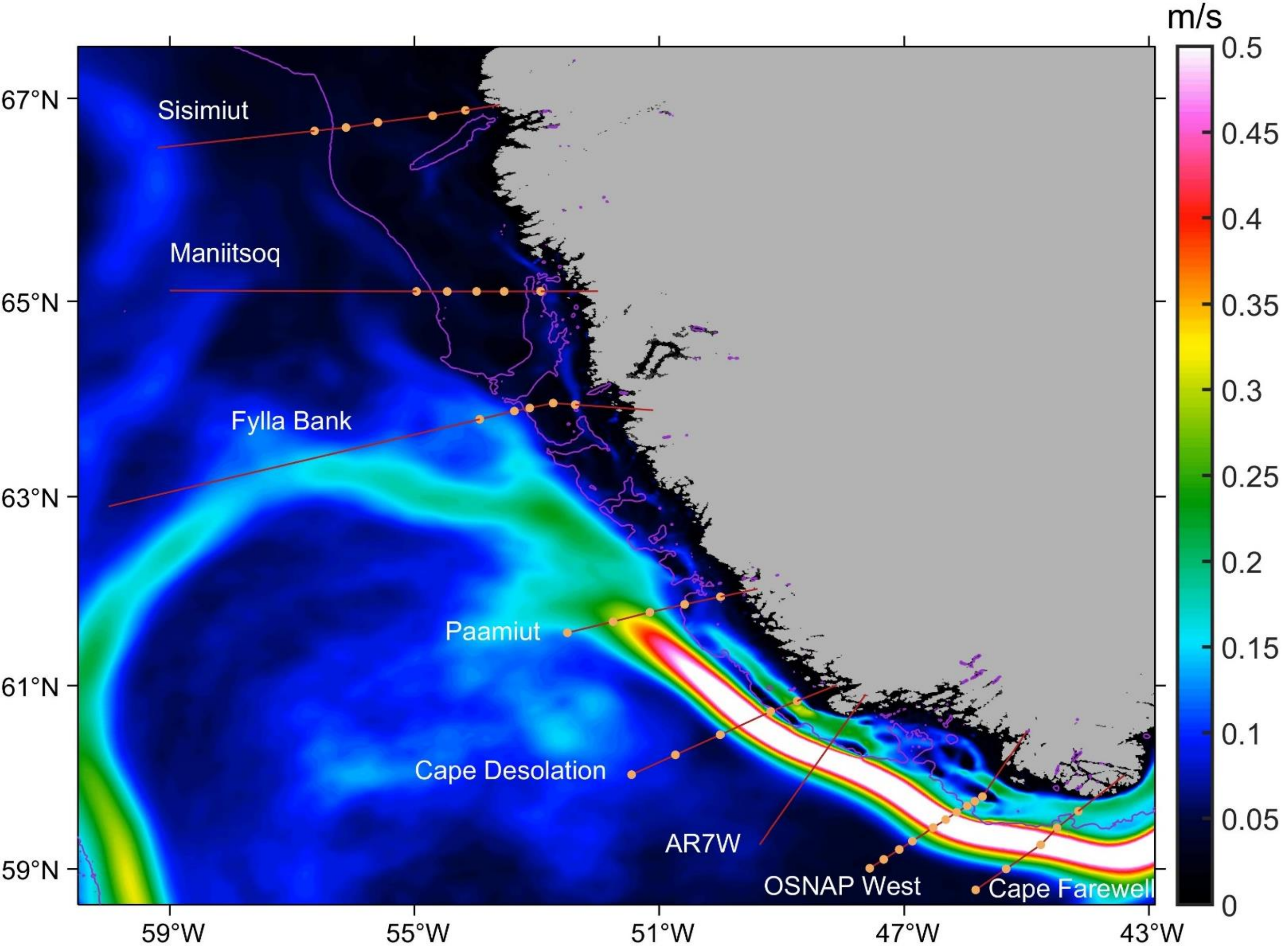
- WGCC <u>extends north</u> to the Sisimiut section and Davis Strait, with bands of narrow flow that have <u>speeds>0.1 m/s</u>.

- It <u>separates</u> between the Maniitsoq and Sisimiut sections, with most of the flow moving <u>towards the shelf-break</u>.

- The speed is close to 0.1 m/s at the Maniitsoq section and <0.05 m/s at the Sisimiut section, same as indicated by an observational study (Myers et al., 2009).

*For further observational comparisons: 0.02 m/s or 0.06 m/s (Azetsu-Scott et al, 2011), as high as 0.1 m/s (Cuny et al., 2005)

# Results - top-50m annual mean speed

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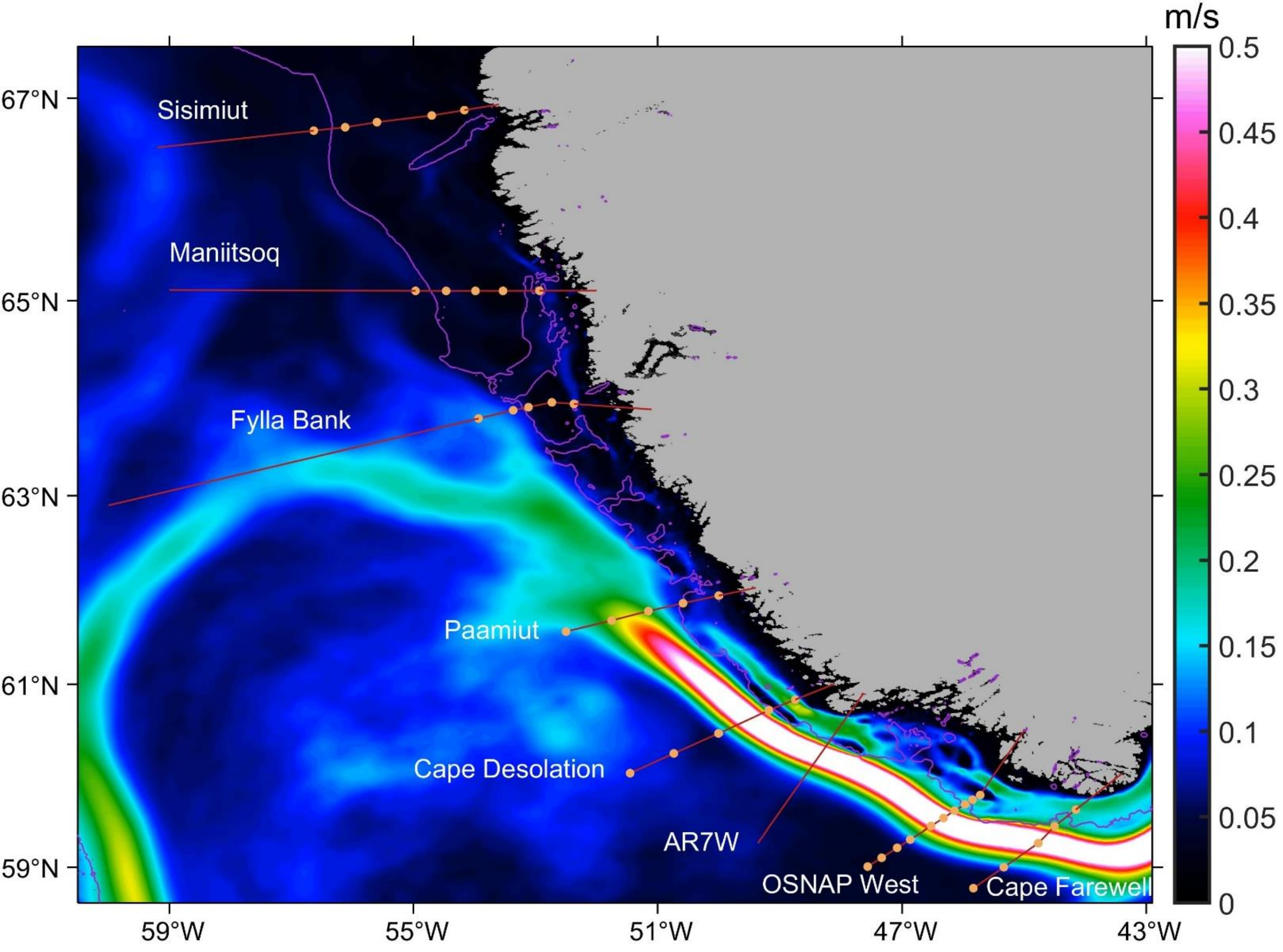
**WGC general structure**

**South of the Fylla Bank:** The WGC is strong with core speeds >0.5 m/s until the Paamiut section, where there is a broad region with speeds >0.2 m/s.

**North of the Fylla Bank:** As the 2000m and 3000m isobaths veer westward sharply, the WGC splits into two branches, with the major one joining the Labrador Current with speeds reaching 0.2m/s, and a narrower, weaker branch heading northward to Davis Strait and into the Baffin Bay.

# Results - top-50m annual mean speed




*Sections used in this study are denoted with dots representing actual stations, and the purple lines denote the 250m isobath.

**The WGC northward branch**

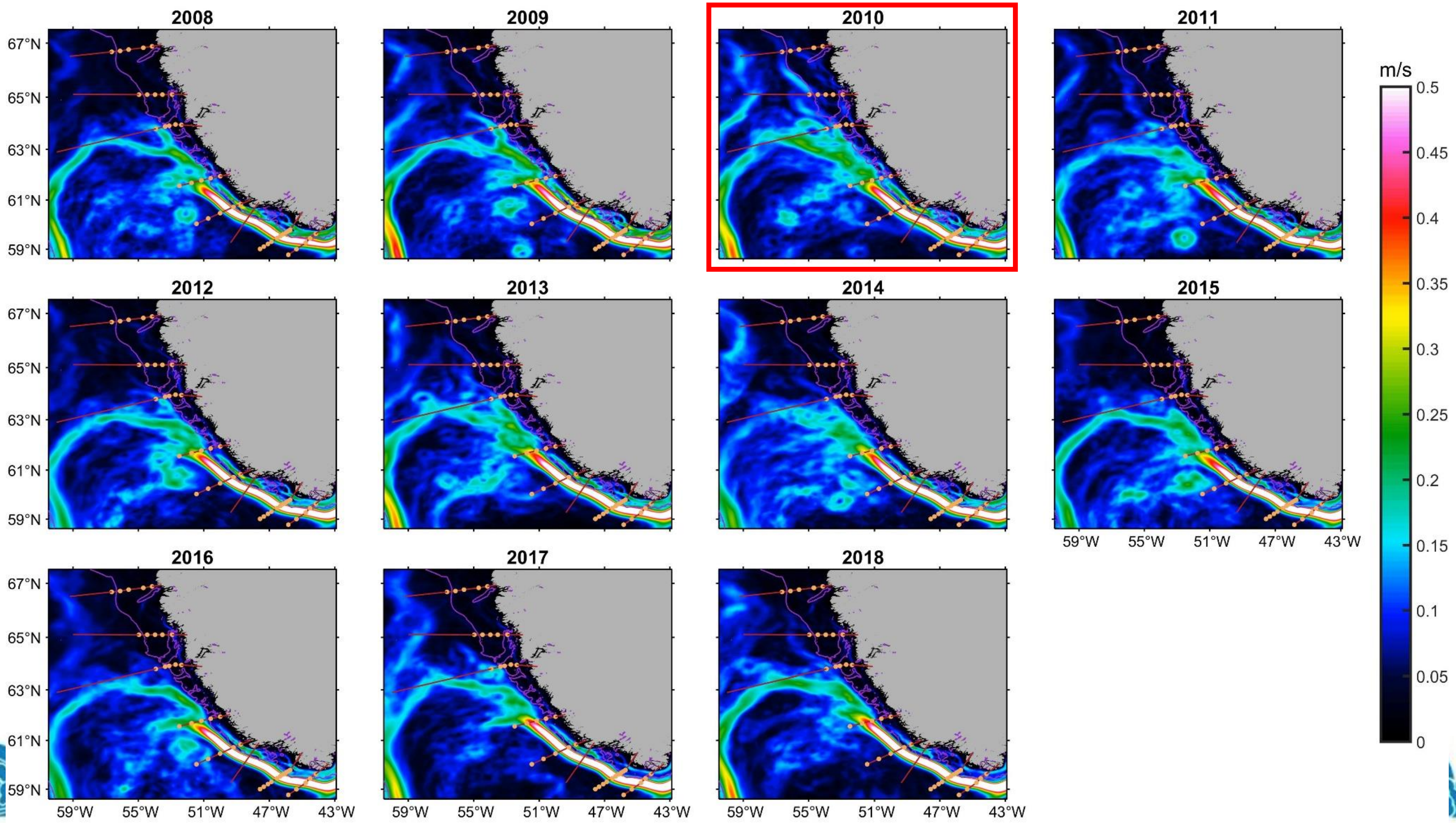
- The northward branch largely <u>follows the curving 500 m isobaths</u>, thus interacting with the observed southward flows that veer eastward from the western strait (Cuny et al., 2005; Curry et al., 2011; Curry et al., 2014).

- The annual speeds of this northward branch could be as low as below 0.05 m/s, and as high as above 0.15 m/s.
  - Observational results: 0.1-0.36 m/s (Stein, 2004), 0.17 m/s (Majumder et al., 2021).
  - Modelling results: could reach 0.1 m/s (Lique et al., 2009).

# Results - top-50m annual speeds

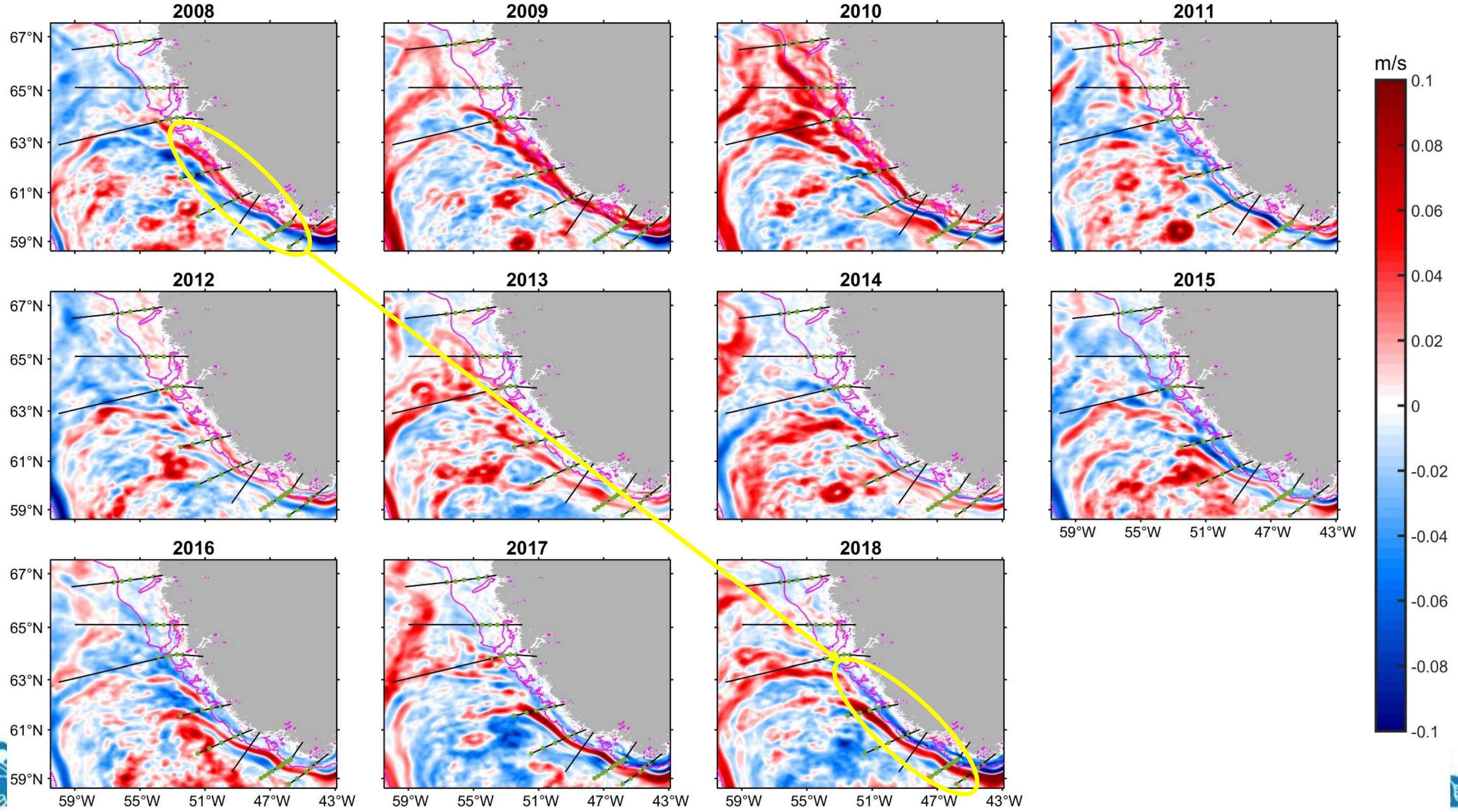
**Anomalous northward speeds in 2010:** north of Fylla Bank, the WGC and WGCC have speeds of ~ 0.15m/s and ~ 0.1m/s respectively, which are the <u>highest</u> in the ten-year period.

**Potential reason:** Myers et al. (2021) pointed out <u>anomalous wind</u> in 2010, leading to anomalously large northward Ekman transport that passed the Davis Strait.



# Results - the anomalies of the top-50m annual speeds

**The opposite inter-annual trends between WGCC speed and WGC speed:** south of Fylla Bank, the WGCC weakens by a speed decrease above 0.1 m/s as the WGC strengthens by a speed increase that could reach 0.2 m/s.




*referred to its mean state

# Results - time-mean transports over 2008-2018

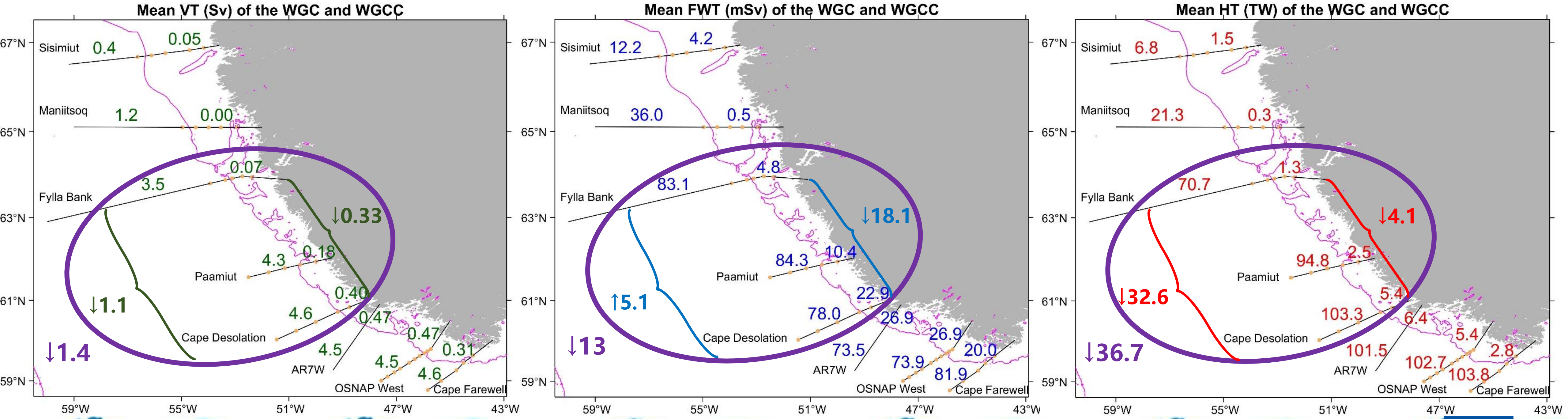
## The exchanges into the interior

The corresponding phenomenon

1. The transport decreases

- Considerable decreases from Cape Desolation to Fylla Bank.
- The total exchanges are the sum of the decreases.

*Numbers denote transports of the WGC (offshore) and WGCC (onshore). FWT and HT are referenced to 34.8 salinity and -1.8°C respectively.



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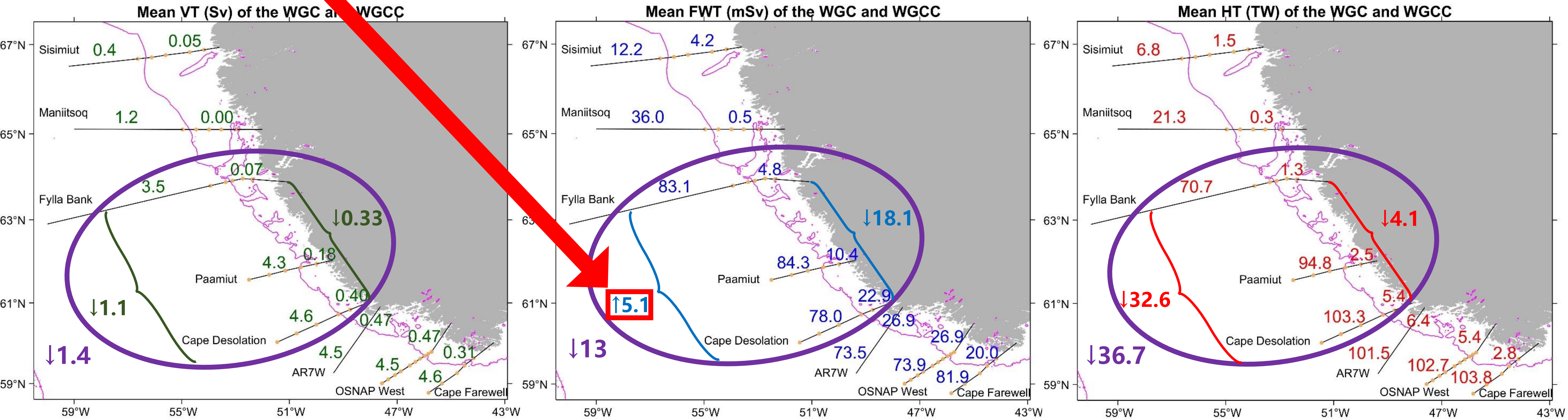


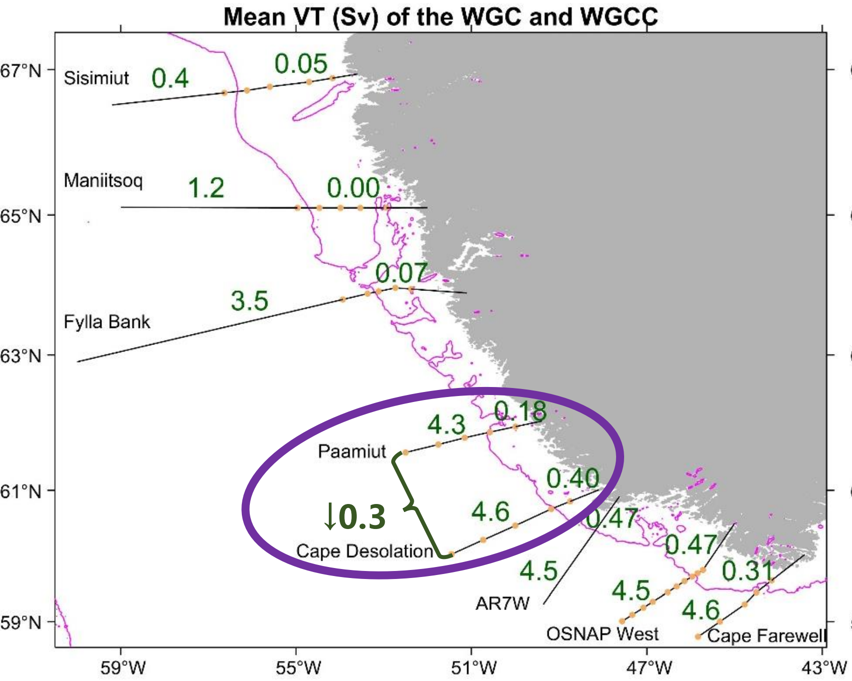
# Results - time-mean transports over 2008-2018

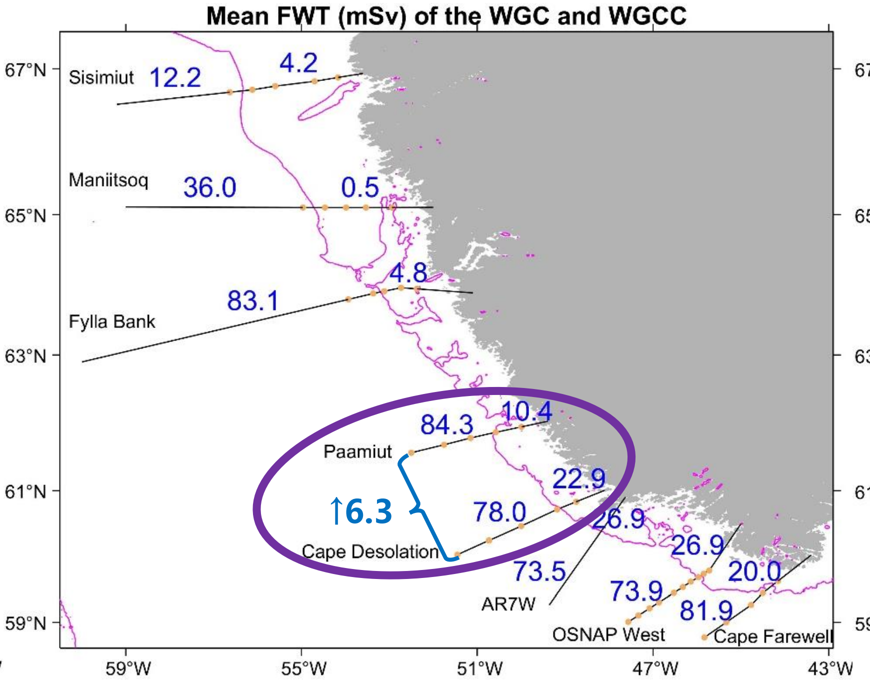
## The exchanges into the interior

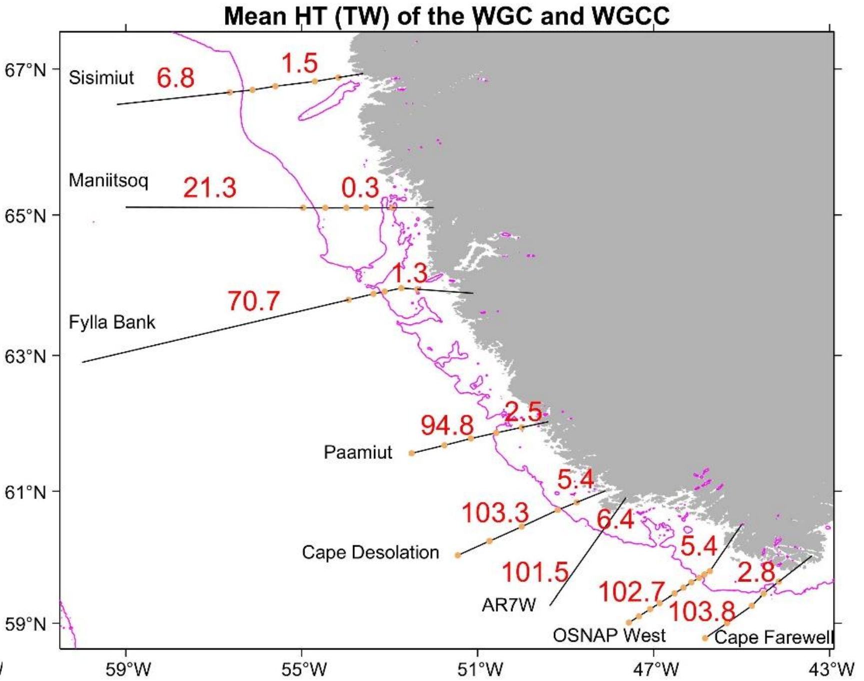
The corresponding phenomenon

2. Decrease differences for different kinds of transports

- From Cape Desolation to Paamiut: as the WGC VT drops by 0.3 Sv, surprisingly the FWT increases by 6.3 mSv, indicating a source of freshwater.



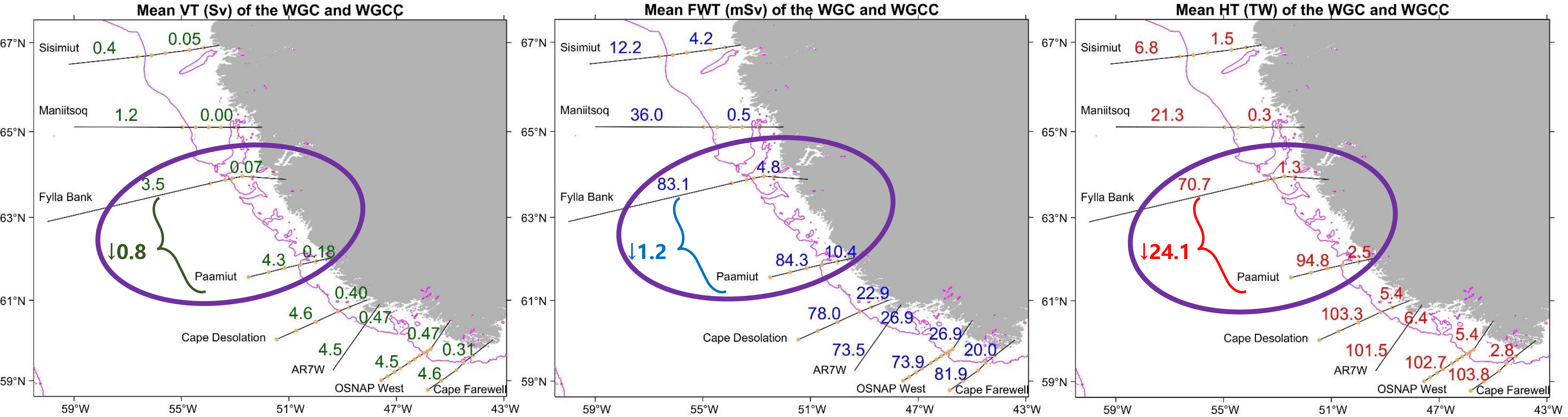
# Results - time-mean transports over 2008-2018

## The exchanges into the interior

The corresponding phenomenon

2. Inter-annual variations among different kinds of transports

- From Paamiut to Fylla Bank: as the WGC VT drops by ~0.8 Sv, the FWT is barely changed, and the HT drops considerably by 24.1 TW, further indicating a cold and fresh source.



## Results - time-mean transports over 2008-2018

- **So the main exchanges from the WGCC to WGC, also from the WGC to interior are between Cape Desolation and Fylla Bank.**

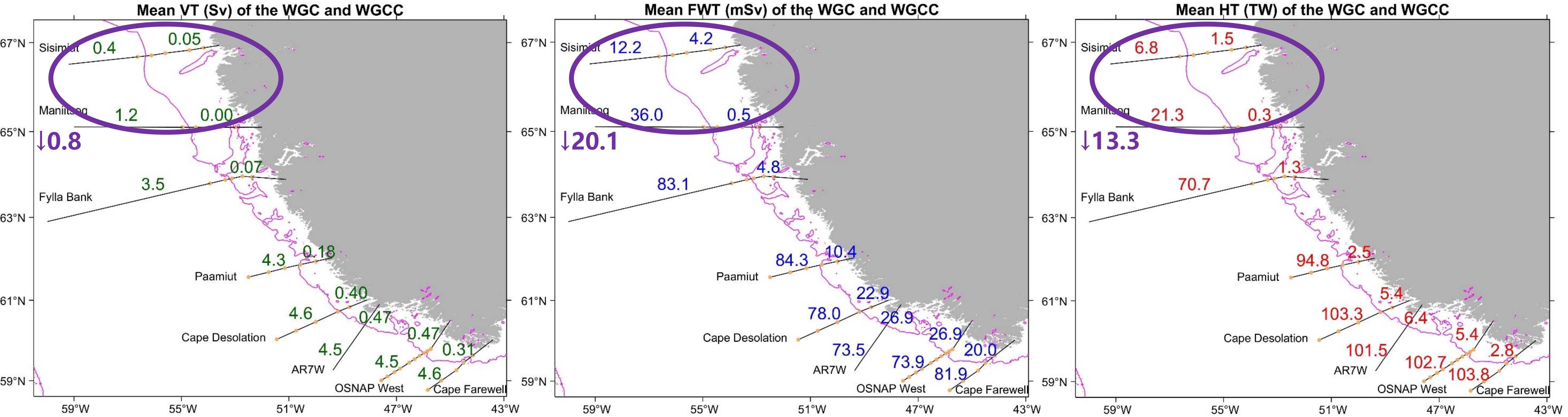
The main exchange into the interior by other observational study:

1. between Cape Desolation and Fylla Bank (Myers et al., 2009)
2. at 61°N-62°N (Majumder et al., 2021)

- **Instead of the WGC, it is the WGCC that is the main source for the freshwater exchange into the interior Labrador Sea.**

# Results - time-mean transports over 2008-2018

**significant exchange from the currents to the northern Lab Sea** between Maniitsoq and Sisimiut

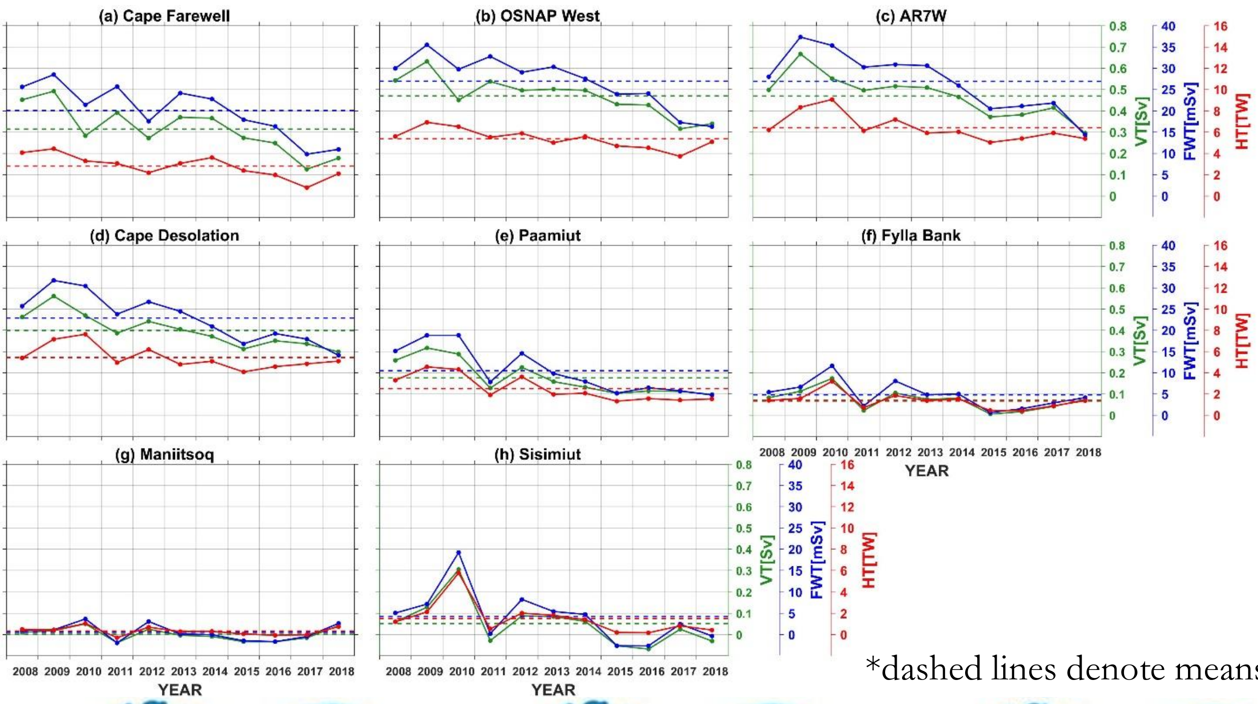


# Results – inter-annual transports

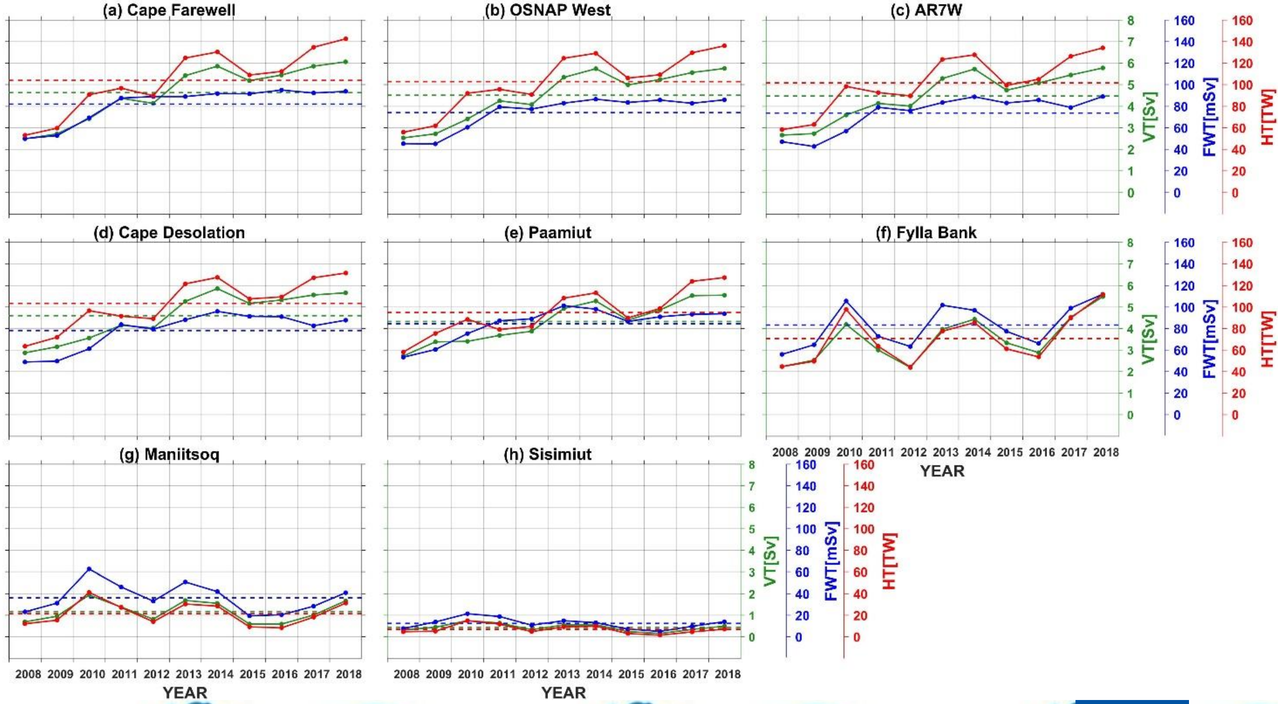
**The transports correspond to the inter-annual events previously discussed.**

- **Overall trend:** South of Fylla Bank, the WGC VT trend is <u>opposite</u> compared to the WGCC.
- **In 2010 (anomalous wind):** The WGCC transports at Sisimiut and WGC transports at Maniitsoq are <u>anomalously high</u>, being ~0.3 Sv and ~1 Sv respectively.

WGCC annual transports




WGC annual transports



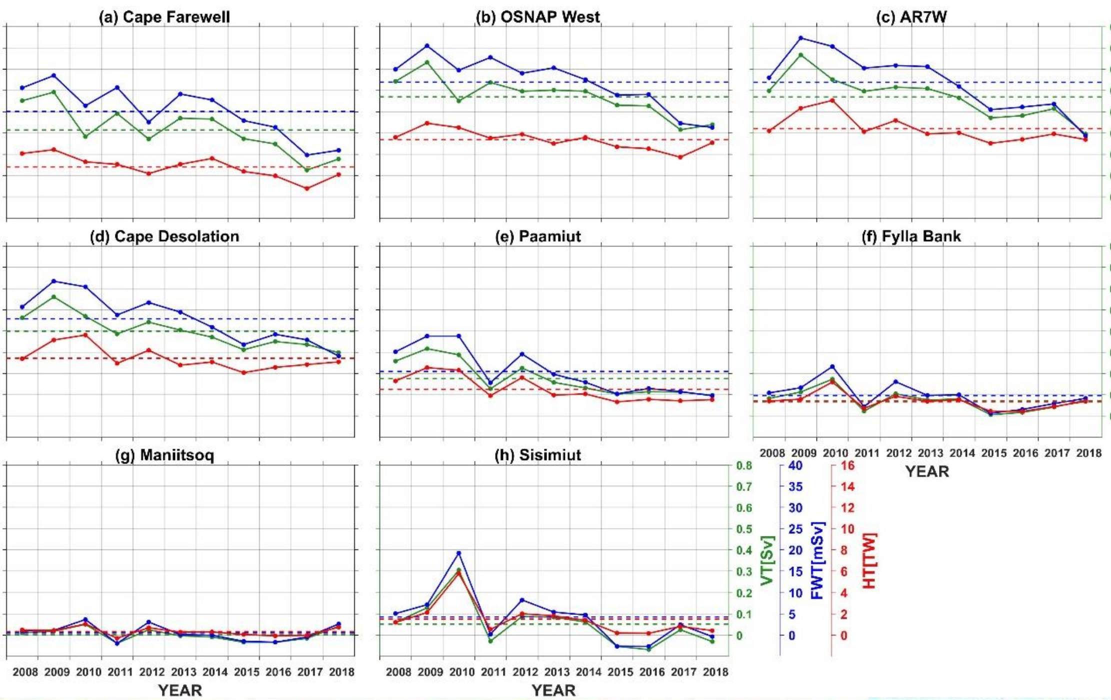

*dashed lines denote means

# Results – inter-annual transports

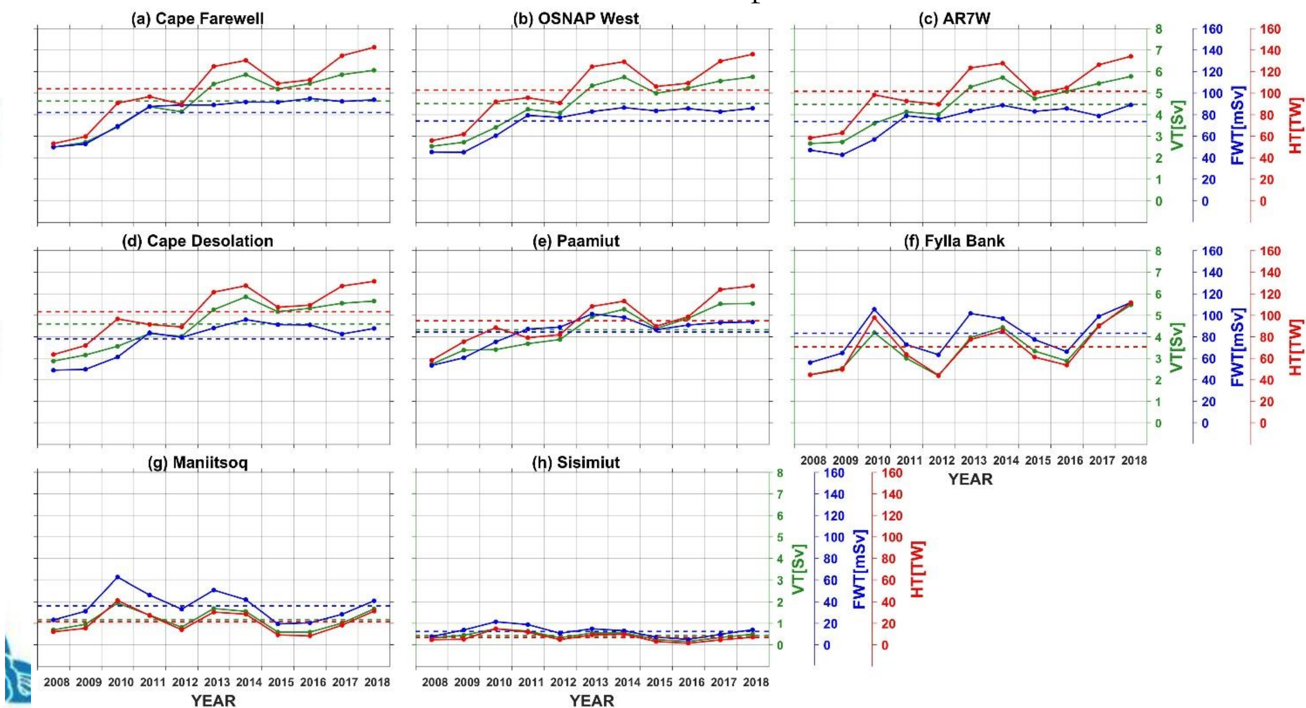
**The transports correspond to some other inter-annual events.**

- **In 2012:** at the northern three sections, the <u>WGCC FWT has another peak</u> while the <u>WGC FWT are minimal values</u>.
  **The event**: <u>record Greenland melt</u> (Nghiem et al., 2012; Tedesco et al., 2013) and <u>downwelling favorable winds</u>, constraining the meltwater near the coast and transporting it northward (Luo et al., 2016).
- **In 2015/2016:** southward WGCC VT of 0.05 Sv at Sisimiut and Maniitsoq
  **The event**: Observations found southward coastal transports south of Davis strait (Rysgaard et al., 2020).

WGCC annual transports




WGC annual transports



# Methods - forcing mechanisms of the currents

**Decomposing the current velocities into wind-forced velocity component and buoyancy-forced velocity component (Bacon et al., 2014)**

- the wind-forced component ($u_w$) is characterized by a cross-shelf gradient in SSH
- the buoyancy-driven component ($u_b$) is characterized by a cross-shelf density gradient

**Detailed calculation:**

Formulas

$$u_b = \frac{R_1}{W}\left(2g'Qf\right)^{1/4}$$

where $W$ is the width of the EGCC, $R_1$ is the first baroclinic Rossby radius, $g'$ is the reduced gravity, $Q$ is the (sea-water) volume transport, and $f = 1.3 \times 10^{-4}\ \mathrm{s}^{-1}$ is the Coriolis parameter.

Variables

**W:** the distance between points where the top-250m averaged speed falls to 70% of the maximum.

**g':** The densities at these points and at 75 m depth (or surface for shallow Sisimiut and Maniitsoq), ρ1 (onshore) and ρ2, are used to estimate $g'=g(\rho 2-\rho 1)/\rho 1$.

**R1:** $R1=NH/(f\pi)$ is estimated at the location of the current maximum, where H is the water depth where S<34.8 and N, the buoyancy frequency, is $N^2= -(g/\rho)(\frac{\partial\rho}{\partial z})$; $\frac{\partial\rho}{\partial z}$ is surface-to-H density difference divided by H.

*To avoid the southward flow at Sisimiut, only the offshore 180km of the section are included in the calculation.

**Constants:** $g=9.8 m/s^2$, $\rho=1000 kg/m^3$, $\rho_{air}=1.293 kg/m^3$

# Methods - forcing mechanisms of the currents

**Method applications**

To the WGCC: using observations (Lin et al., 2018)

To the East Greenland Coastal Current (EGCC): using observations (Sutherland & Pickart, 2009) and modelling (Bacon et al., 2014).

**We follow Bacon et al. (2014) as our study also uses a numerical model.**

**Detailed calculation:**

Formulas

$$u_{\mathrm{wind}} = \sqrt{\frac{\rho_{air}}{\rho}\frac{C_{10}}{C_D}} \cdot U$$

where $\rho_{\mathrm{air}}$ is the air density, $\rho$ is the water density, $C_{10}$ is the surface drag coefficient, $C_D$ is the bottom drag coefficient, and $U$ is the wind velocity.

Variables

$C_{10} = 10^{-3}\left(\frac{2.7}{|U|} + 0.142 + \frac{|U|}{13.09}\right)$ where |U| is the absolute value of U.

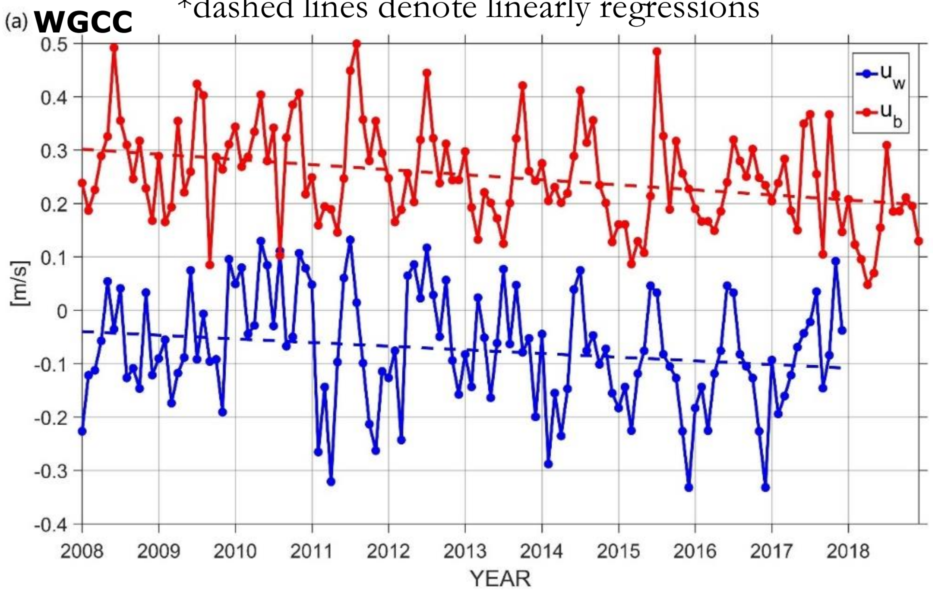
$C_D$ is the bottom drag coefficient, set to a constant ($10^{-3}$).

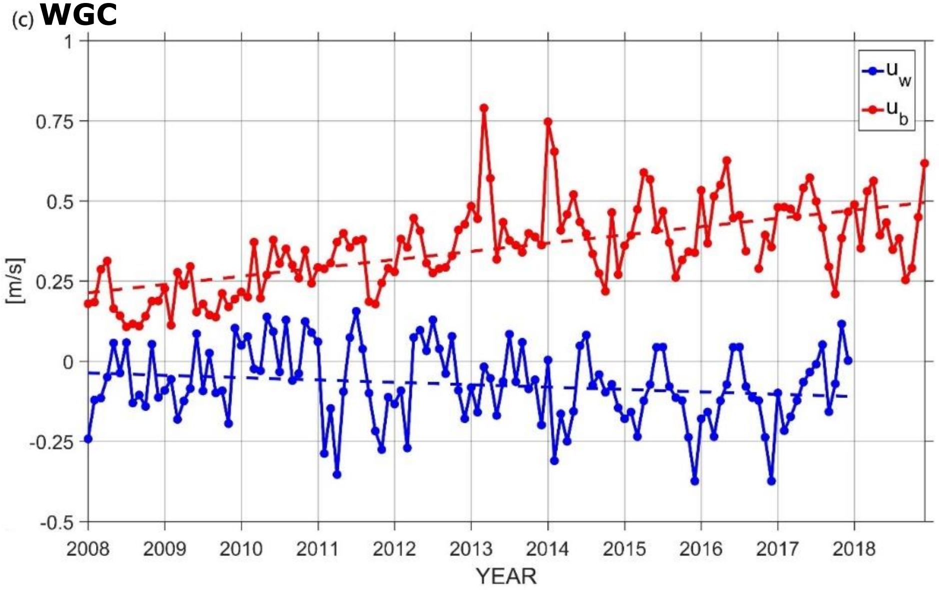
U is the along-shelf (the component normal to the sections) 10-m wind speed from the DFS over 2008-2017, averaged over the coordinate points comprising each section that covers the width of each current.

**Constants:** $g=9.8 m/s^2$, $\rho=1000 kg/m^3$, $\rho_{air}=1.293 kg/m^3$

# Forcing mechanisms of the currents - $u_w$ and $u_b$

*dashed lines denote linearly regressions



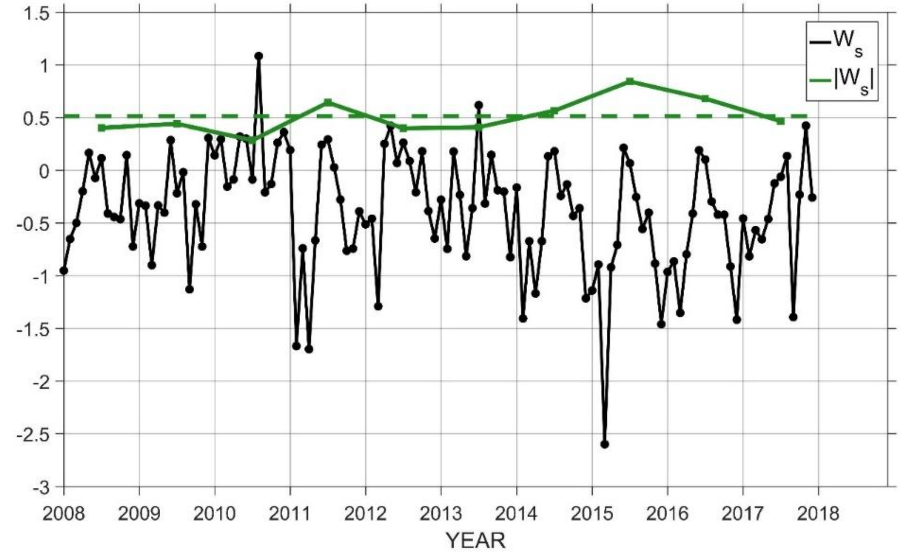

**At Cape Desolation**

- **Most of the time:** as $u_w$ is negative except in summer, upwelling favorable winds prevail that counter the buoyancy-driven flow (Whitney & Garvine, 2005).
- **During 2010:** when $u_w$ is mostly positive, downwelling favorable winds prevail that augment the flow. This wind anomaly in 2010 is indicated by Myers et al. (2021).

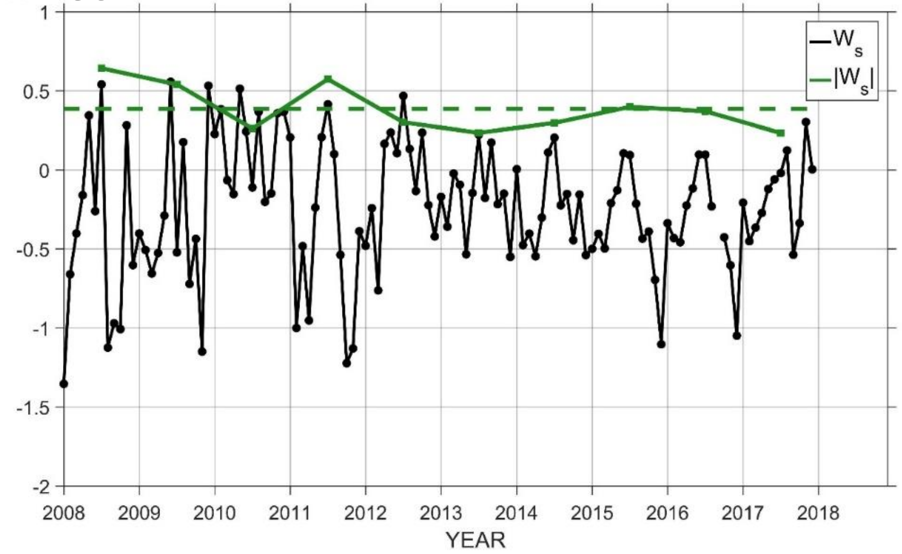
**The trends of the WGC/WGCC transports could be largely explained by the trend of $u_b$/both the $u_b$ and $u_w$.**

# Forcing mechanisms of the currents - wind strength index ($W_s=u_w/u_b$)

(b) **WGCC** *dashed lines denotes the mean absolute values




(d) **WGC**




### Basics about the $W_s$

$W_s$ denotes the relative importance between wind and buoyancy forcing.

- $|W_s|>1$: the current is predominantly wind-driven.
- $|W_s|<1$: the current is predominantly buoyancy-driven.

### At Cape Desolation

- As $|W_s|$ is mostly <1 (means of ~0.5 and 0.4), <u>the WGCC and WGC are predominantly buoyancy driven</u>.

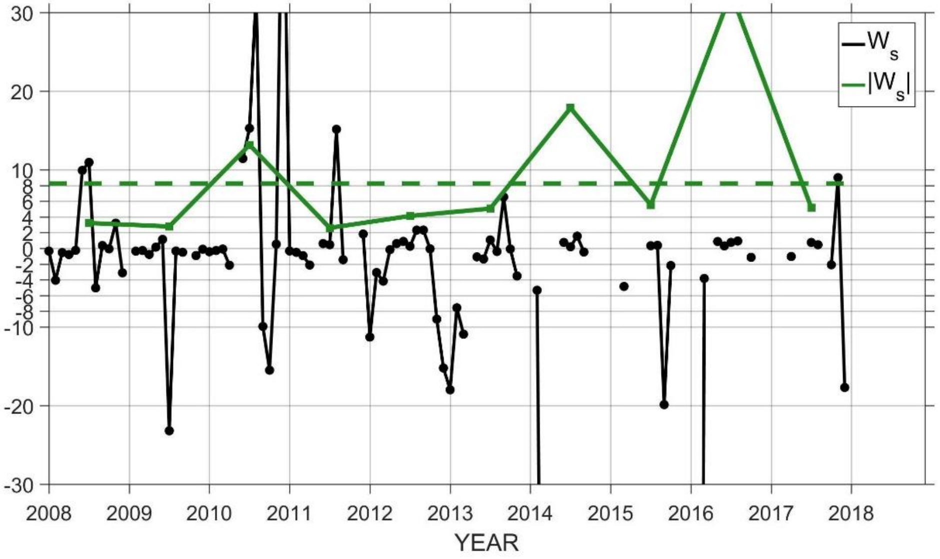
- the possibility of anomalously strong <u>upwelling favorable winds</u> is larger than that for the downwelling favorable winds, thus having a <u>larger impact</u> on the currents overall.

Reasons:

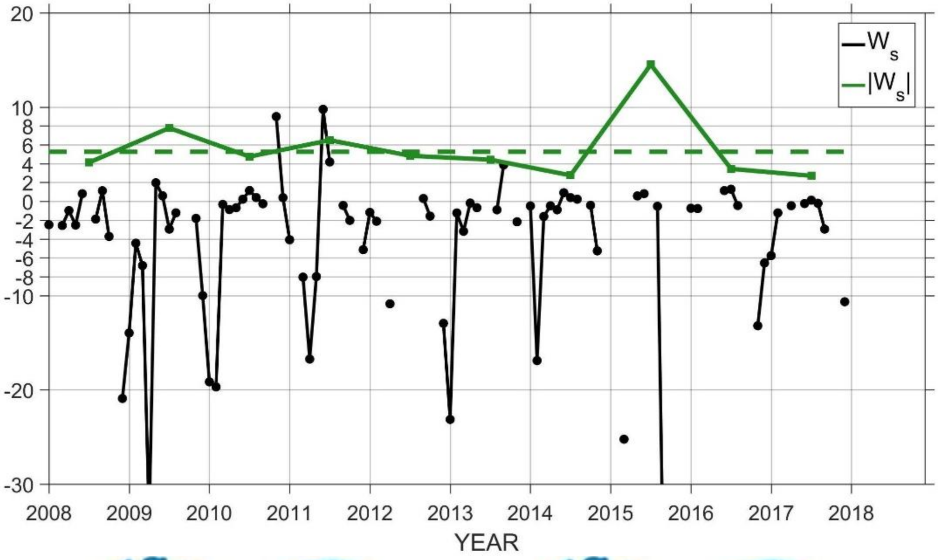
- When the wind is downwelling favorable ($W_s$ >0), $|W_s|$ is mostly <0.5.
- When the wind is upwelling favorable, the frequency of events with $|W_s|>0.5$ or even $|W_s|>1$ is significantly more likely.

# Forcing mechanisms of the currents - wind strength index ($W_s=u_w/u_b$)

**WGCC**




**WGC**




**$u_w$ and $u_b$**

- $u_w$ is similar among sections, consistent with large atmospheric scales.
- But the buoyancy terms evolve, changing the relative importance between wind and buoyancy forcing.

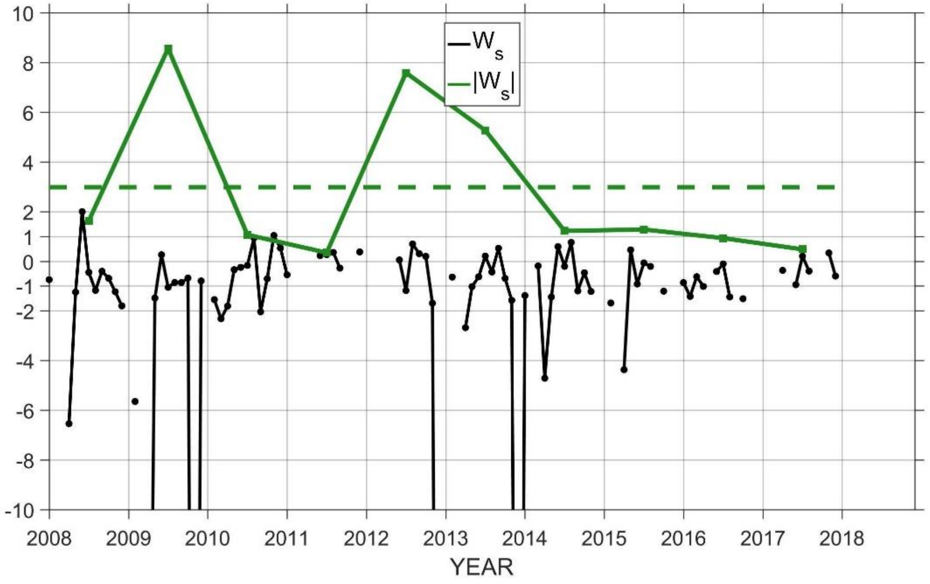
**At Fylla Bank**

As the frequency of $|W_s|>1$ and that of $|W_s|<1$ are both high, wind and buoyancy forcing should be both important to the WGCC and WGC, though the frequency of $|W_s|<1$ for the WGCC is larger before 2009.

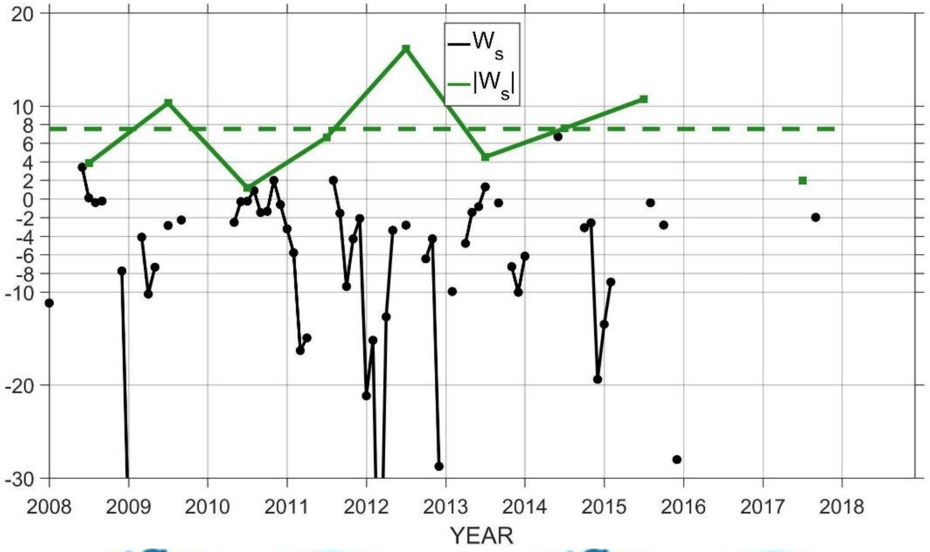
*mean $|W_s|$ is much larger than 1, since extremely large $|W_s|$ exists sometimes, especially when $W_s<0$.

# Forcing mechanisms of the currents - wind strength index ($W_s = u_w/u_b$)

WGCC




WGC




**$u_w$ and $u_b$**

- $u_w$ is similar among sections, consistent with large atmospheric scales.
- But the buoyancy terms evolve, changing the relative importance between wind and buoyancy forcing.

**At Sisimiut**

Similarly wind and buoyancy forcing are both important to the WGCC, while the wind forcing should be dominant in forcing the WGC as $|W_s|$ is mostly >1.

*mean $|W_s|$ is much larger than 1, since extremely large $|W_s|$ exists sometimes, especially when $W_s$<0.

## Conclusions

**1. The current system extends to Davis Strait and exchanges into the interior and north basin, with its shelf component the effective freshwater source for the interior.**

- 13 mSv and 36.7 TW into the interior between Cape Desolation and Fylla Bank
- 20.1 mSv and 14.4 TW into the north

Means over 2008-2018

– Changing current system as Greenland and Arctic continue melting?

**2. At southwest Greenland, the shelf component strengthens while the shelf break component weakens inter-annually, both by a $>0.1$ m s$^{-1}$ speed change over 2008-2018.**

– Due to the Greenland and Arctic melt effect on density gradient and SSH?

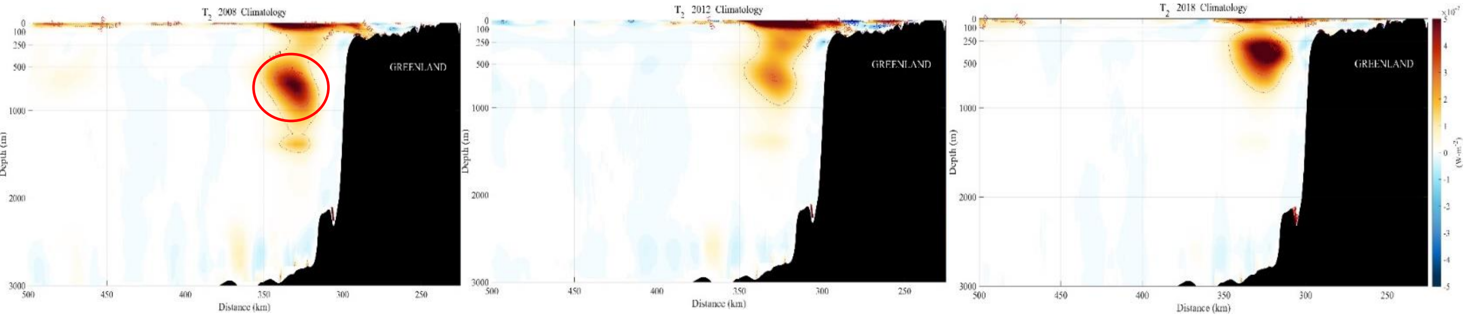
**3. The current system is buoyancy driven near southwest Greenland, with wind forcing more dominant in the north.**

# Ongoing eddy work – the variability of the WGC instability and its link to Irminger Water

**sectional T2 offshore of Cape Desolation/Paamiut**

The lower core rises with year, with its value decreasing to the lowest in 2012 and afterward increasing to the highest in 2018

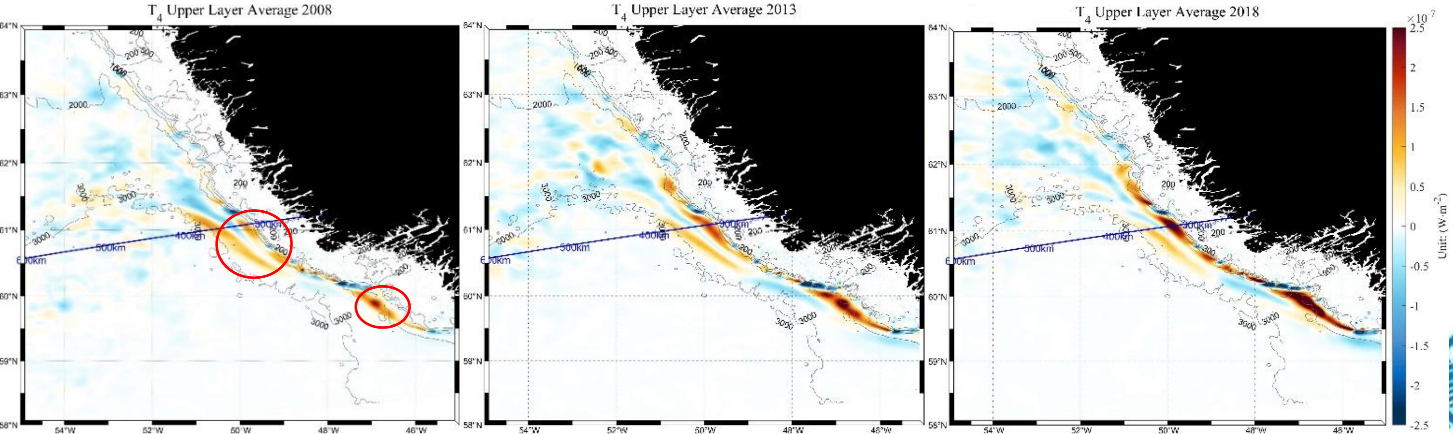
2008 2012 2018




**upper T4 averaged over 100-300 m**

Areas with positive values: larger values after 2013, especially in 2017/2018

2008 2013 2018




**May Relate to**

- the freshening of the WGC after 2013
- changing IW amounts and position

**The definition of the IW?**

***Another idea**

The difference between the WGCC and WGC in exchanges should be due to Ekman and (sub-)mesoscale eddy transports.

⇩

**Quantifying eddy and Ekman transports of the WGCC and WGC**

* We have positive upper T2 signal on the shelf

**Thank you!**