
# Interannual Impact of Extreme wintertime weather on the North Atlantic subtropical stratification

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# Background

SOMOVAR WP3

- The North Atlantic Subtropical Gyre
  - the largest heat reservoir on Earth
  - warming since 1970s (IPCC)
  - the mechanism on interannual variability is not clear

- Question:
  - How extreme wintertime atmospheric forcing patterns can modify the subtropical ocean stratification?

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# Methodology - Heat budget

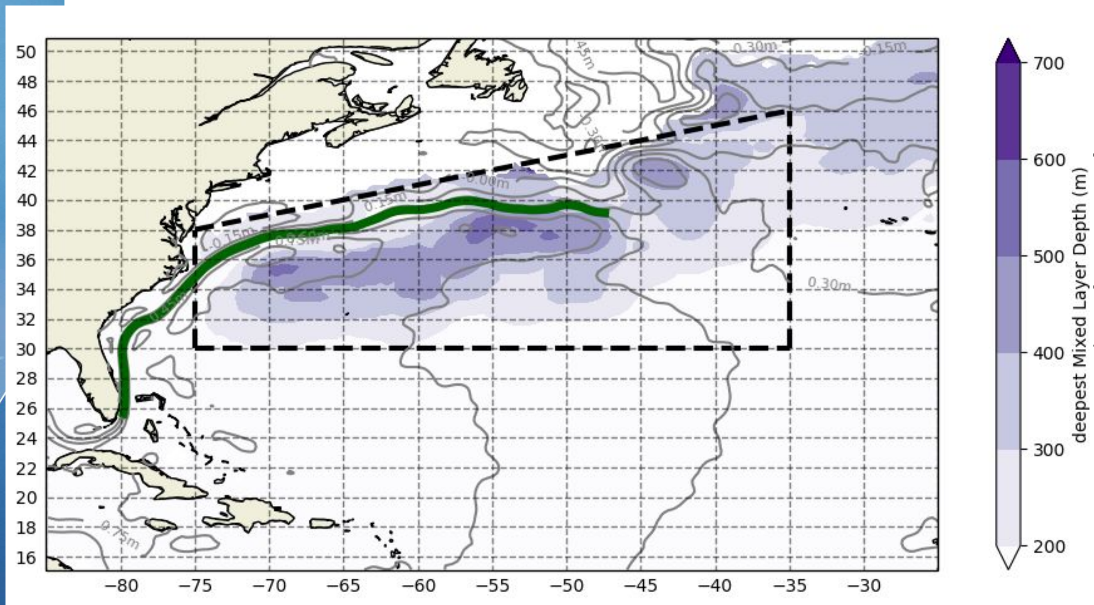



**Figure 1: Domain of study (black dashed line); Deepest mixed layer depth (MLD), in the unit of m (purple color contours); Sea surface height (SSH) of 0.39 m (green thick line); SSH (grey thin contours); The MLD is from ISAS15-ARGO, and SSH is from AVISO. Mean is taking from 2002 - 2018 period.**

$$\rho_o C_p \cdot \int_V \left\{ \frac{DT}{Dt} = F \right\}$$

$\varrho_o$=1,026×10³ kg/m³ Reference density at bottom of mixed layer
$C_p$=4,2×10³ J/(kg·°C) ocean heat capacity
V: volume of domain of study, with a depth of H=800 m

$$\boxed{\partial_t \mathrm{OHC}} = \boxed{\int_S Q_{\mathrm{net}} dS} - \boxed{\mathcal{H}_{\mathrm{Geo}}} - \boxed{\mathcal{H}_{\mathrm{Ek}}} + \boxed{\mathcal{H}_{\mathrm{Mix}}}$$

Ocean heat content change rate

air-sea surface heat loss

Divergence of Geostrophic advection

Divergence of Ekman advection

Mixing

# Interannual Variability - Accumulated Heat budget Analysis

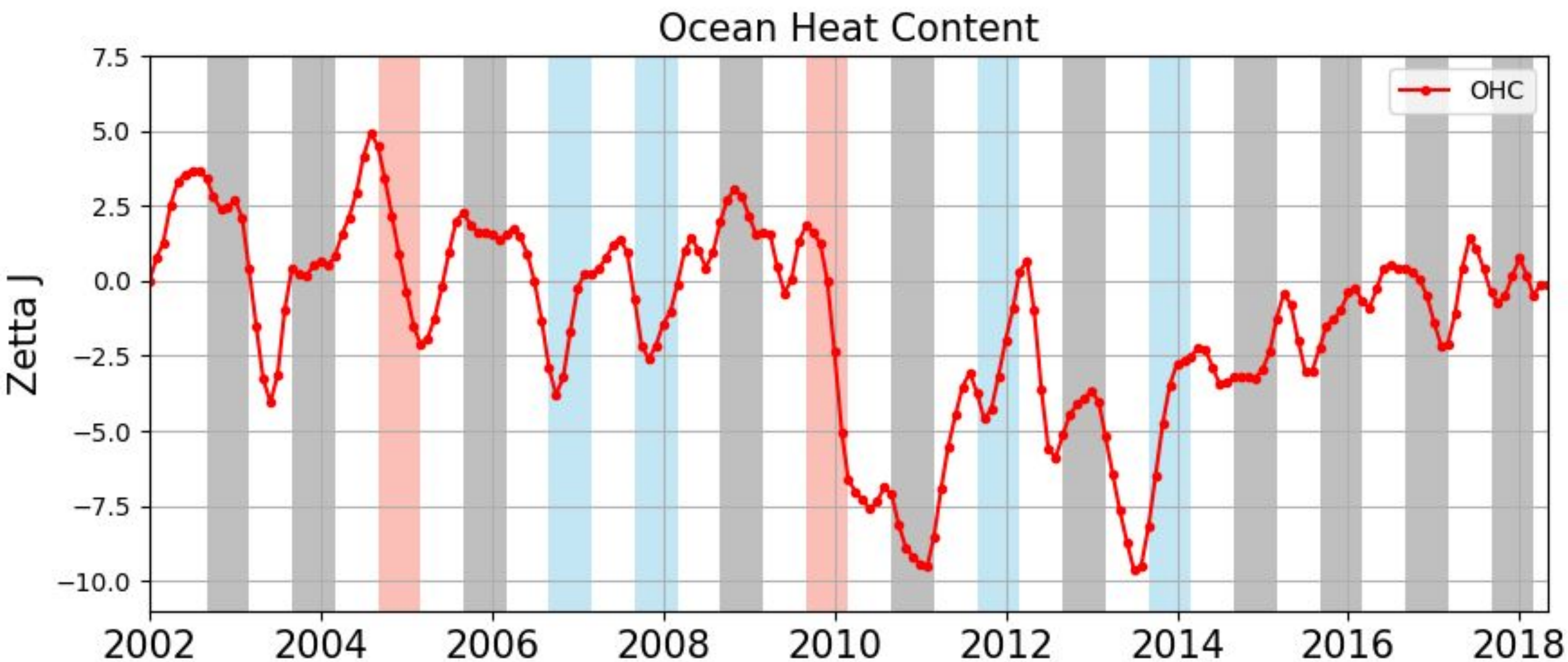



**Figure 2: OHC accumulated from January 2002, in the unit of Zetta J (1 Zetta J = 1 x 10 $^{21}$ J). Shaded is the late fall and winter period (September - March). Shaded in red are winters with negative OHC changes, and in blue are with positive OHC changes.**

- Negative: 2005 and 2010; Positive: 2007, 2008, 2012, and 2014

- Subtropical region :
  - Eighteen Degree Water -> largest heat storage capacity (Maze et al 2009)
- What's impact of **interannual** variability of heat content on EDW?
  - **Multi-decadal impact, see poster (Maze, GMMC 2019)**

# What's Eighteen Degree Water (EDW)?

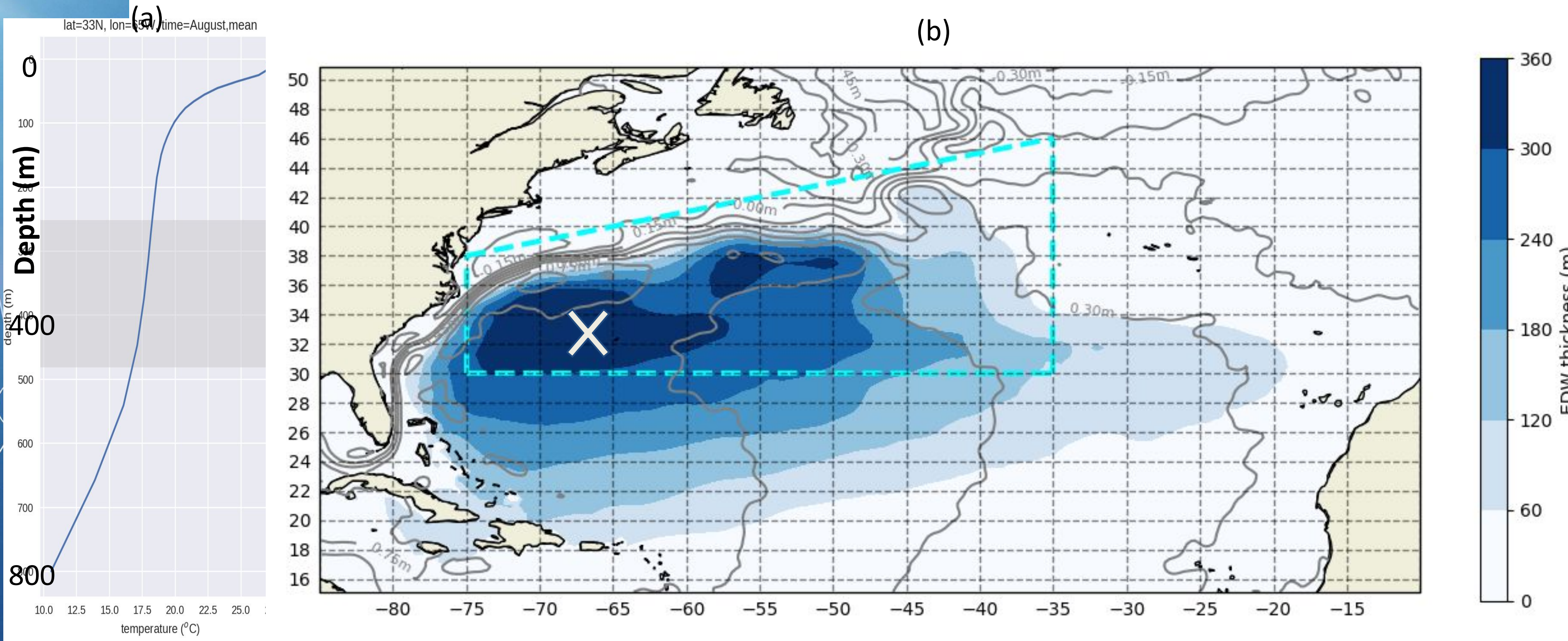



**Figure 3: (a) The August mean temperature profile at 33N, 65W. Shaded area is l'EDW; (b) The climatology mean of EDW thickness. The EDW is defined using the density criteria of 26,2--26,6 kg/m$^3$, and the potential vorticity (PV) criteria of PV < 1,5x10$^{-10}$m$^{-1}$s$^{-1}$ (Maze and Marshall 2011). The climatology mean is calculated using ISAS15-ARGO monthly data of 2002-2018. The grey contours show the climatological mean of sea surface height (SSH) in the unit of m.**

EDW <- -> OHC: anti-correlated (Dong and Kelly 2004)

# Interannual Variability - EDW ventilated volume

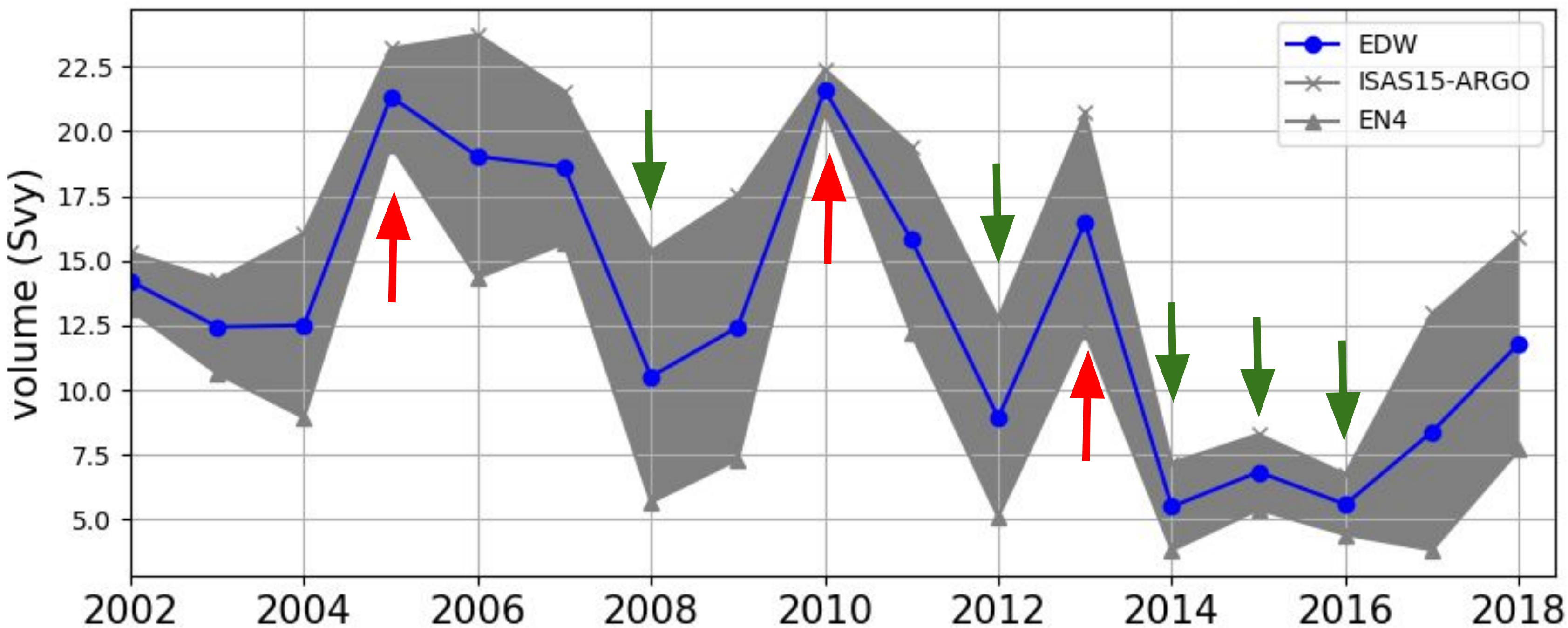



**Figure 4: the 2002 - 2018 EDW ventilated volume early-Spring maxima. The EDW volume is calculated by extending the surface outcropping region (surface density between 26.2 - 26.6 kg·m $^{-3}$) to the mixed layer depth calculated using iSAS15-ARGO (blue solid curve), and using EN4 (orange solid line).**

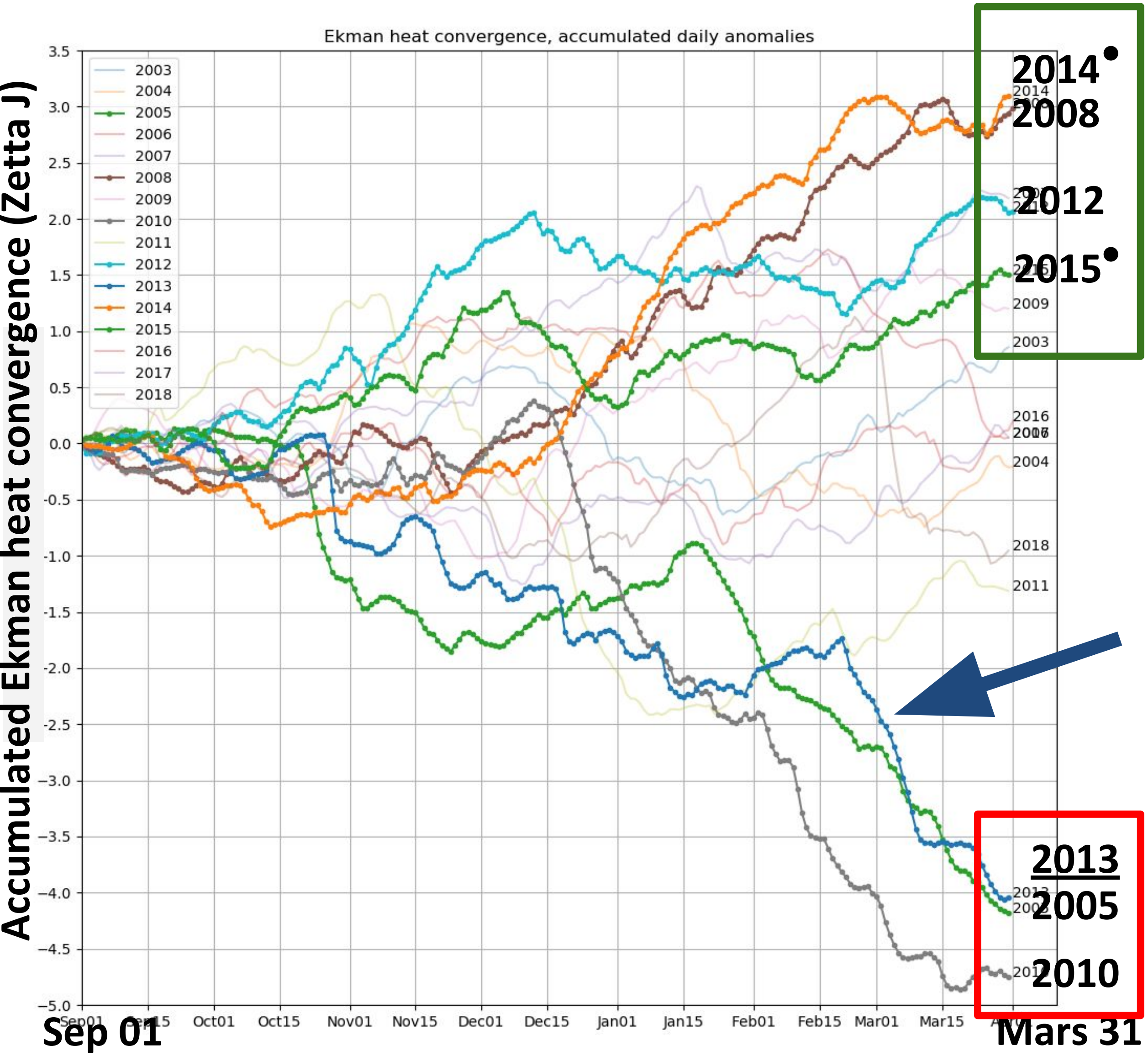
- Strong years: 2005, 2010, and 2013
- Weak years: 2008, 2012 and 2014-2016

# Interannual Variability - Accumulated Heat budget Analysis

| Year | OHC change | Geostrophic | Ekman | Air-sea |
|---|---|---|---|---|
| 2005 | −6.6 | −2.7 | −3.6 | −0.3 |
| 2008 | 0.5 | −4.0 | 2.7 | 1.8 |
| 2010 | −8.5 | −0.9 | −4.5 | −3.0 |
| 2012 | 4.1 | 0.6 | 1.3 | 2.1 |
| 2013 | 0.0 | 3.8 | −3.0 | −0.9 |
| 2014 | 5.7 | 1.1 | 3.4 | 1.2 |
| 2015 | 1.9 | −0.5 | 1.3 | 1.2 |
| 2016 | 1.6 | −0.6 | 0.2 | 0.8 |

**Table 1: The OHC changes over the EDW ventilation season (September–March) and their corresponding dominant contributing factors, in the extreme years. These factors include the geostrophic heat advection, the Ekman heat advection, and the air-sea heat transfer. The shaded rows are years with a strong EDW formation, the unshaded with a weak EDW formation. The unit is in ZettaJ.**

# Ekman heat convergence - daily data




Well separated strong EDW formation years from weak years

- weak: 2008, 2012, 2014, and 2015
- strong: 2005, 2010, 2013

Example: September 2012 - March 2013 (blue dotted curve):

- October 26-30, 2012, **Hurricane Sandy** (aftermath)
- 2012 **Mid December Blizzard,** US midwest (aftermath, NWS 2015a, 2016a)
- January 9-13, **Wind Storm Gong** (prelude), Iberia (Liberato, 2014)
- February 21-March 10, Late February **Winter Storm**, and **Nor'easter,** 2013 (aftermath, US south and New England, NWS 2019, Ryan et al)
- Late March **Storm Complex**, US midwest and Washington D.C. (aftermath, Ryan et al)

**Figure 8: Interannual anomalies of daily accumulated Ekman heat convergence during the period of September - March of 2003 - 2018, in the unit of ZettaJ. 1 ZettaJ = 1× 10 $^{21}$J**

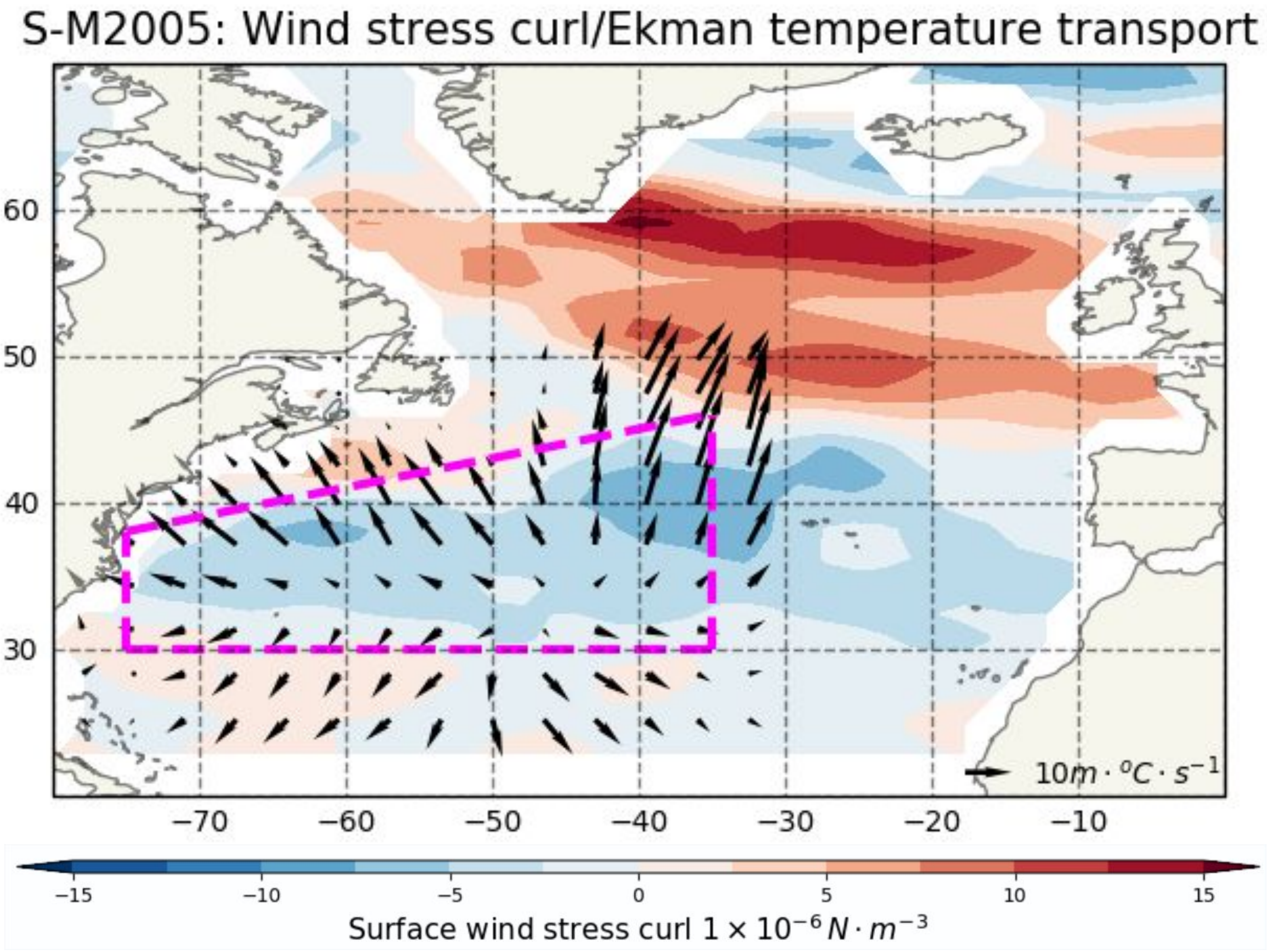



**Figure 5(b) The September-March mean of the near-surface wind stress curl anomaly (colored contours) and the Ekman temperature transport (arrows)**

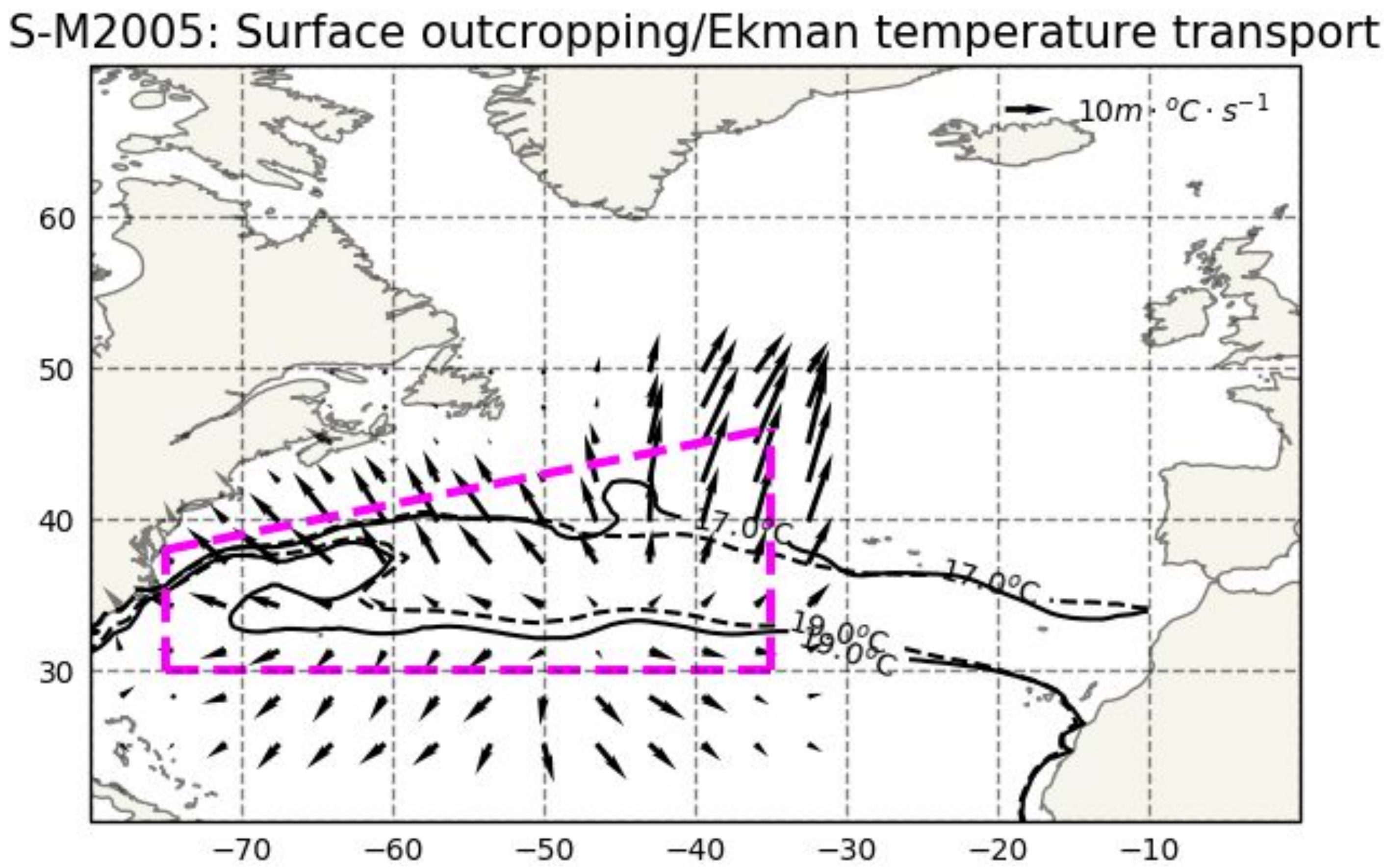



**Figure 5(c) The 2005 September-March mean of the Ekman temperature transport (arrows), and 17-19 celsius degree isotherms of deepest mixed layer, of 2005, in black solid line, 2002-2018 mean in black dashed line.**

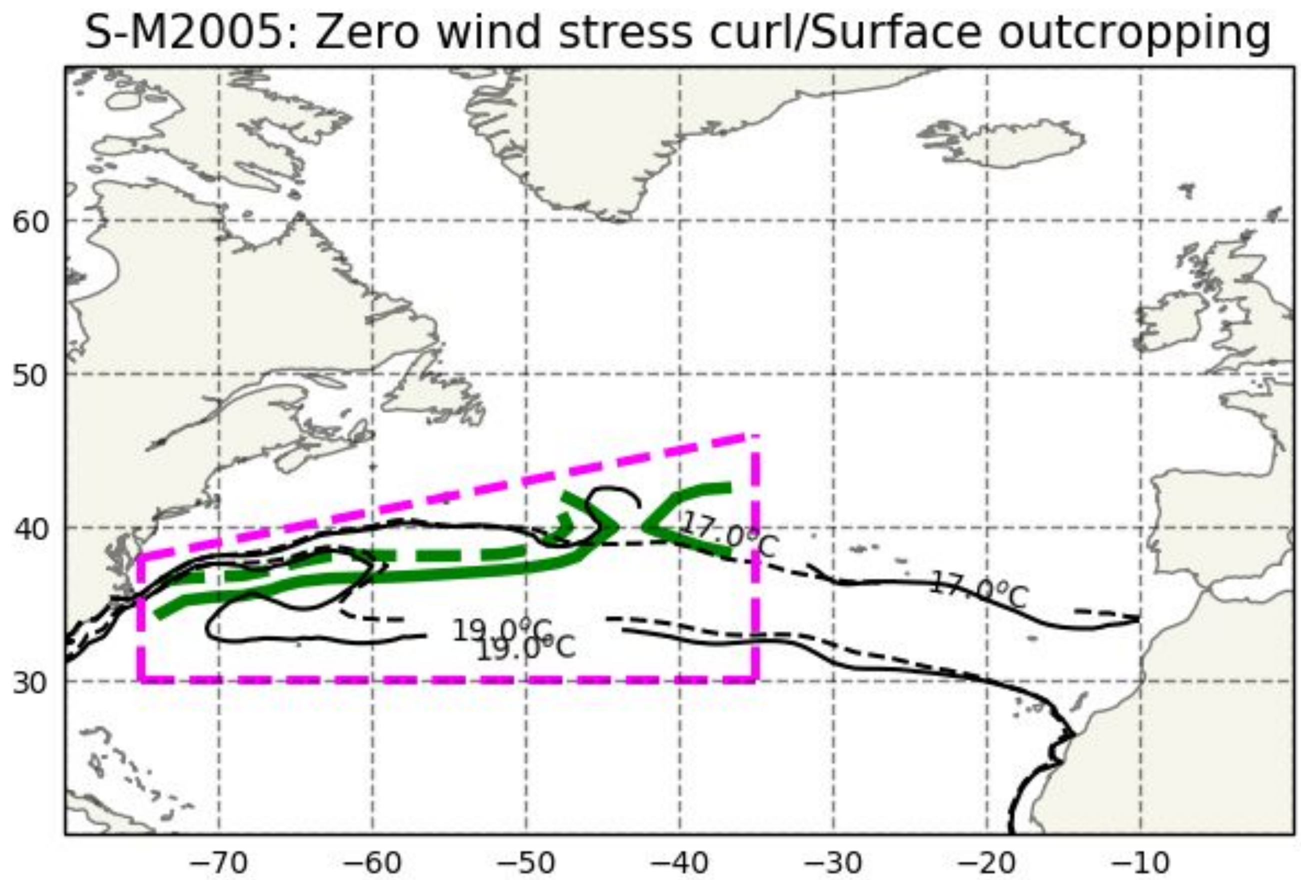



**Figure 5(d) The 2005 September-March mean of 17-19 celsius degree isotherms of deepest mixed layer (in black solid line), and that of 2002-2018 mean (in black dashed line), the zero wind stress curl line (in green solid line) and that of 2002-2018 mean (in green dashed line).**

- Southern shift of Gulf stream <--> an decrease of ocean heat content in subtropical gyre. (Joyce et al 2019)

# Conclusion

- Calculated ocean heat content and contributing factors to understand EDW formation extreme years.
- Found strong / weak EDW ventilation years corresponds with several weather regimes: **ambiguous**.
- Found that **Ekman heat advection** the best indicator of EDW extreme years.
- Ekman heat advection is the driving mechanism to explain the EDW extreme occurrences.
- For a passing storm, both **intensity** and **duration** have an impact on extremity of EDW ventilation

# Thanks!