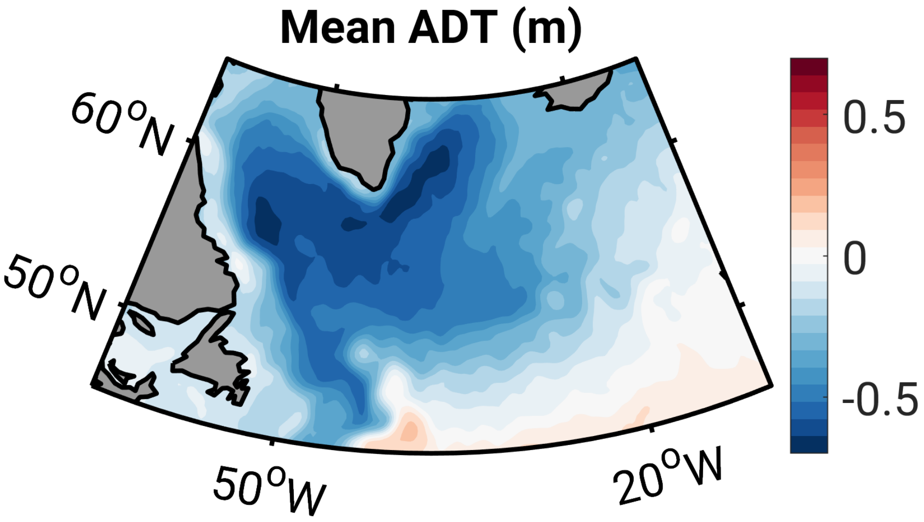
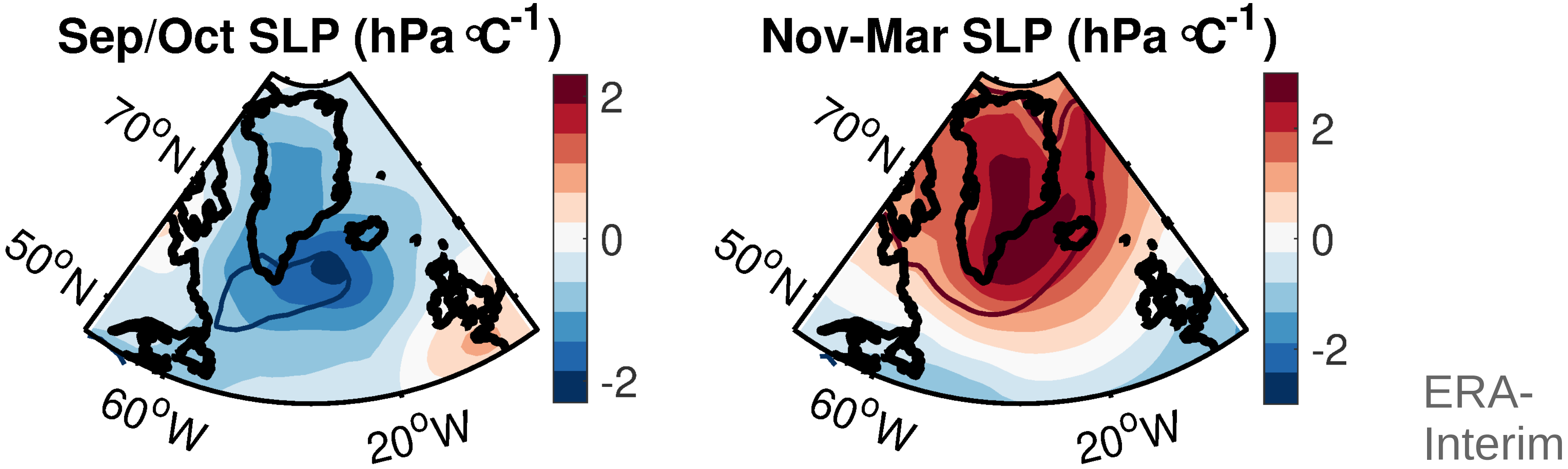
Variability and impacts of surface freshwater in the North Atlantic



M. Oltmanns, J. Karstensen, G. W. K. Moore, S. A. Josey

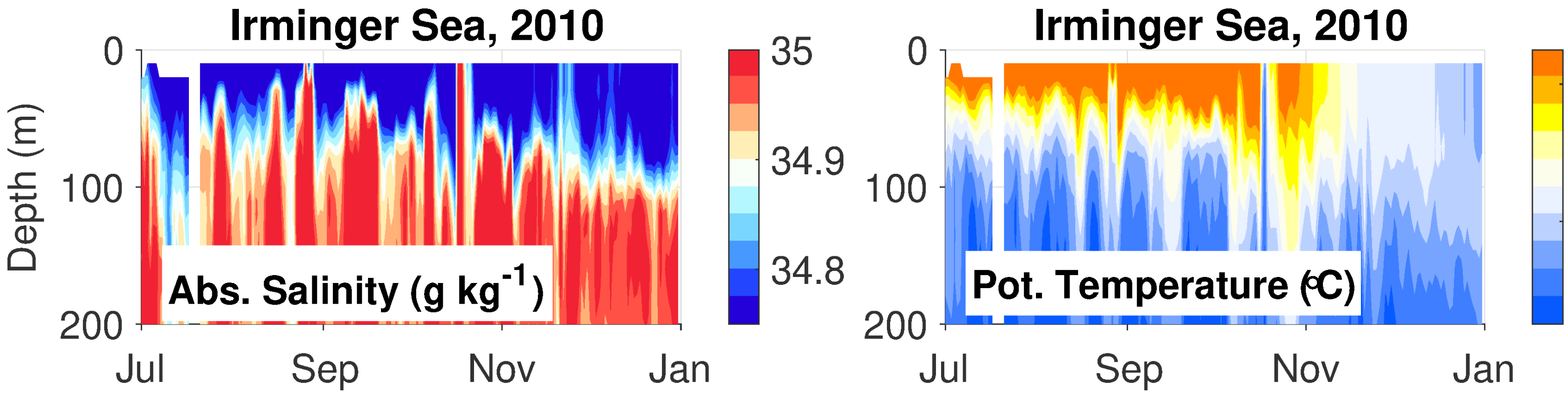
The atmospheric response to increased SST implies a positive feedback that can support its persistence across seasons.



Transient response **Equilibrium response**

Kushnier et al. 2002; Ferreira and Frankignoul 2005; Deser et al. 2007; Czaja and Franignoul 1999: Gastineau et al. 2013

Hypothesis



Mooring observations

By increasing stratification, freshwater influences the mixed layer depth, the SST and, in turn, large-scale atmospheric dynamics.

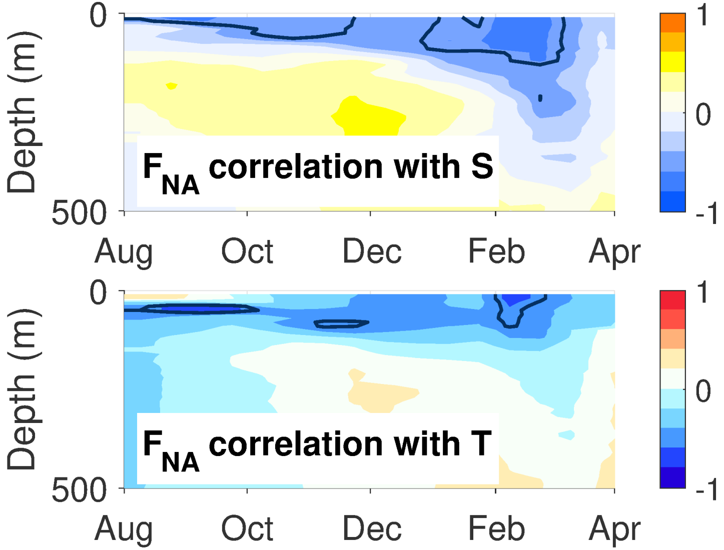
Outline

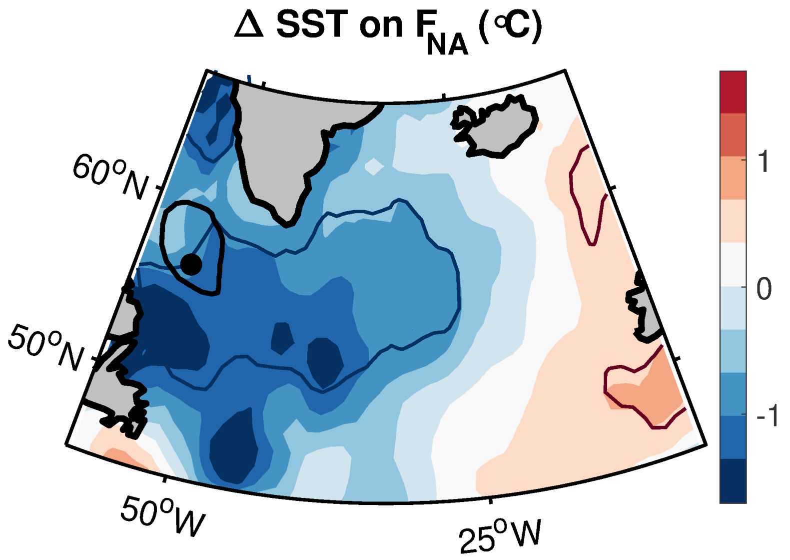
1) Seasonal effects of surface freshwater
2) Implications for interannual climate variability
3) Examples of large freshwater events

Testing the negative summer NAO as freshwater index

F_{NA}:
- Increased Arctic sea ice export
- Enhanced melting over Greenland
- Faster surface cooling in fall and winter

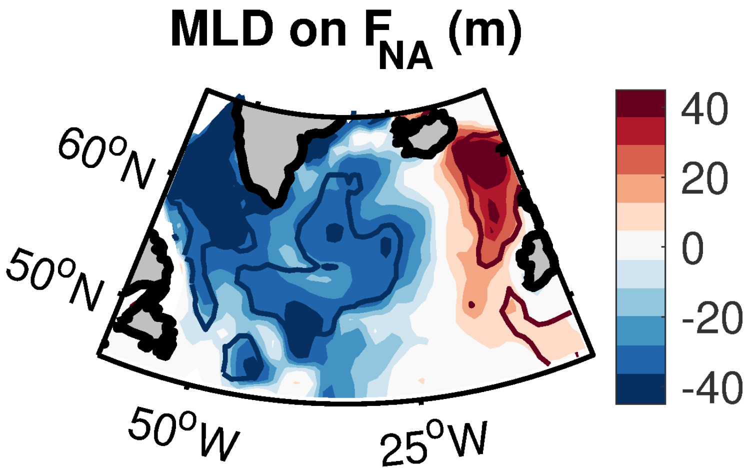
Folland et al. 2009; Smedsrud et al. 2017; Hanna et al. 2013

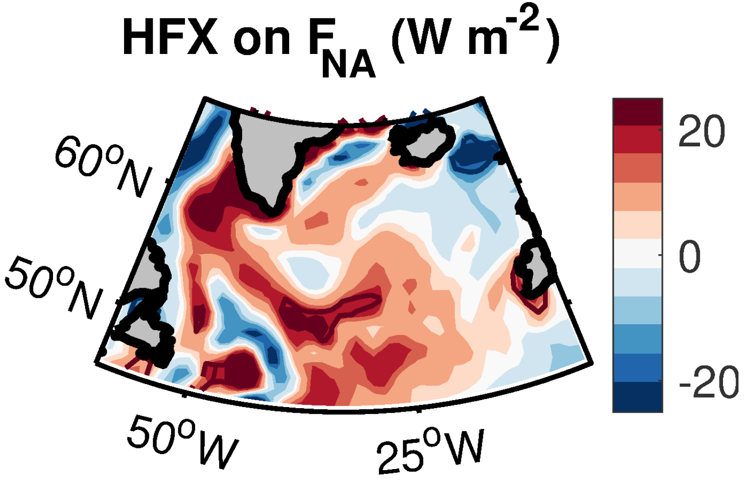




15-year long mooring and Argo observations from the Labrador Sea; satellites

Tracing the increased surface cooling



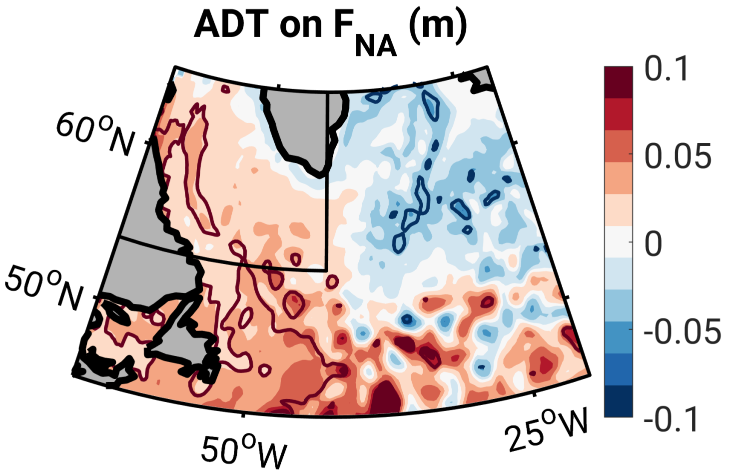


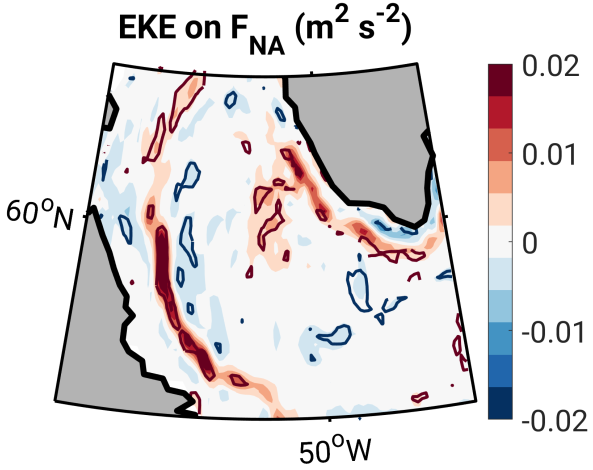
$$d \approx \frac{Q \cdot dt}{c_p \cdot \rho \cdot dT}$$

d: mixed layer depth
Q: heat flux
c_p: heat capacity

Shallower mixed layers can account for the faster cooling, whereas surface currents, eddies and heat fluxes cannot.

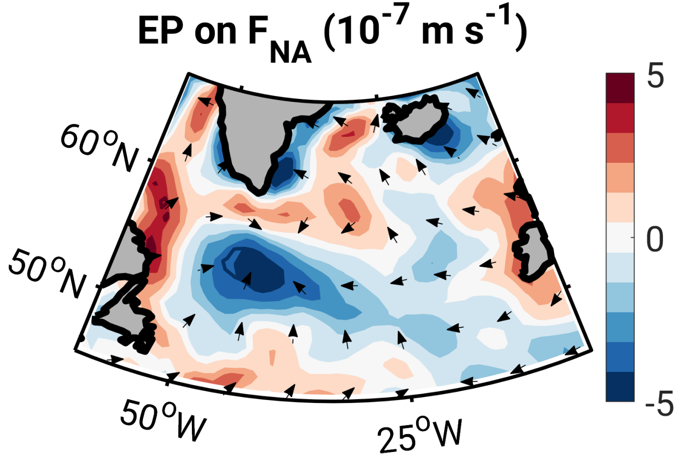
A high F_{NA} favors an enhanced freshwater accumulation.



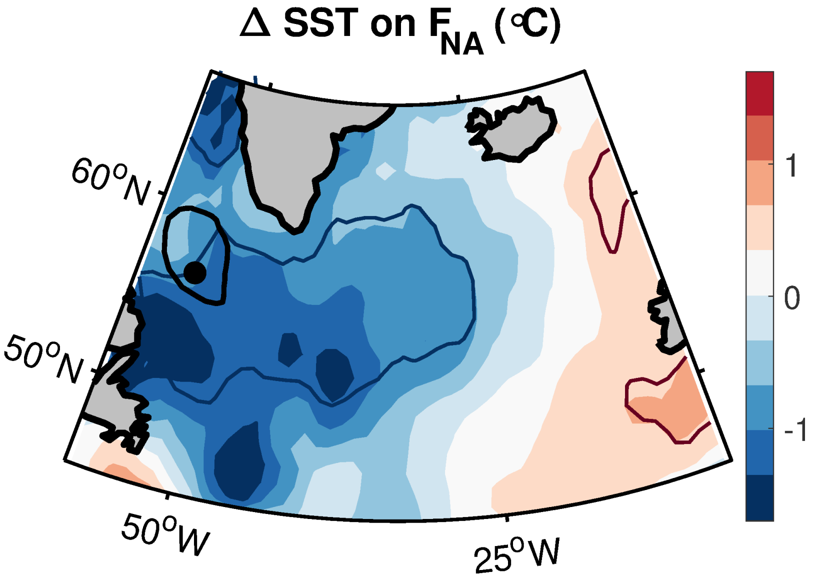


ERA-Interim, satellites

- Increased ice export
- Enhanced melting
- Weaker boundary currents
- Larger lateral buoyancy exchanges
- Stronger Ekman convergence



Conclusion 1: Freshwater promotes the appearance of negative SST anomalies in winter.

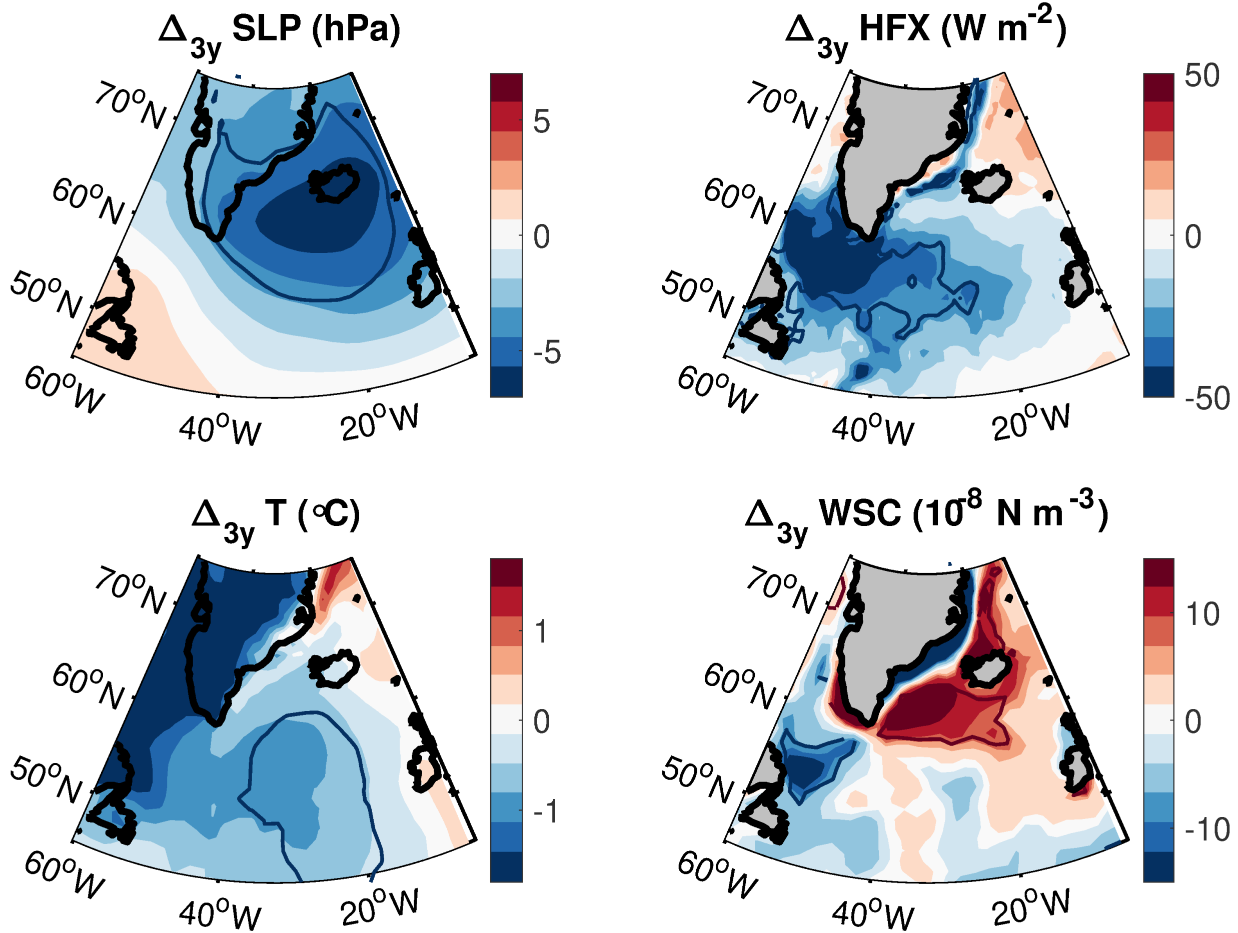


Implication: SST anomalies can propagate through the year and intensify through reemergence and atmospheric feedbacks.

Czaja and Frankignoul 2002;
Timlin et al. 2002;
Cassou et al. 2007;
Gastineau et al. 2013

Hypothesis: A cooling signal can persist beneath the surface throughout summer and amplify in subsequent winters.

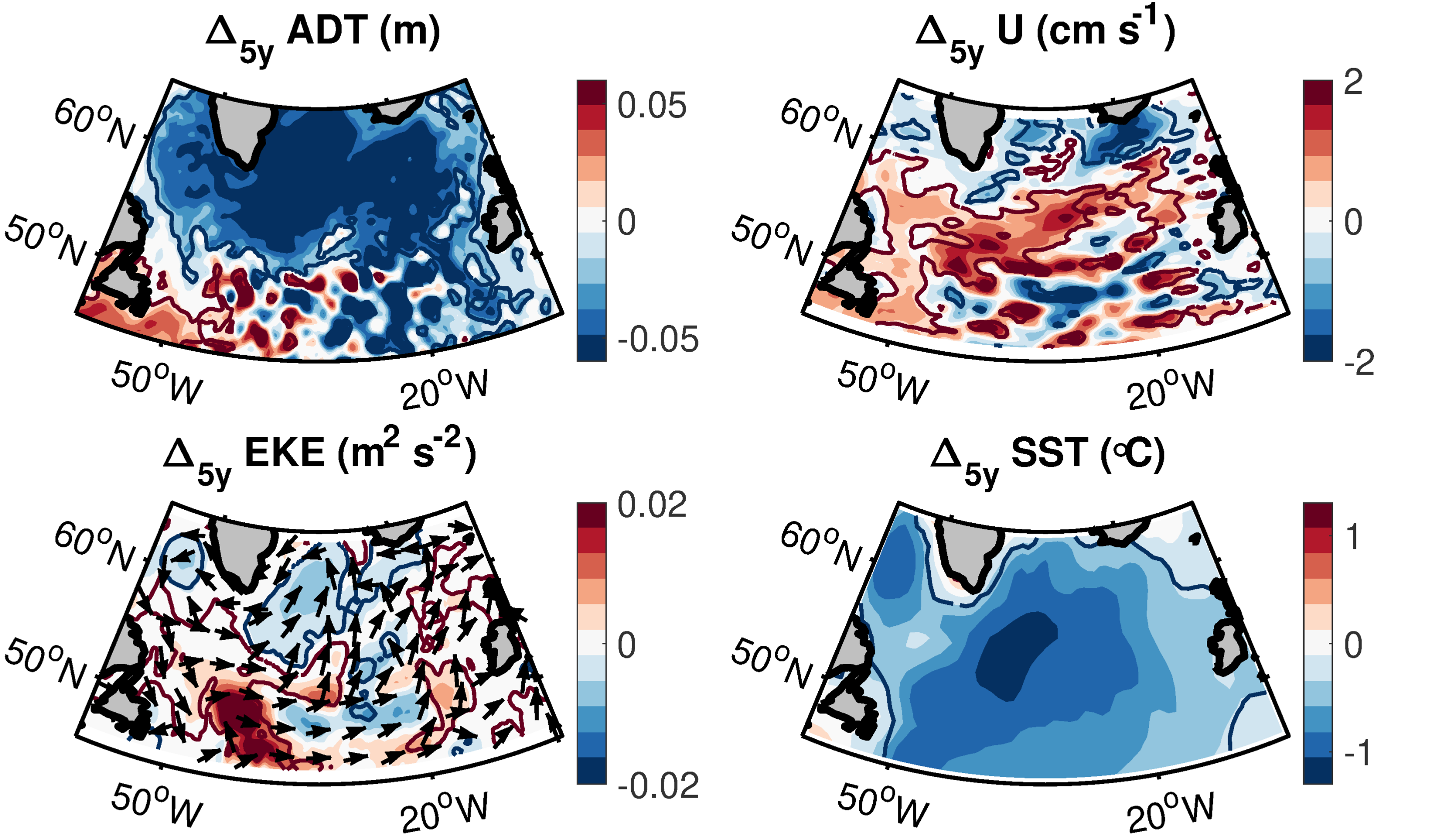
Interannual effects of surface freshwater: atmosphere



Fresh years are followed by more storms and larger ocean heat losses.

ERA-Interim

Interannual effects of surface freshwater: ocean



Satellites

Fresh years are followed by a stronger and colder gyre.

Conclusions 2

- Fresh years are followed by more storms, higher heat losses and cold air advection over the northwest coast.

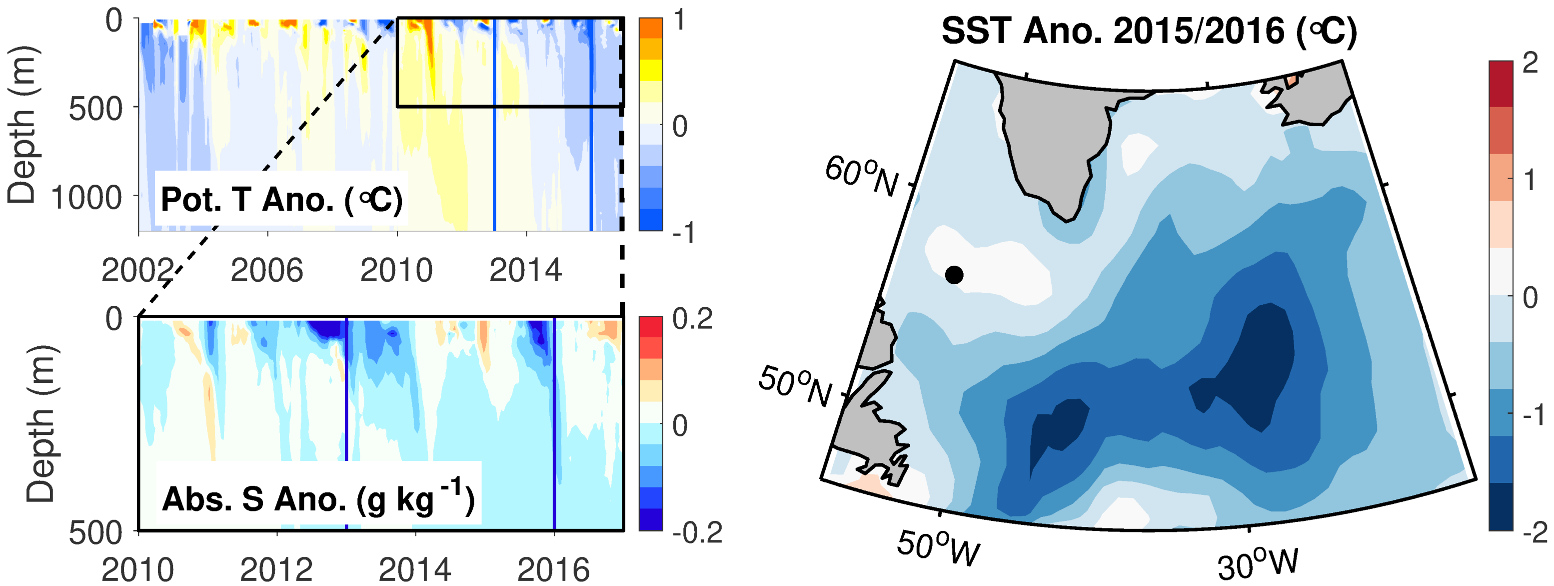
- The increased storminess is associated with a larger wind stress curl, key driver of the subpolar gyre circulation. Marshall et al. 2001; Häkkinen et al. 2011

- The stronger gyre circulation results in a faster eastward flow which impedes cross-gyre transports. Luyten and Stommel 1986; Pedlosky 2013; Häkkinen et al. 2013

- After fresh years, there is enhanced mixing along cold currents, and reduced mixing along the warm currents.

- Fresh years are followed by intense cooling of the subpolar region. Ocean and atmospheric dynamics contribute similarly.

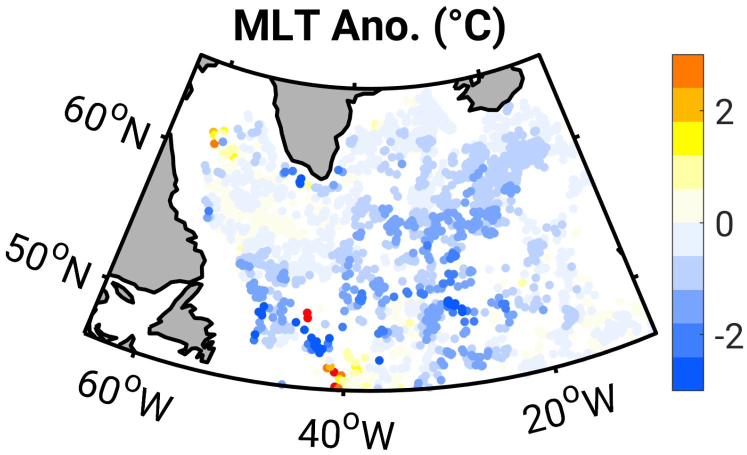
Example: Anomalous freshening in 2012

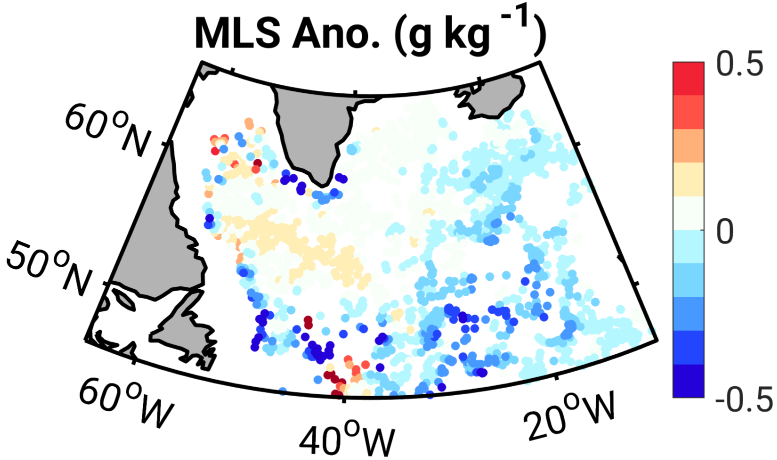


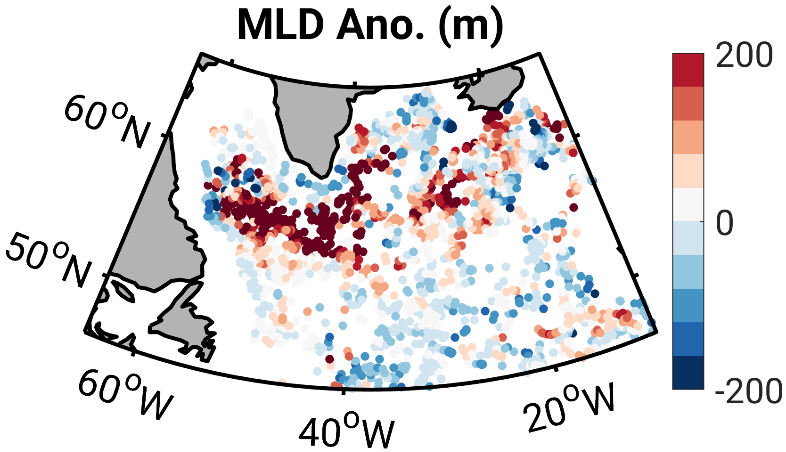
15-year long mooring and Argo float observations; satellites

The large freshwater event in 2012 was followed by deep and far-reaching cooling over the subpolar North Atlantic.

The North Atlantic cold anomaly: winters 2014-2016



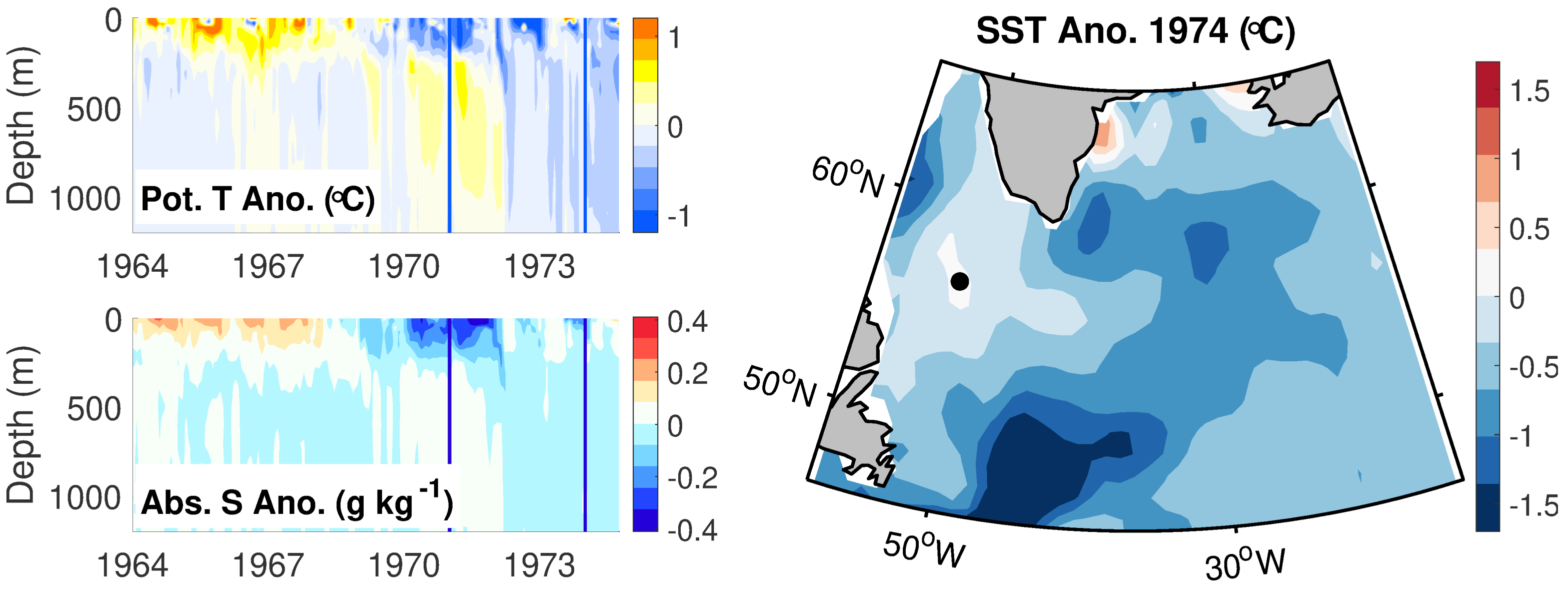




The North Atlantic cold anomaly was coldest in regions where the mixed layer was fresh and shallow.

Argo floats (with climatologies from Holte et al. 2017)

Example: The Great Salinity Anomaly 1969-1972



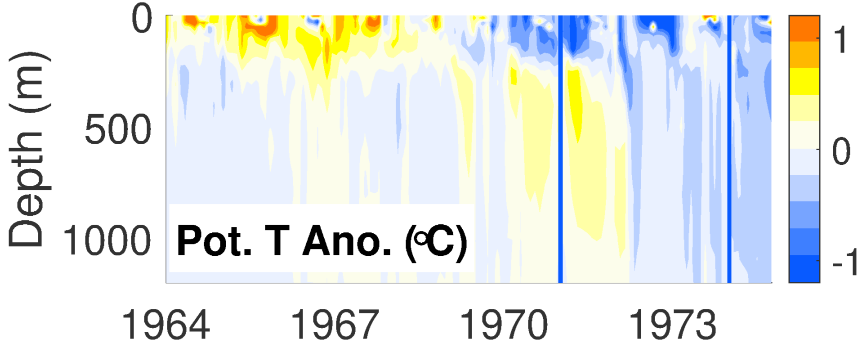
Ocean weather station Bravo; Hadley Centre SST

The Great Salinity Anomaly was followed by one of the harshest winters on record in the subpolar region.

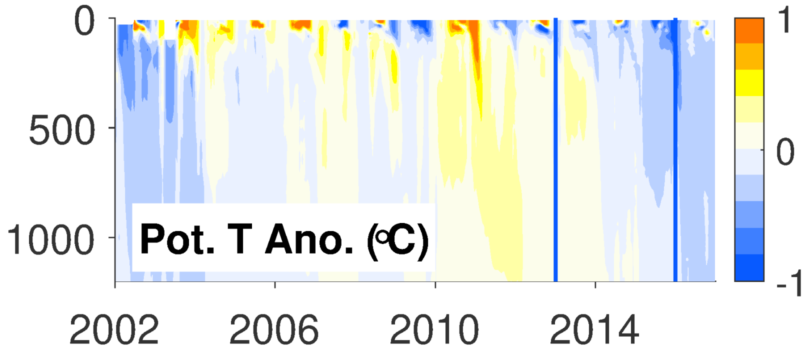
Gelderloos et al. 2012

Amplitude of the cooling in the Labrador Sea

1969 Anomaly



2012 Anomaly



Heat content decrease in the upper 1500 m:
~ 1.9 x 10^9 J m^{-2} after 1969
~ 2.1 x 10^9 J m^{-2} after 2012

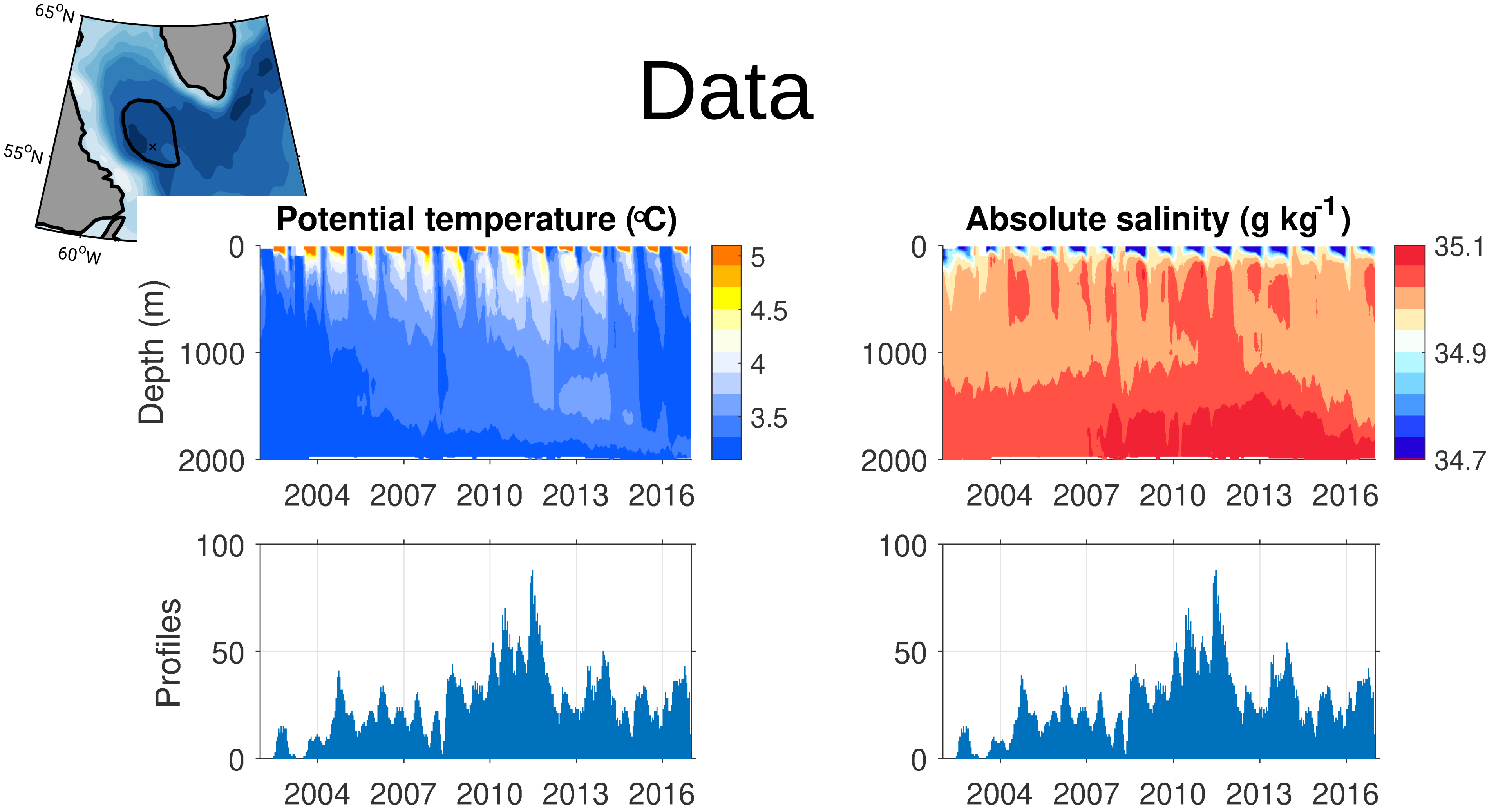
Conclusion 3: Past freshwater events were followed by deep, intense and widespread cooling.

Summary

- Fresh surface layers cool faster.
- The faster cooling promotes an increased storminess.
- The storms driver higher heat losses and strengthen the gyre.
- Recent freshwater events were followed by deep, intense and far-reaching cooling of the subpolar region within a few years.
- Increased future freshening can trigger stormier and colder winters without requiring a decrease in deep convection.

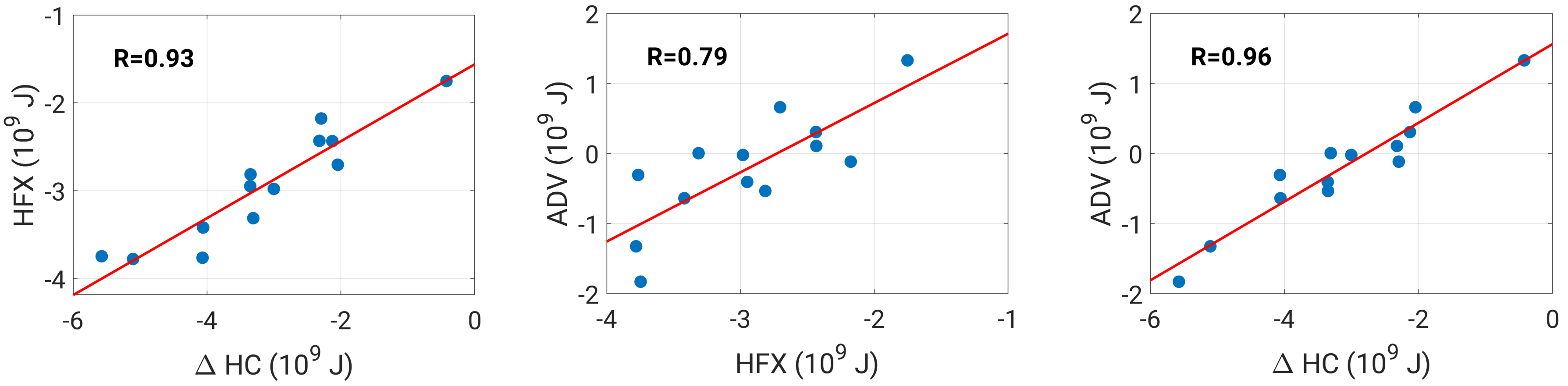
Oltmanns et al., in revision

Data



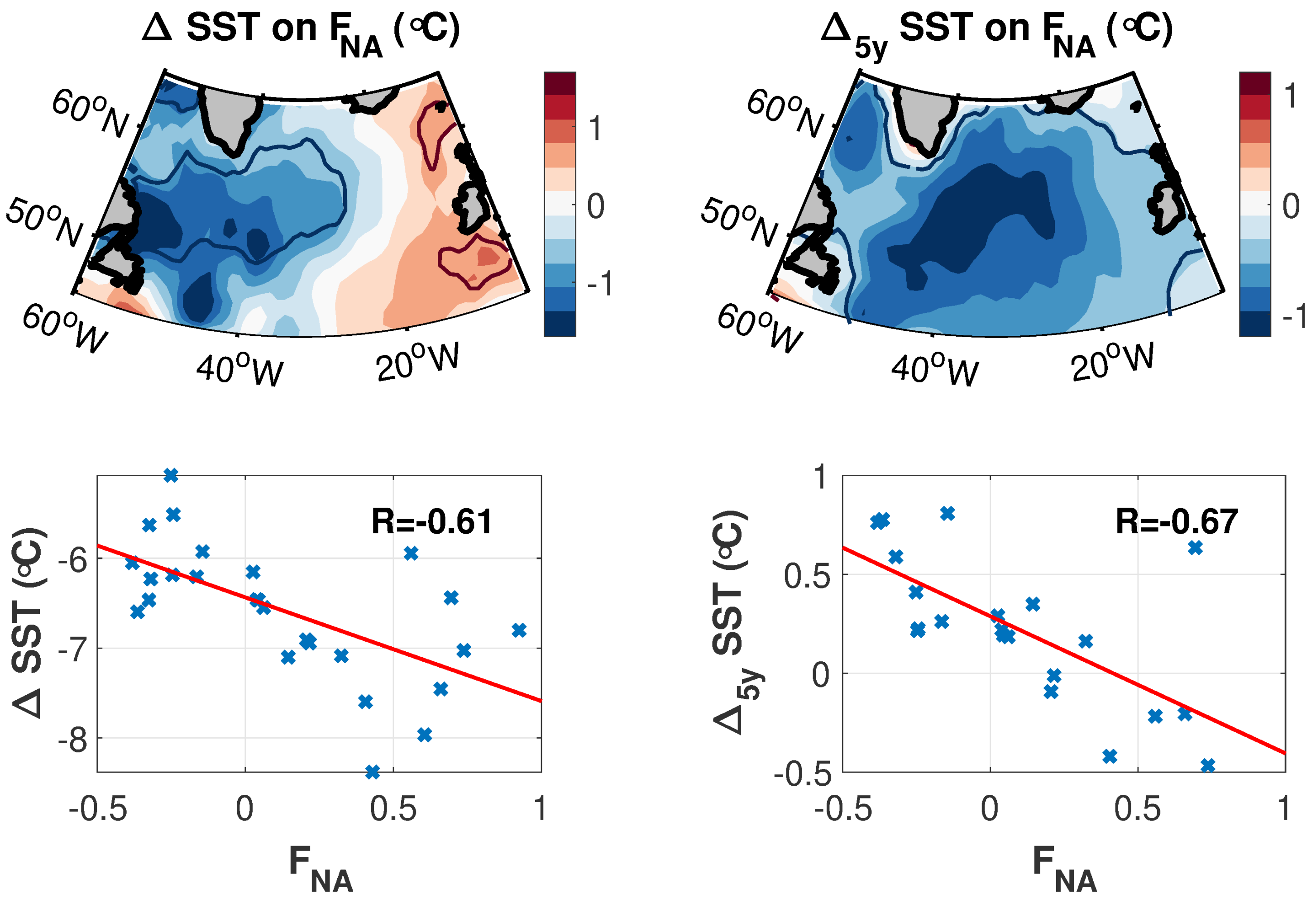
65°N
55°N
60°W
Potential temperature (°C)
Absolute salinity (g kg⁻¹)
Depth (m)
0
1000
2000
5
4.5
4
3.5
35.1
34.9
34.7
2004
2007
2010
2013
2016
Profiles
100
50
0

Winter heat budgets for the Labrador Sea

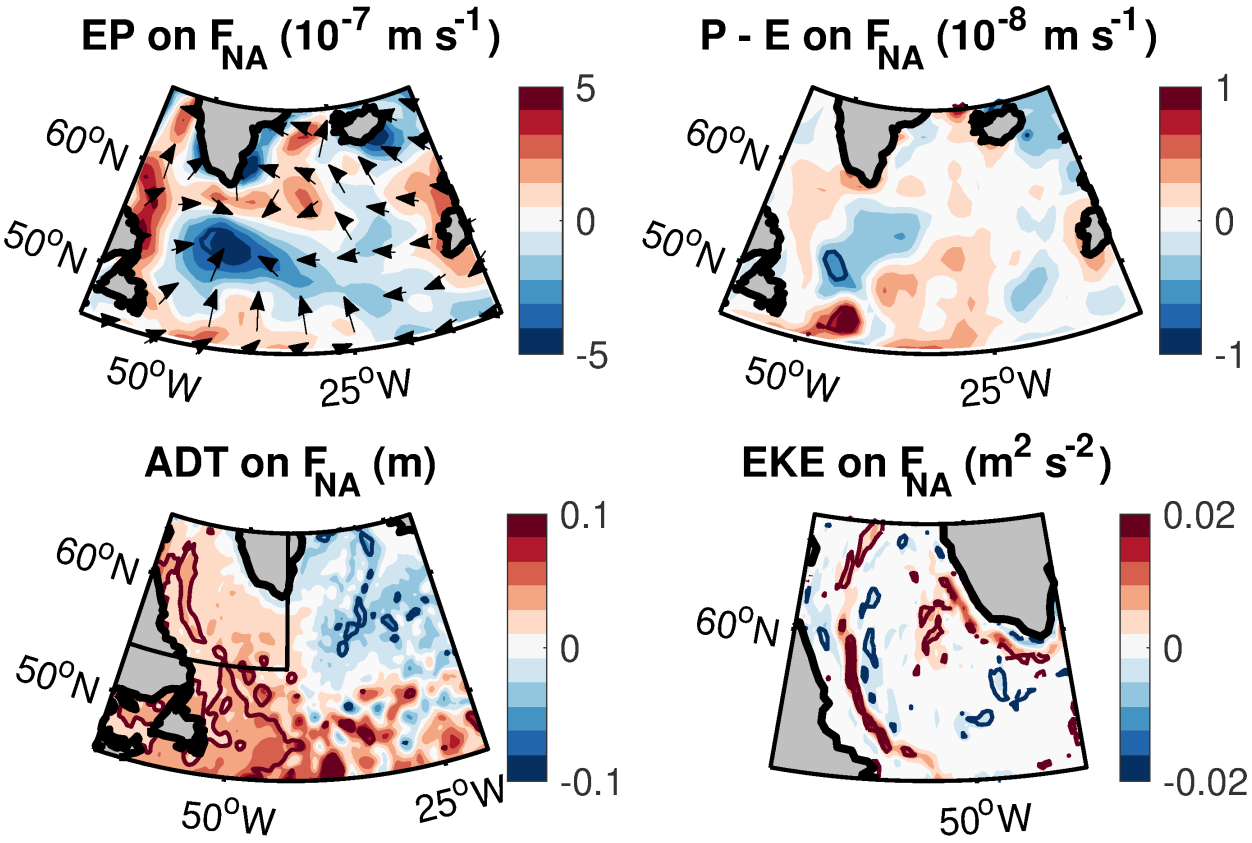


15-year long mooring and Argo float observations, ERA-Interim

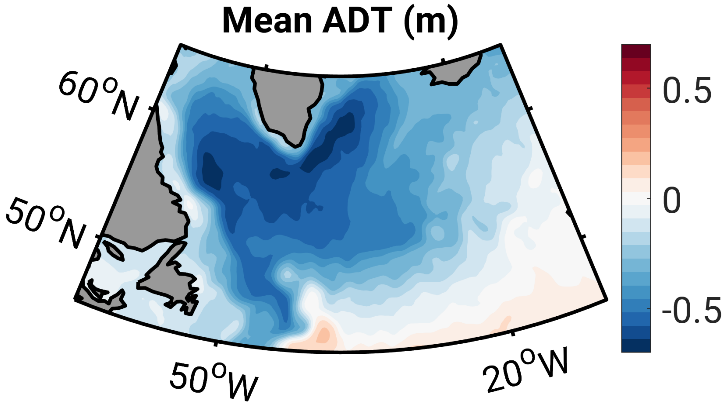
Increased surface heat losses and ocean dynamics contribute about equally to the observed cooling.

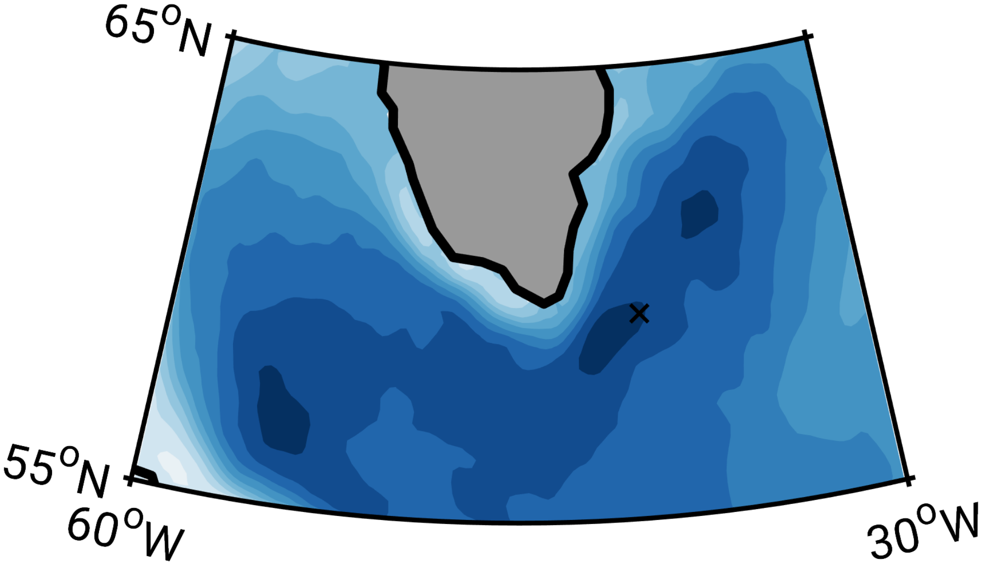

Δ SST on F_{NA} (°C)
Δ_{5y} SST on F_{NA} (°C)
60°N
50°N
60°W
40°W
20°W
1
0
-1
R=-0.61
R=-0.67
Δ SST (°C)
Δ_{5y} SST (°C)
F_{NA}
-6
-7
-8
-0.5
0
0.5
1

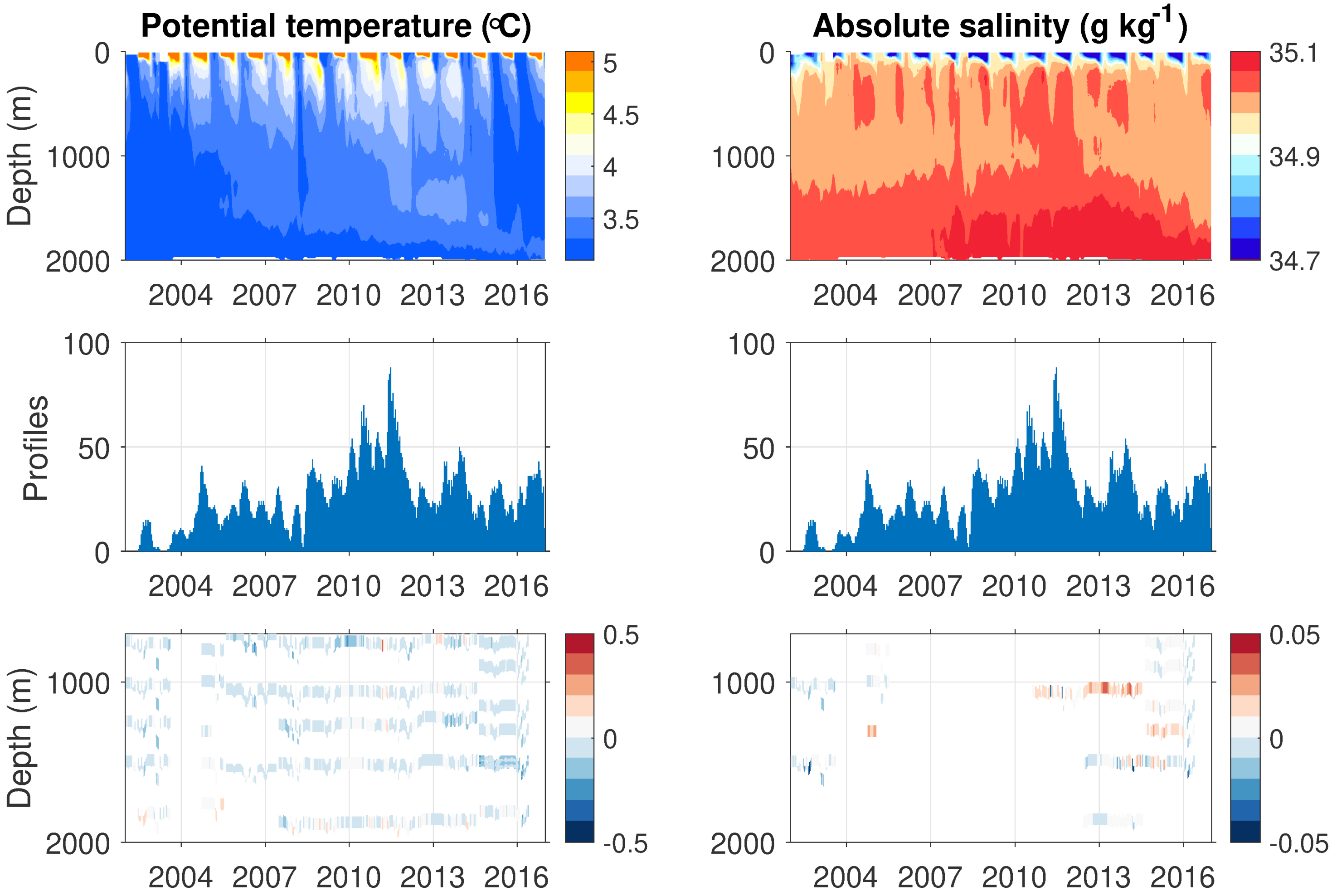
Tracing the increased surface freshening



ERA-Interim, satellites


Mean ADT (m)
60°N
50°N
50°W
20°W
0.5
0
-0.5

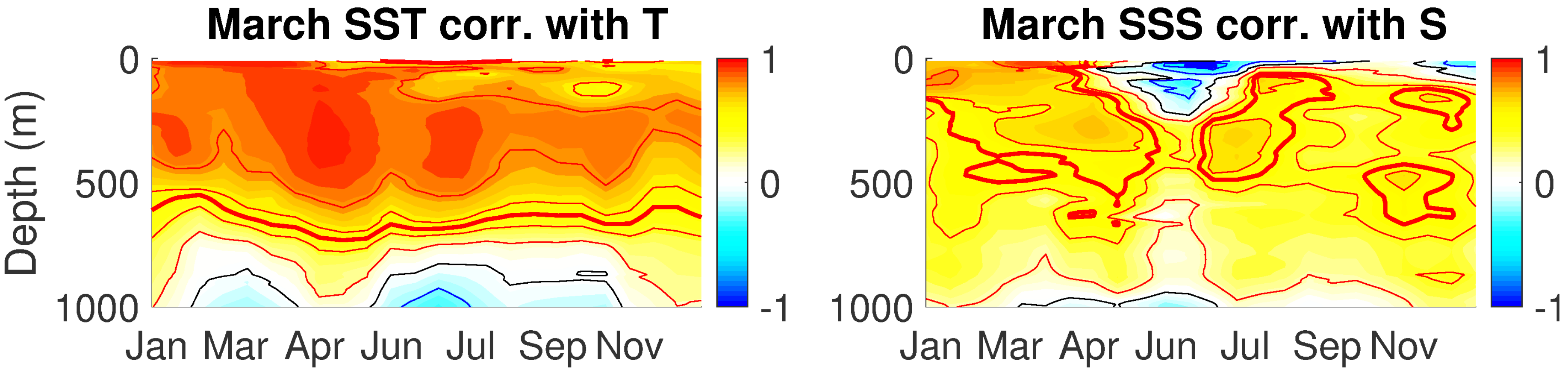

65°N
55°N
60°W
30°W



Potential temperature (°C)
Absolute salinity (g kg^{-1})
Depth (m)
Profiles
0
1000
2000
100
50
2004
2007
2010
2013
2016
5
4.5
4
3.5
35.1
34.9
34.7
0.5
-0.5
0.05
-0.05

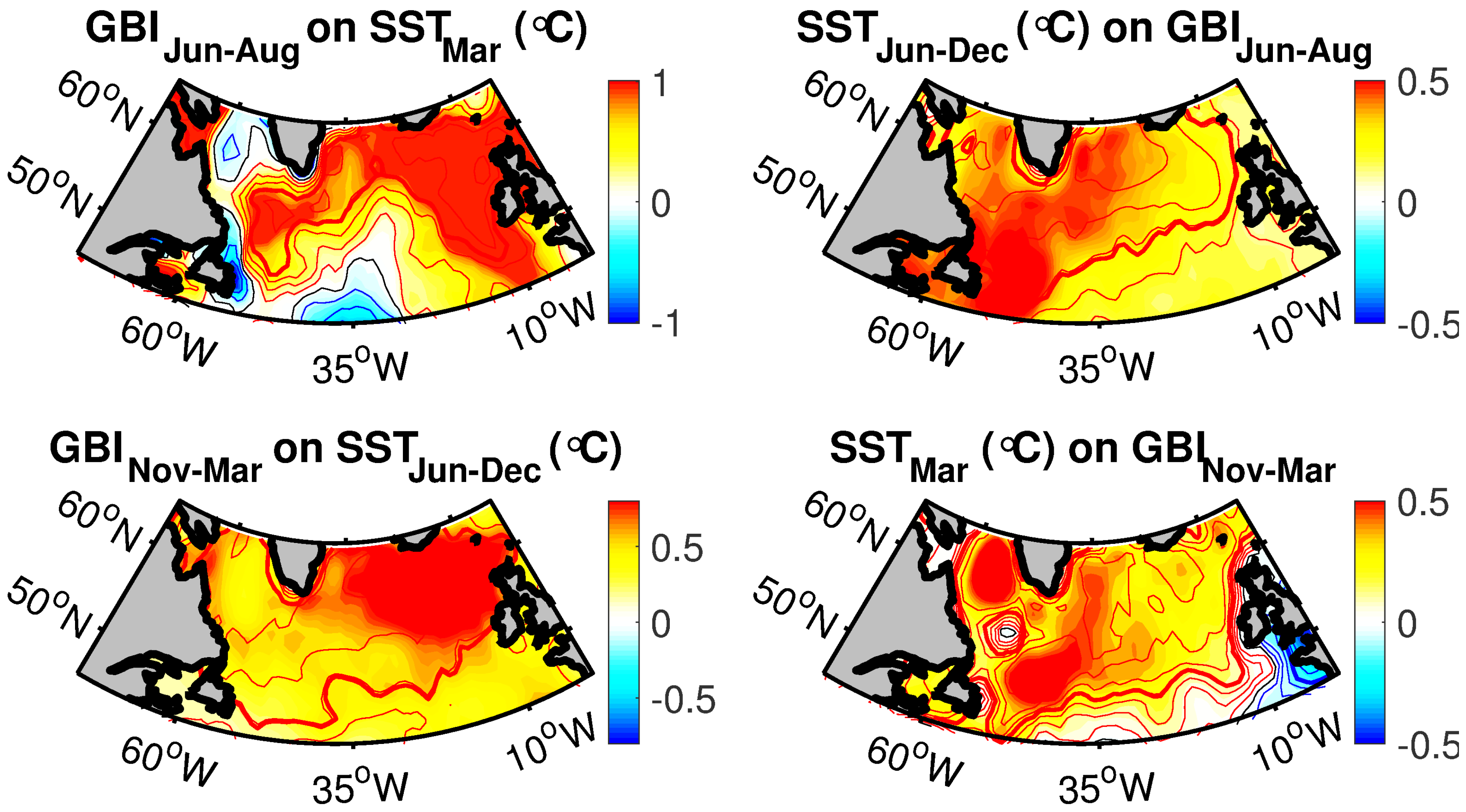
A cold anomaly can propagate through the year and intensify as a result of reemergence and positive atmospheric feedbacks.

Czaja and Frankignoul 2002; Timlin et al. 2002 Cassou et al. 2007; Gastineau et al. 2013



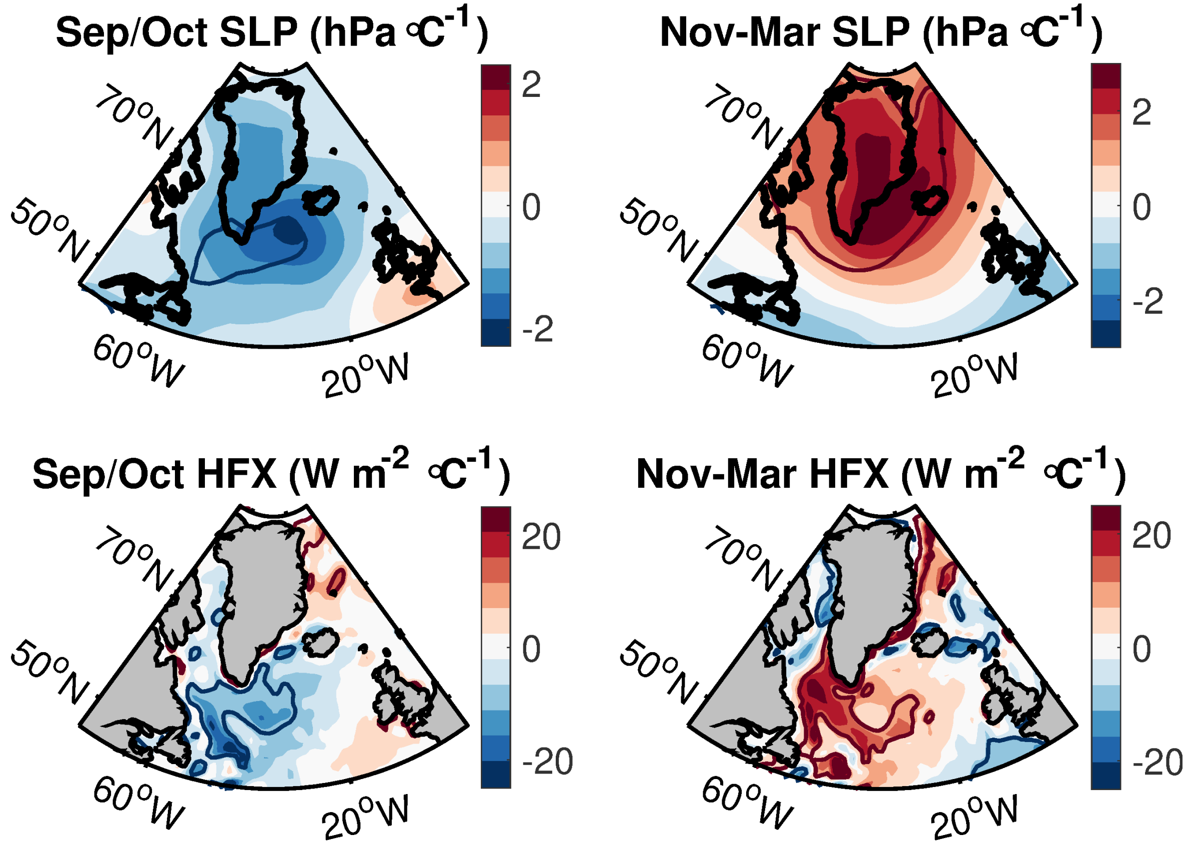
Based on mooring and Argo observations

A loop of positive feedbacks



Transient response

Equilibrium response



The atmospheric response to increased SST implies a positive feedback that can support its persistence across seasons.

Kushnier et al. 2002;
Ferreira and Frankignoul 2005;
Deser et al. 2007;
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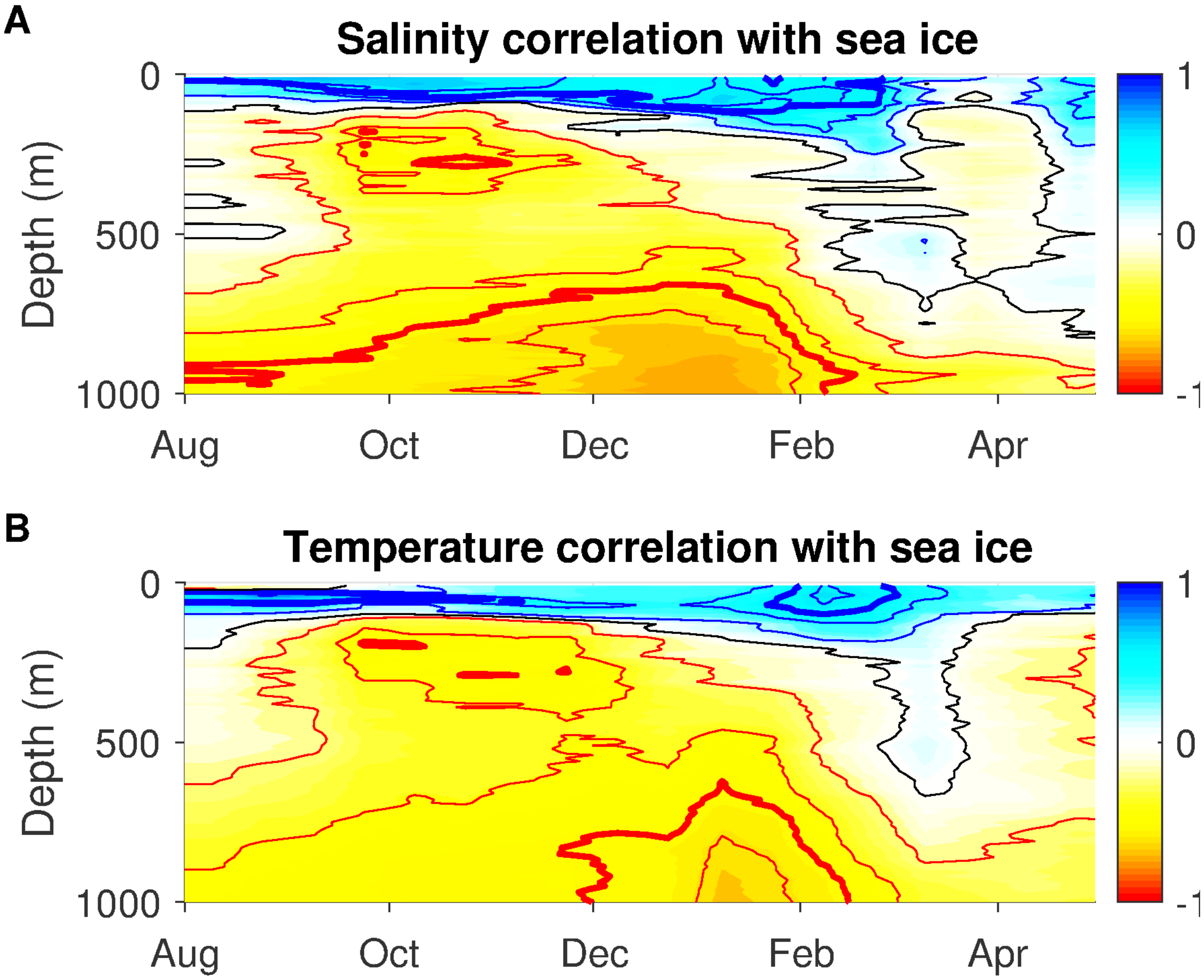
A
Salinity correlation with sea ice
0
500
1000
Depth (m)
Aug
Oct
Dec
Feb
Apr
1
0
-1
B
Temperature correlation with sea ice
0
500
1000
Depth (m)
Aug
Oct
Dec
Feb
Apr
1
0
-1