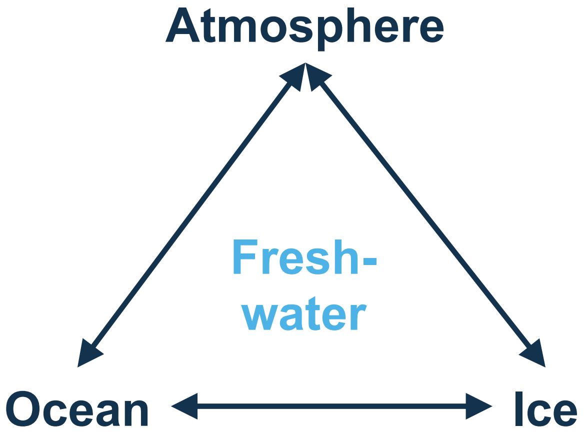
Freshwater-driven feedbacks between the Arctic and the North Atlantic

Marilena Oltmanns
ASOF Meeting, October 2021



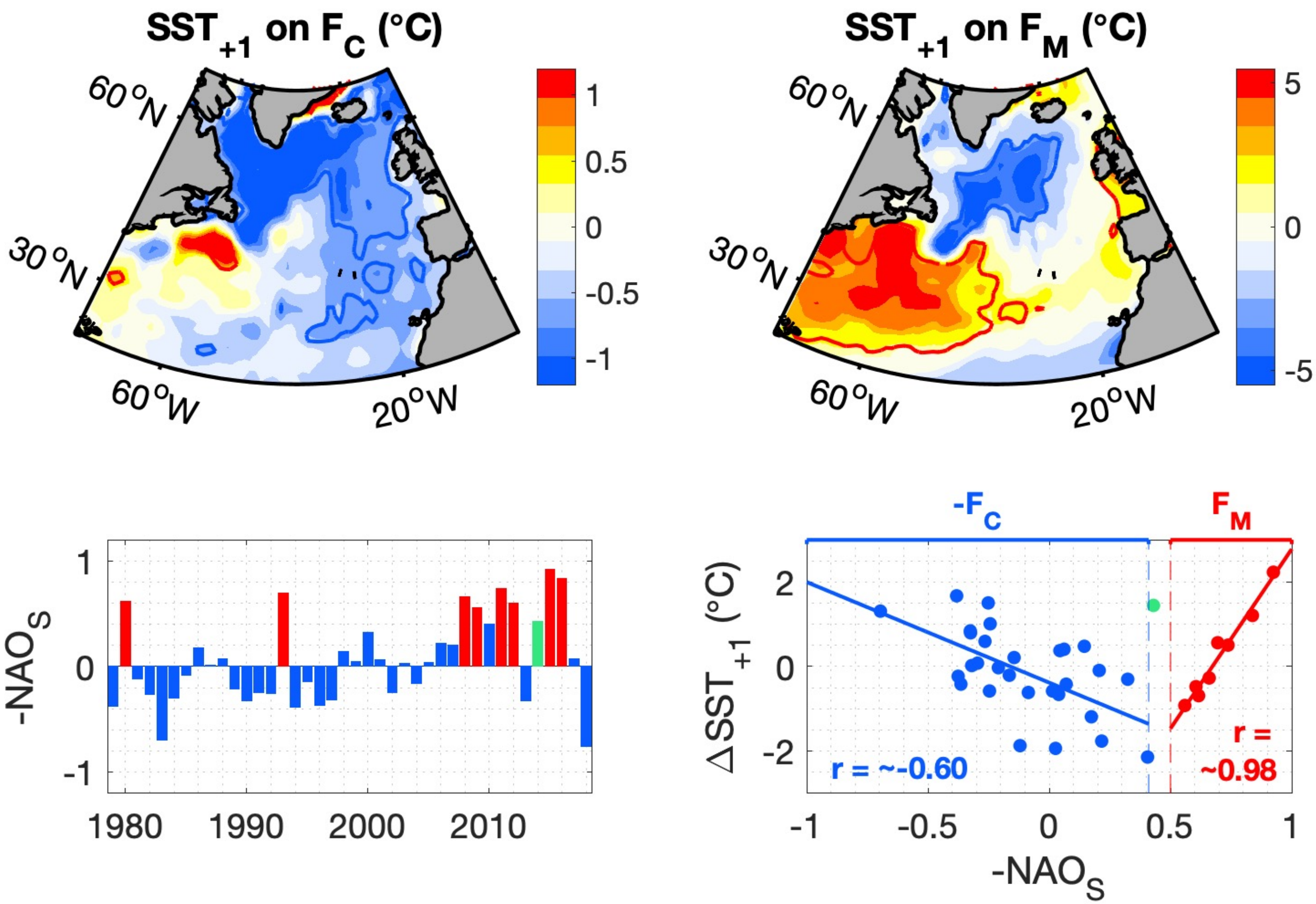
Outline

1. Influences of freshwater

2. A circulation-driven freshwater cycle

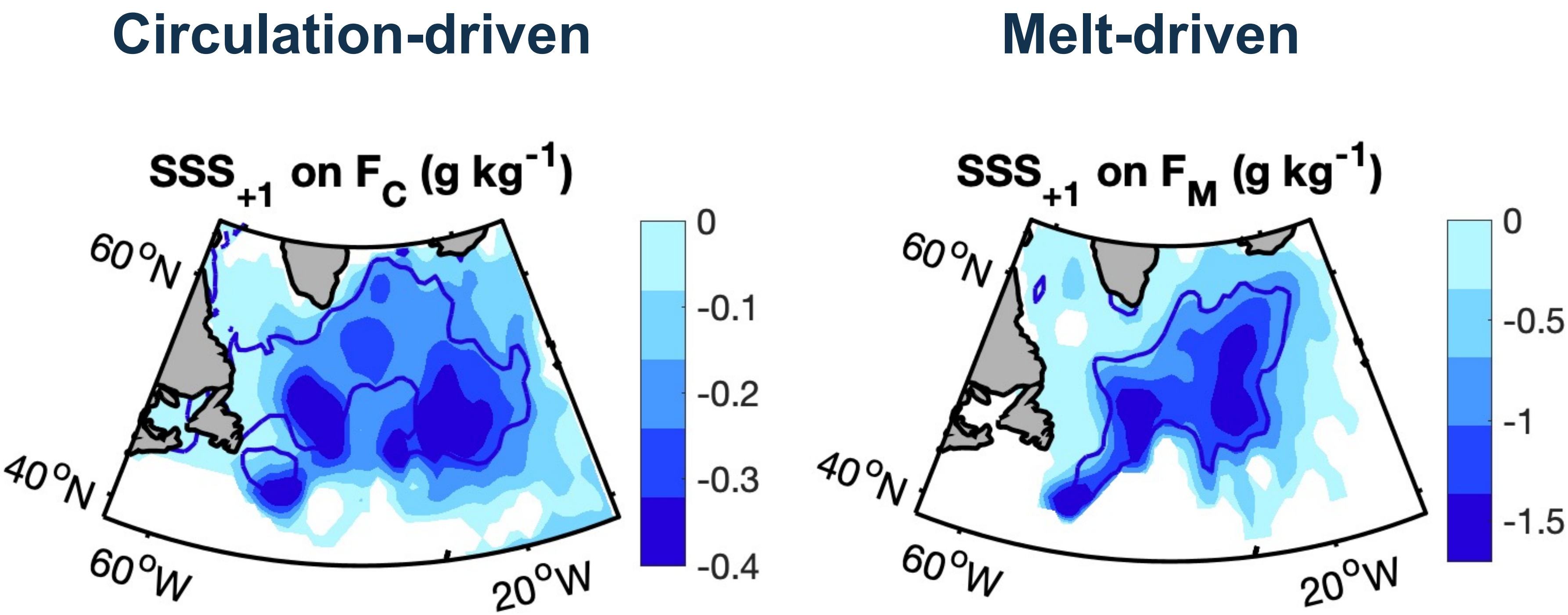
3. Interference by melting

Two types of freshwater events trigger cold anomalies in the subpolar region in winter.



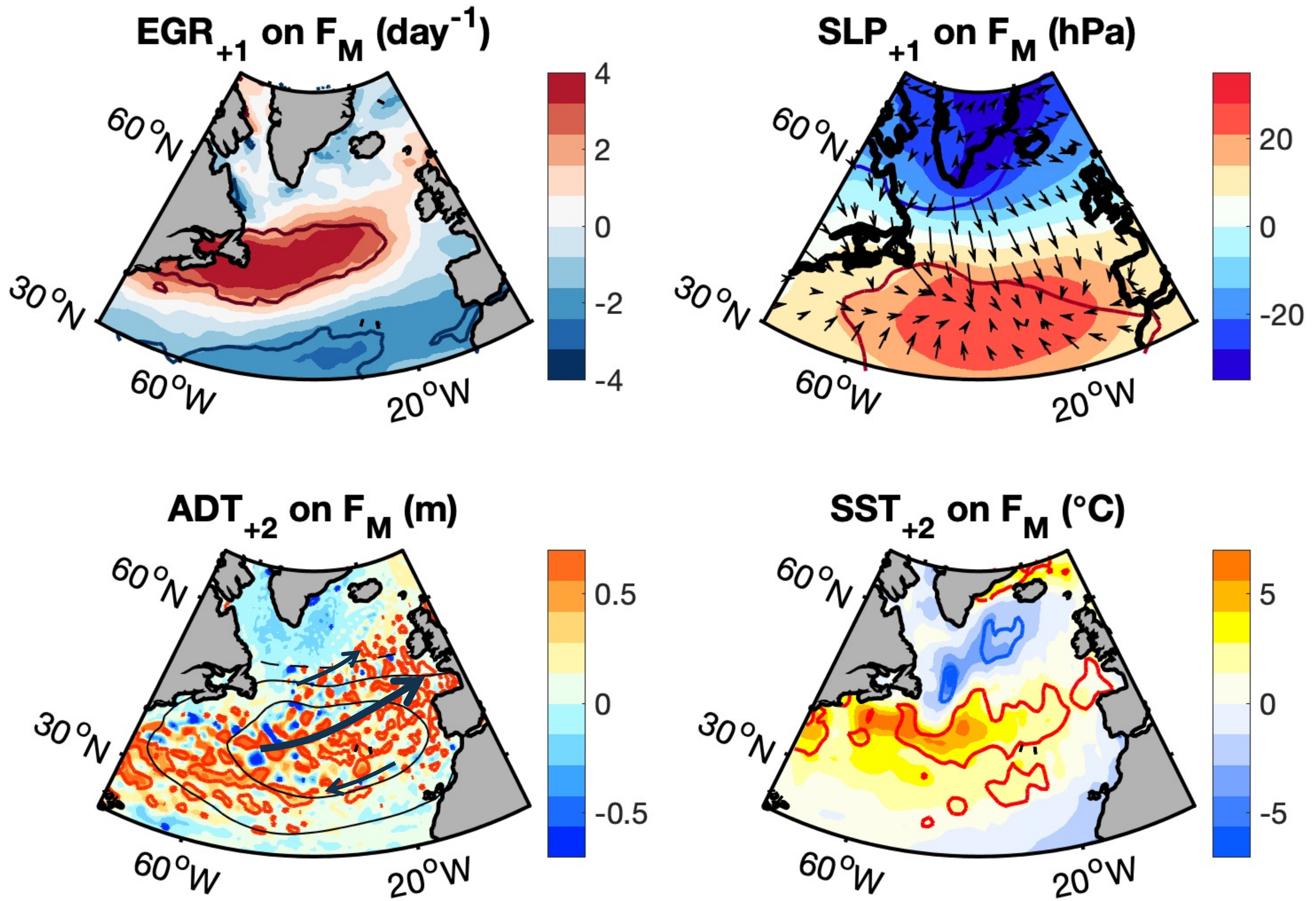
Regressions in winter (January-March) on the NAO from the preceding summer (NAO_S); ΔSST refers to the meridional SST gradient.

Melt-driven events are due to more freshwater in the currents; circulation-driven events are due to a change of the currents.



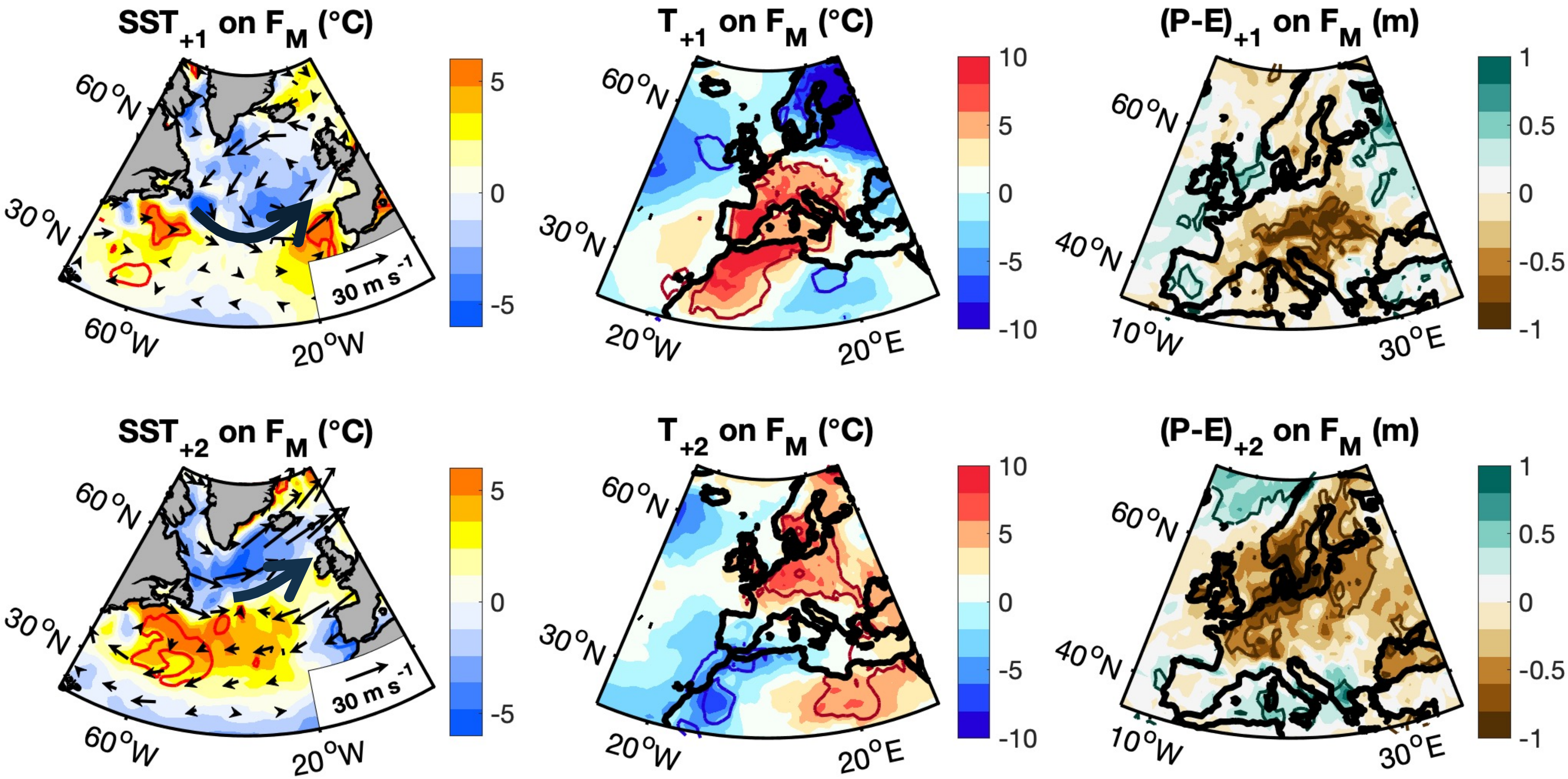
Regressions in the winters following the summer NAO with SSS obtained from mass balance; based on remote sensing and reanalysis data 1979-2019

The sharper SST fronts lead to an increased atmospheric instability and, in turn, a northward shift of the North Atlantic Current.



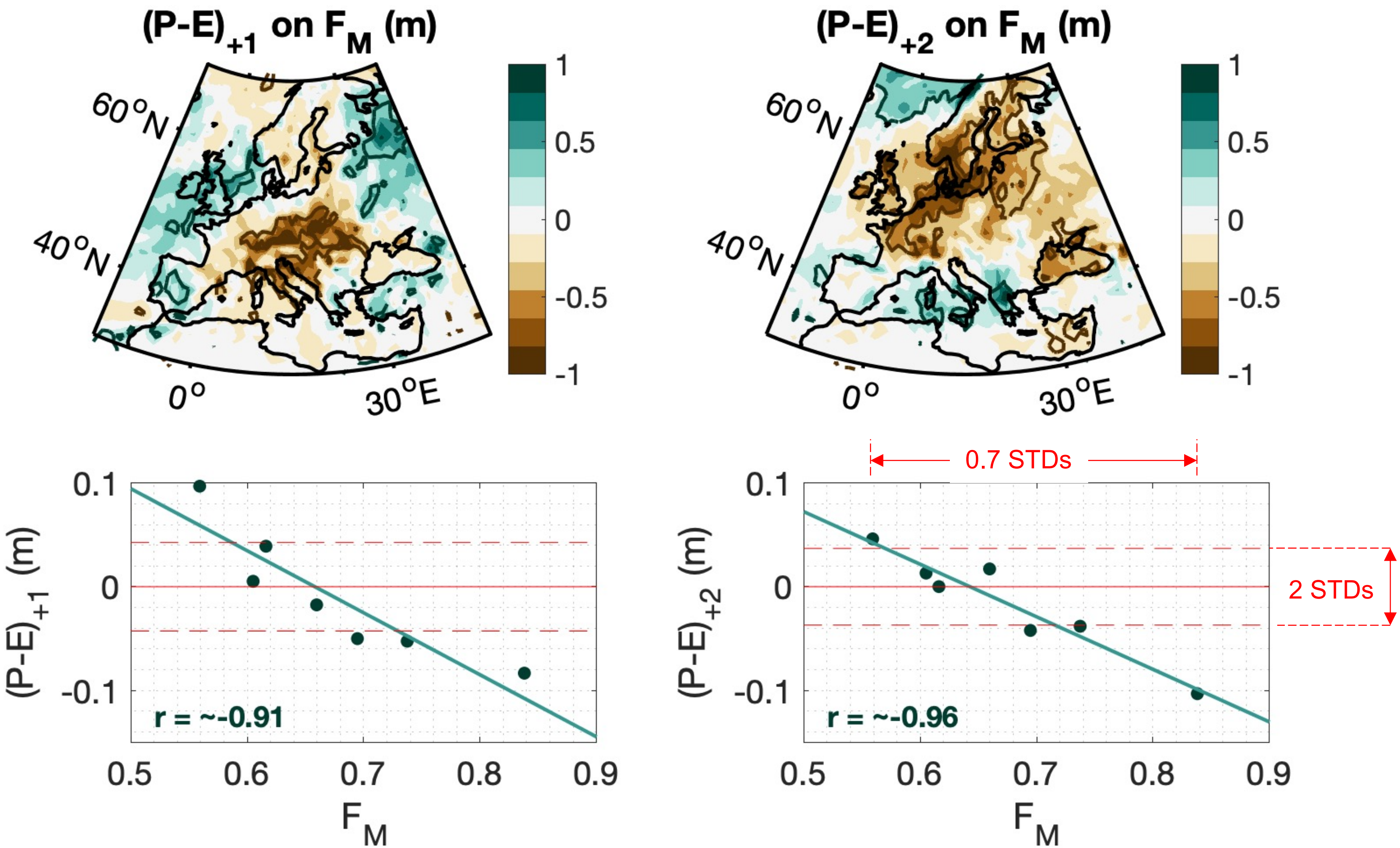
Regressions in winter with EGR and SLP from ERA5, ADT from Copernicus, SST from NOAA

In subsequent summers, the jet stream follows the SST front, giving rise to warmer and drier weather over Europe.



Regressions in summer (May-August) with SST from NOAA, T and (P-E) from ERA5

There is a high sensitivity to small freshwater variations.



Once the freshening exceeds a threshold ($-NAO_S > 0.5$), an additional freshening of 0.6 g kg^{-1} (or 0.7 STDs), is associated with a ~4 STD change in European summer rainfall.

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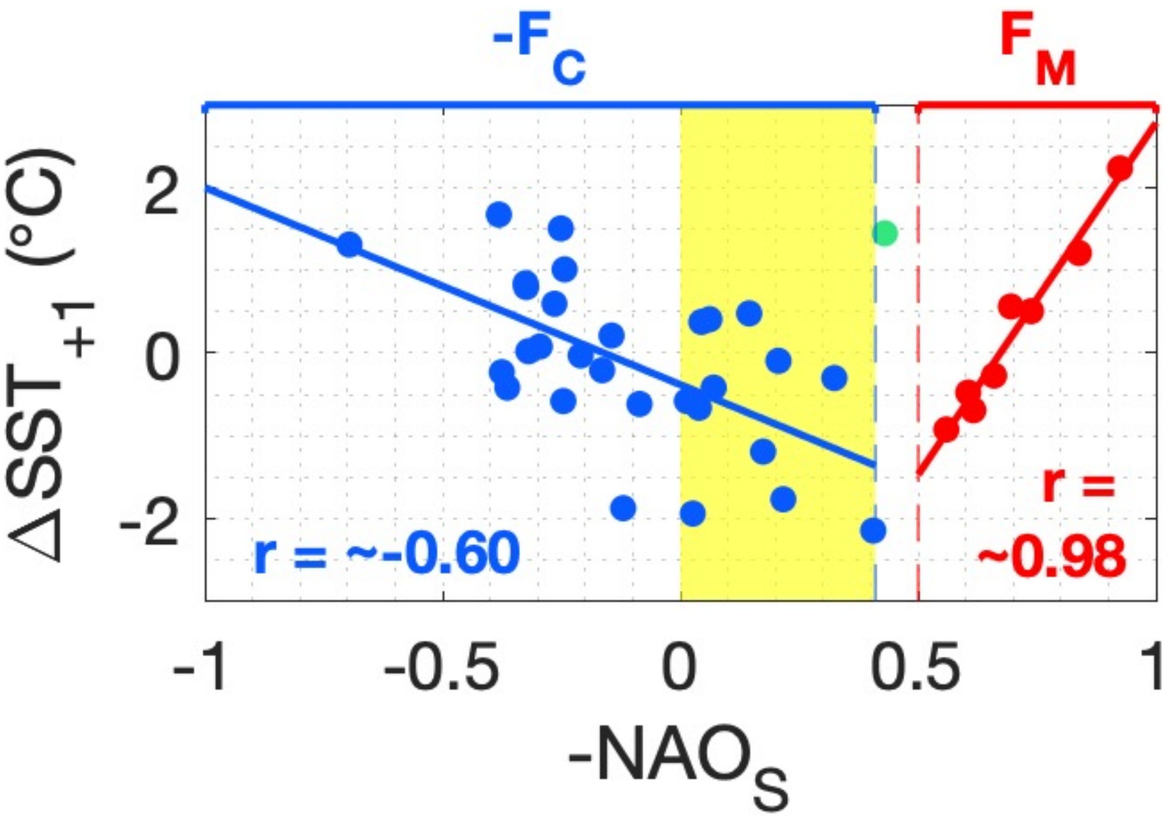
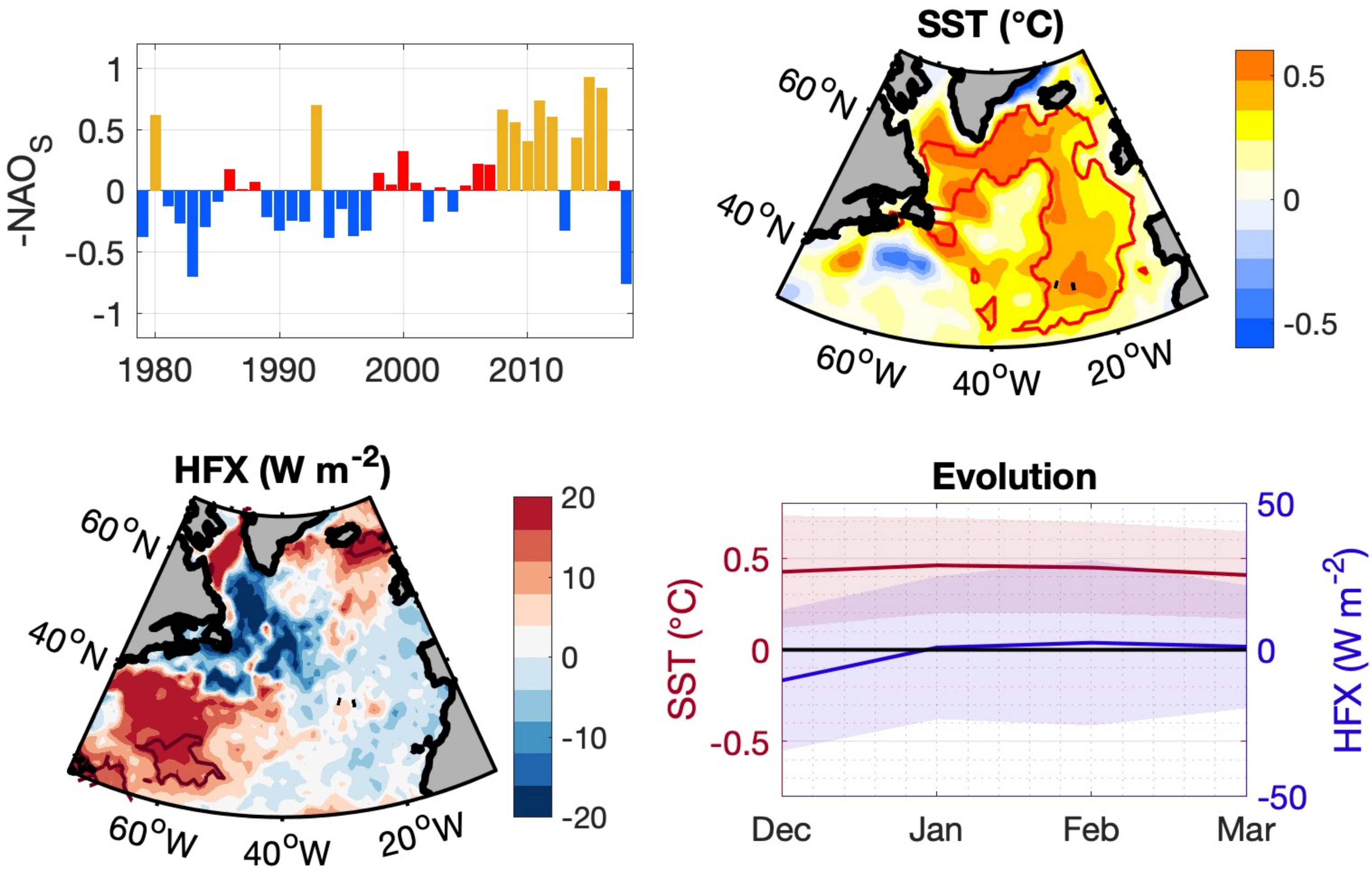
What happens in the absence of strong freshwater events?

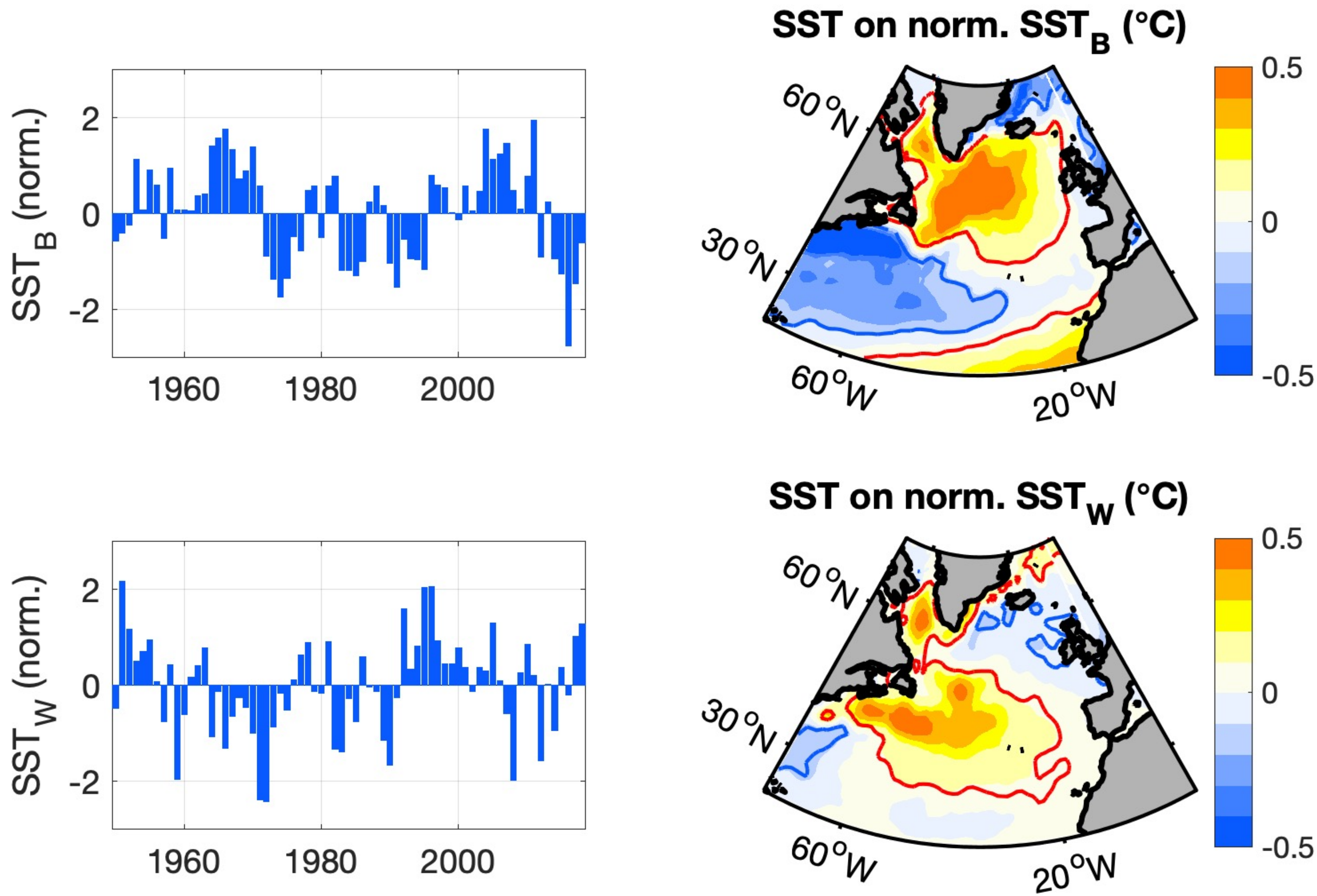


Freshwater modulates the buoyancy-driven northward flow.



Composites and heat budget based on SST from NOAA and ERA5 atmospheric data

Freshwater periods occurred regularly over the last 70 years.

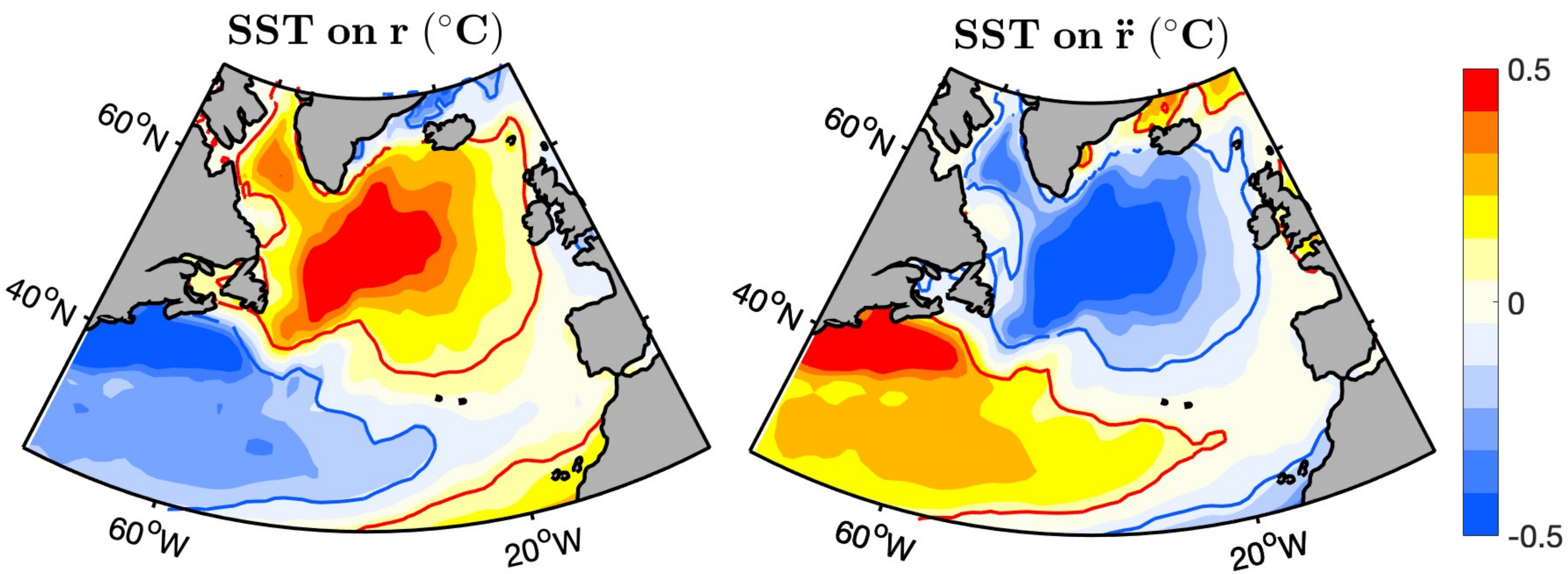


Based on merged NOAA and Hadley SST data in winter (January-March)

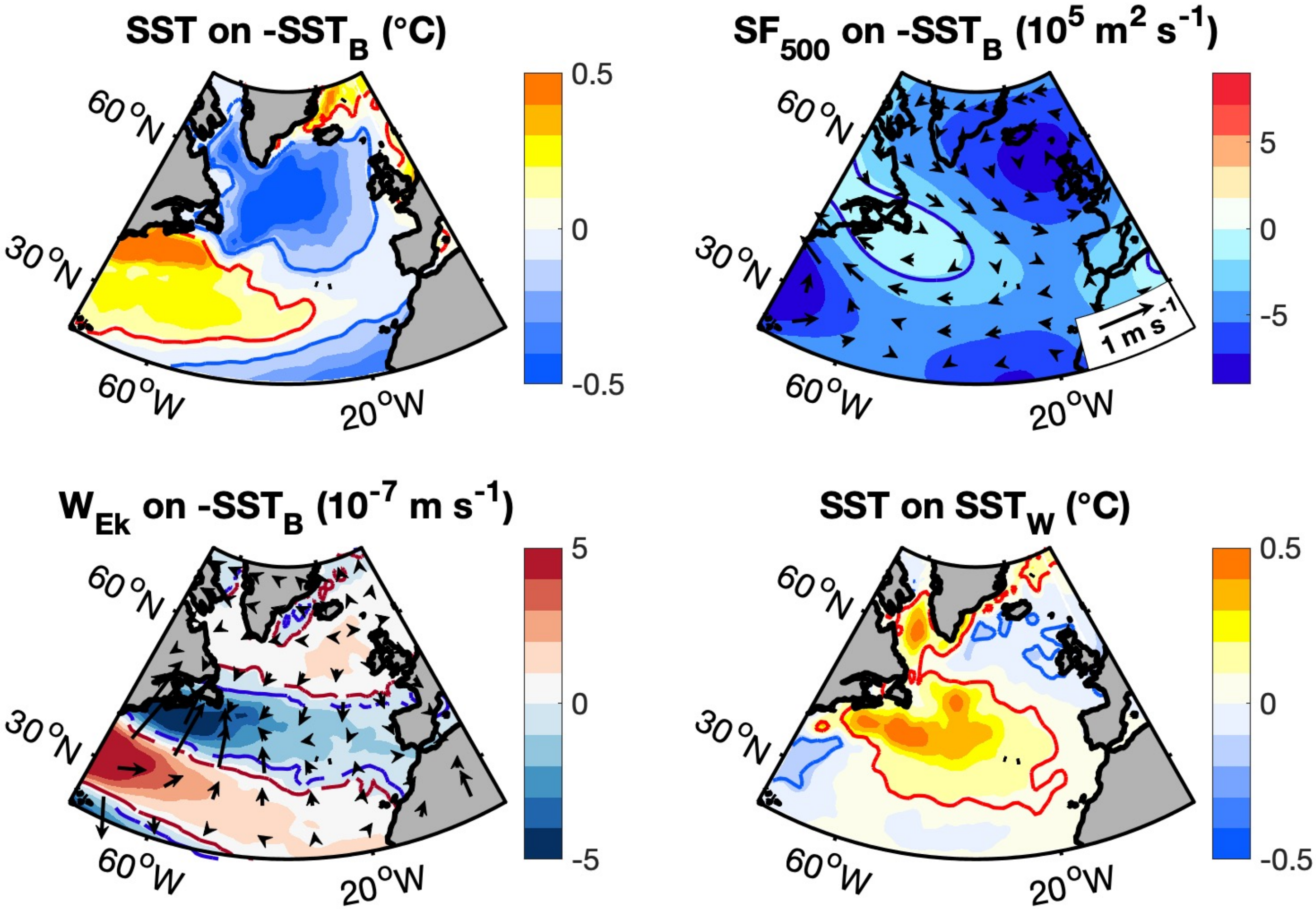
The two SST patterns form a cycle.

$$SST(x,y,t) = r(t)\cdot SST_B(x,y) + s(t)\cdot SST_W(x,y) + SST_R(x,y,t)$$

$$\dot{r}(t) = s(t), \qquad \dot{s}(t) = -r(t)$$

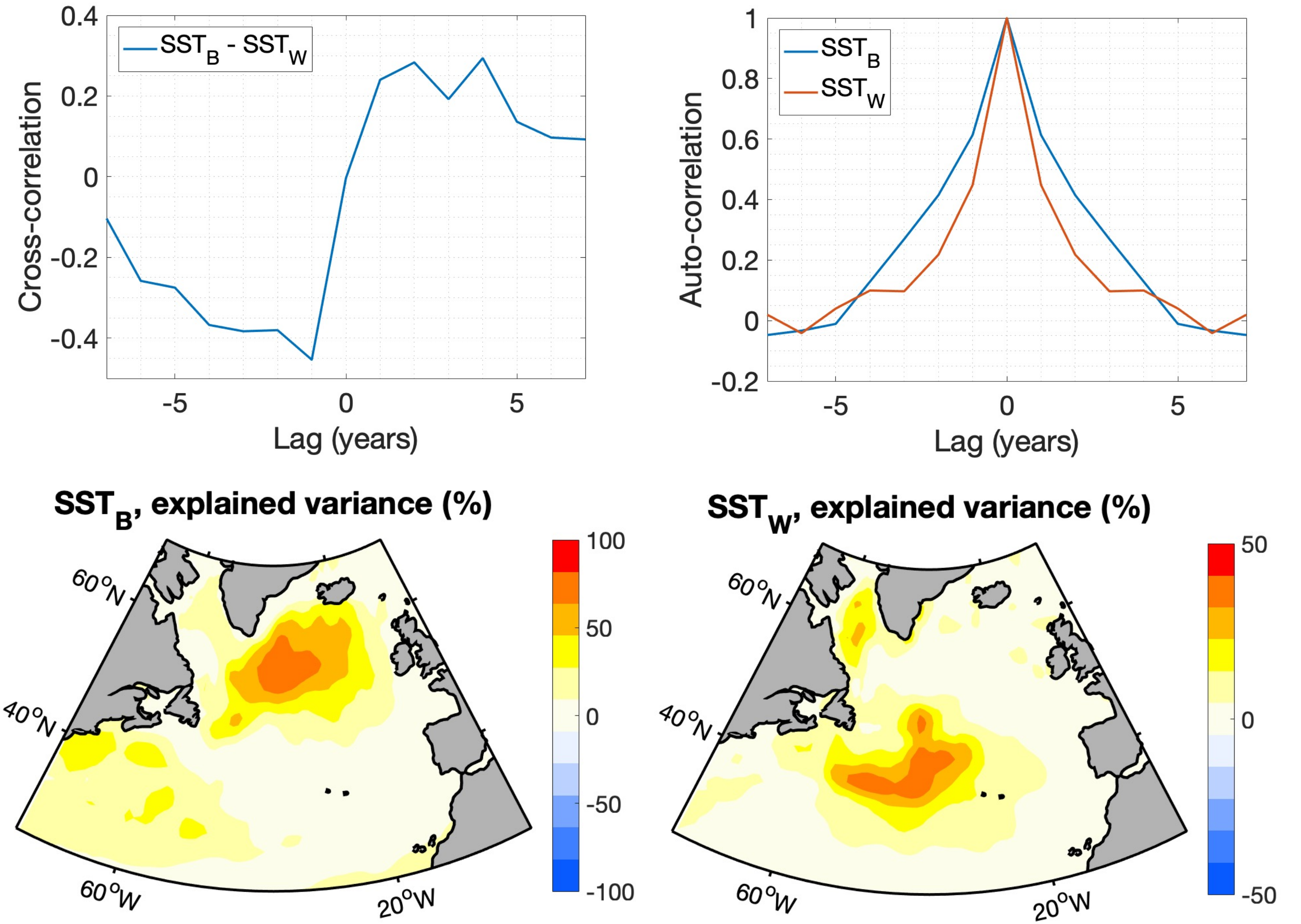


The wind-driven pattern emerges from the atmospheric feedback to the buoyancy-driven SST pattern.

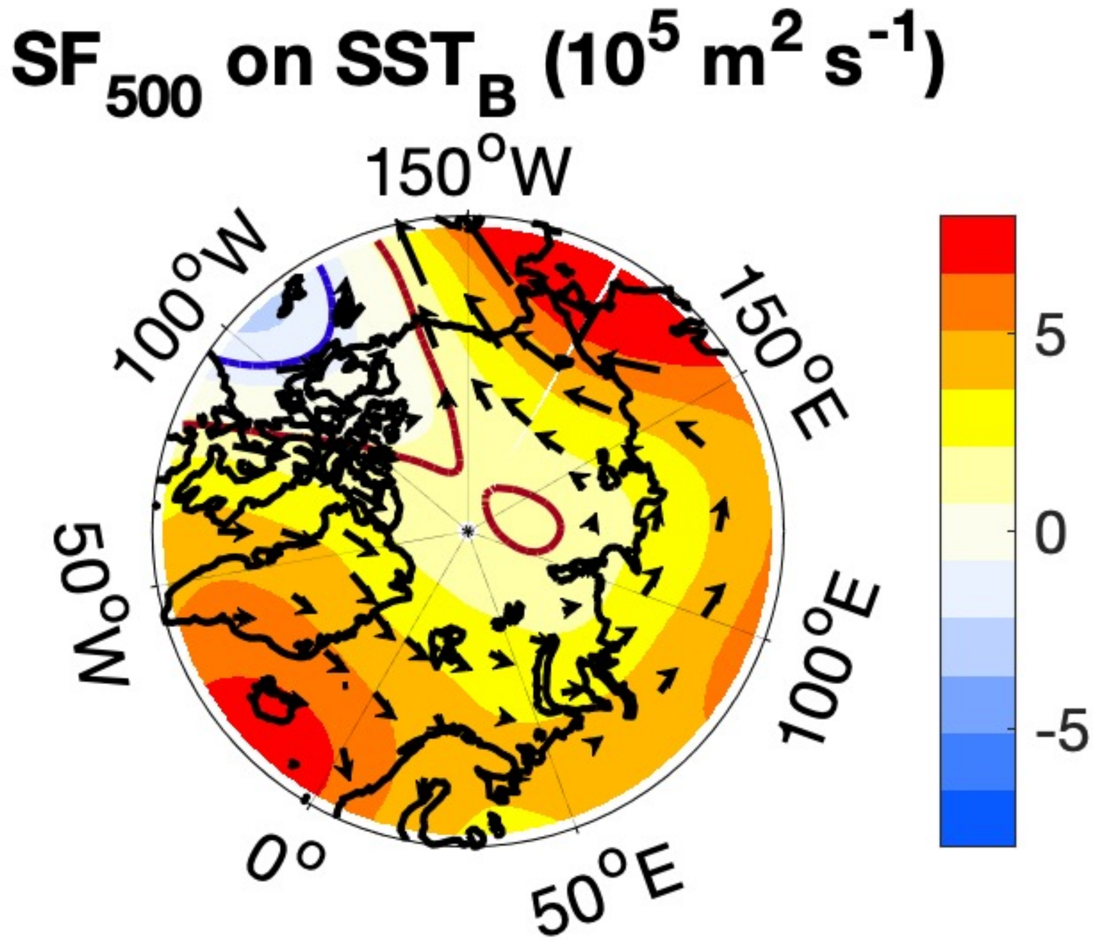


Regressions based on 50 SST-forced ensemble simulations with ECHAM5 over 40 years; SF is the atmospheric stream function at 500 hPa.

The cycle explains over 50% of the SST variance in the subpolar region.

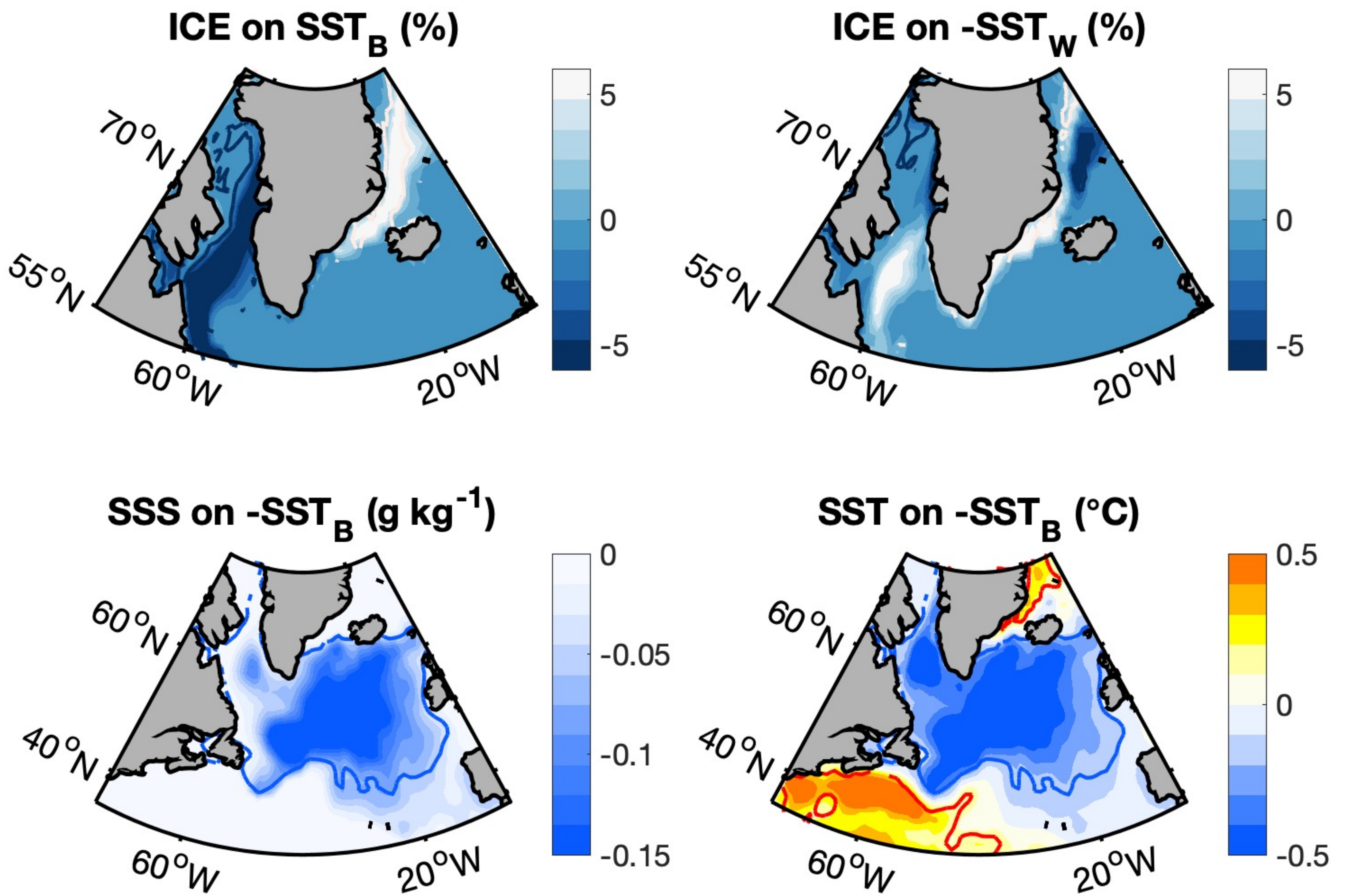


The buoyancy-driven SST pattern promotes a more cyclonic (or less anti-cyclonic) circulation over the Arctic.



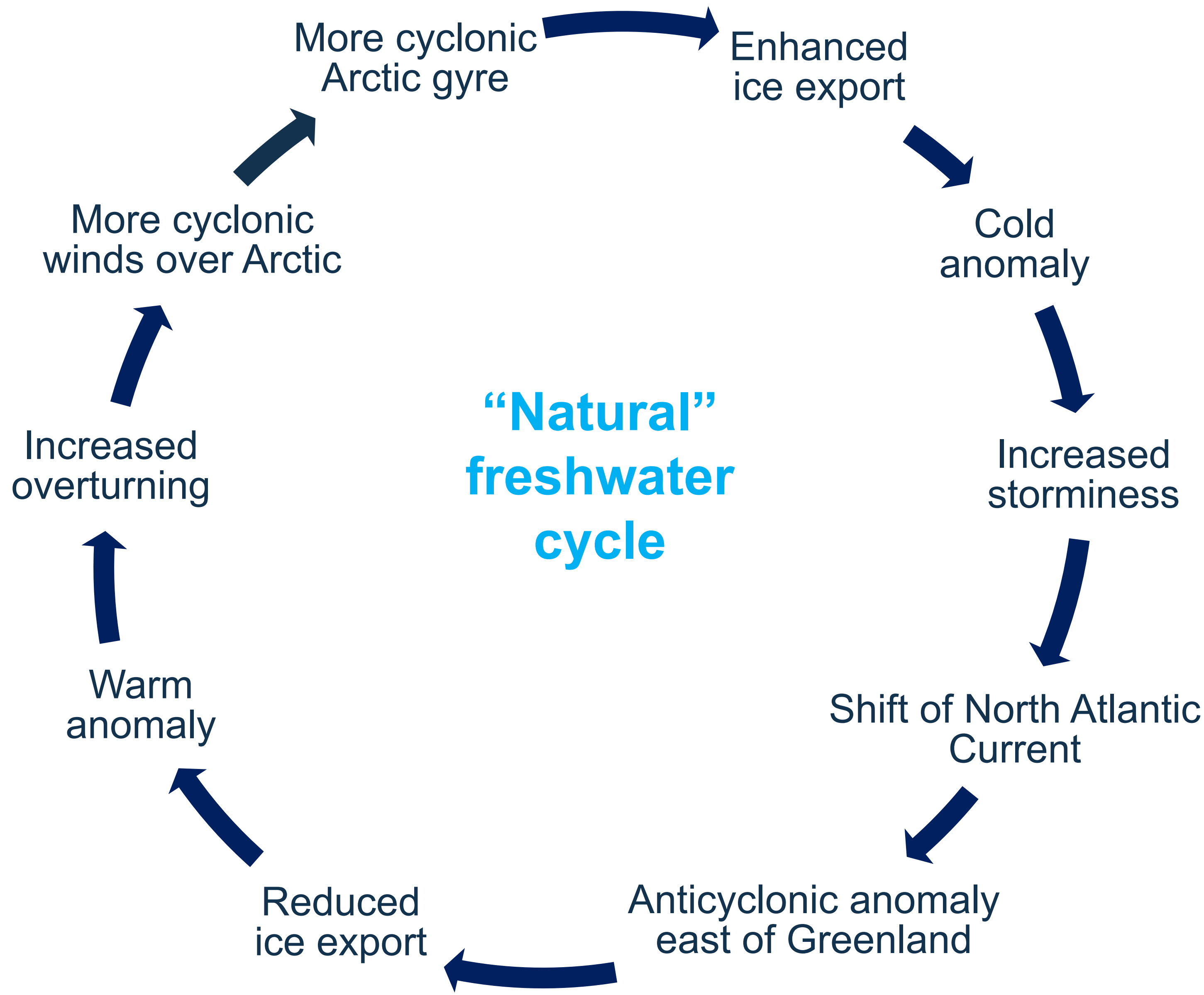
Based on 50 SST-forced ensemble simulations with ECHAM5 over 40 years; using the SST pattern in the North Atlantic, south of 65 N (not in the Arctic).

The cycle is modulated by Arctic sea ice export.



Based on ice concentration data from NOAA, 1979 – 2020

Summary of the freshwater cycle.



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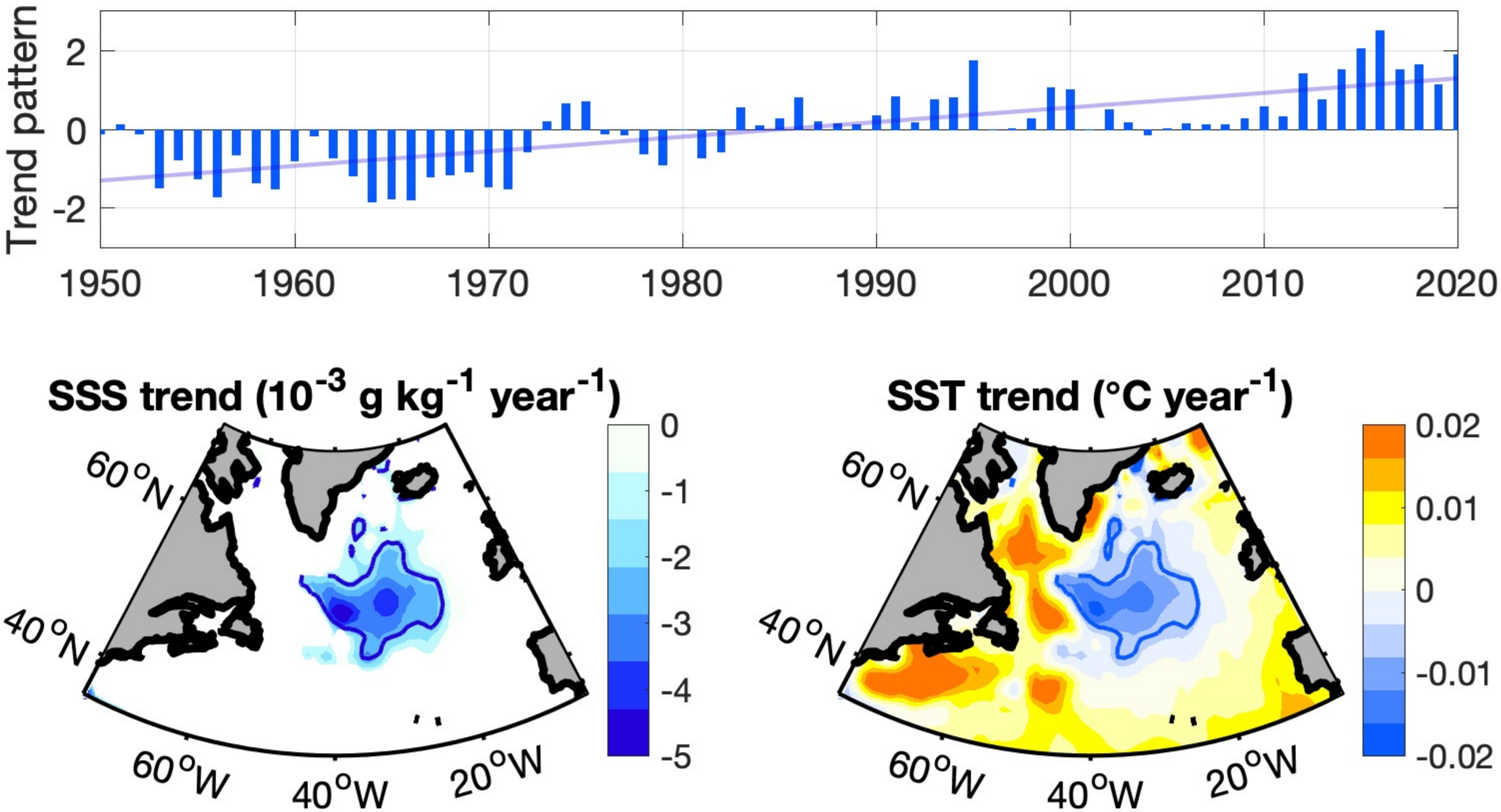
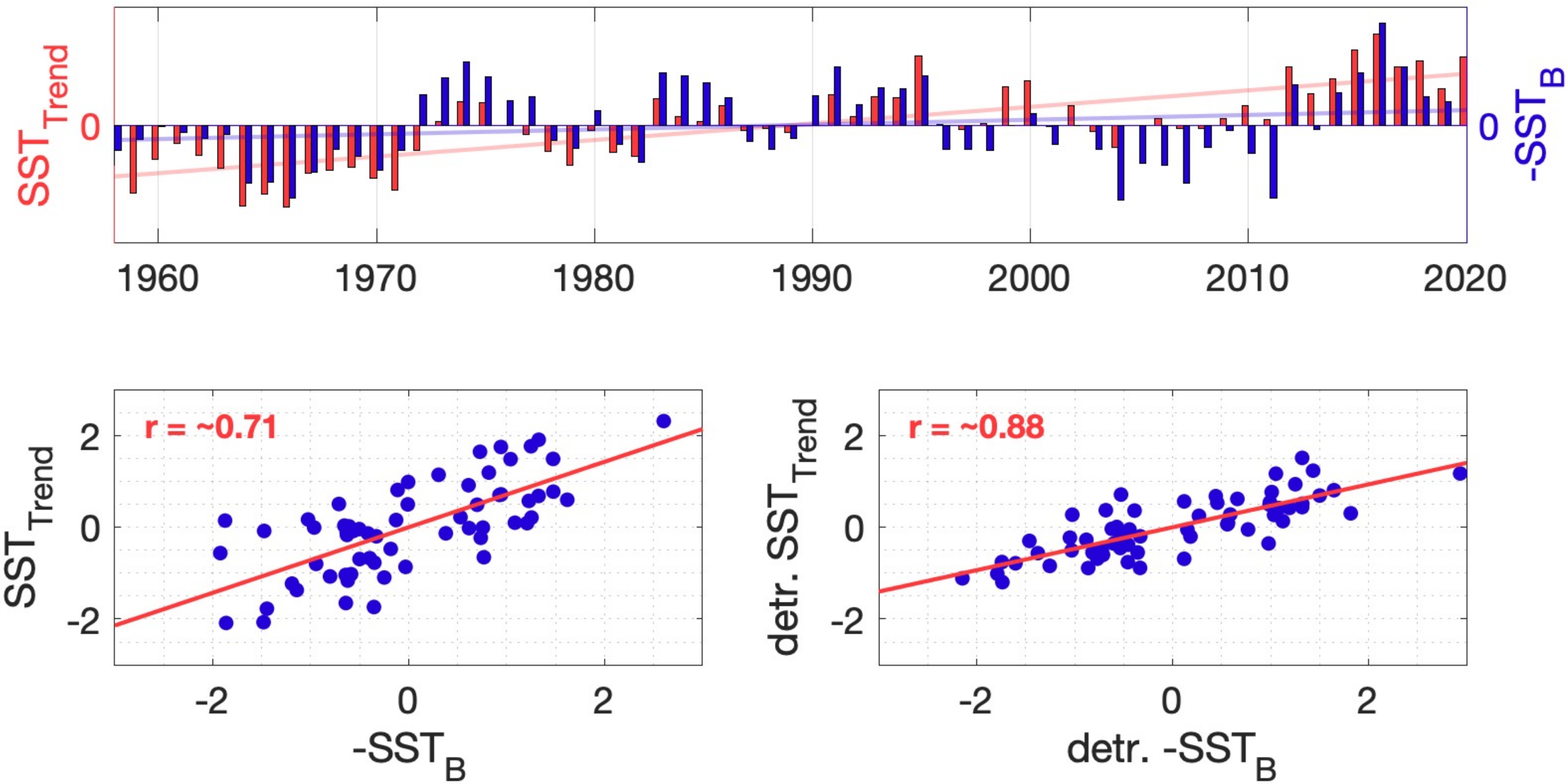
Over the last 70 years, the surface freshening has increased.



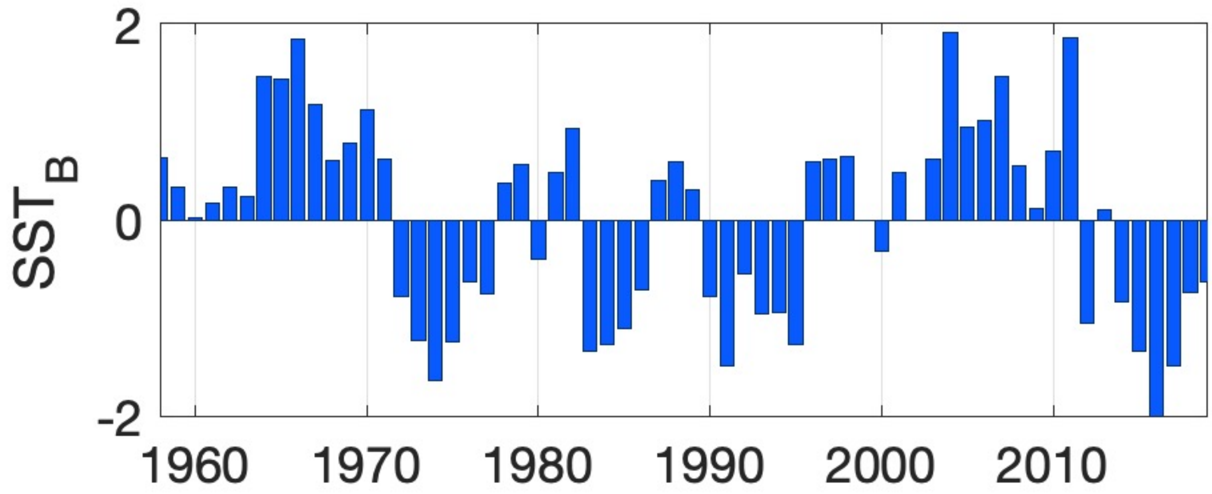
Trend in winter, with SSS obtained from surface mass balance

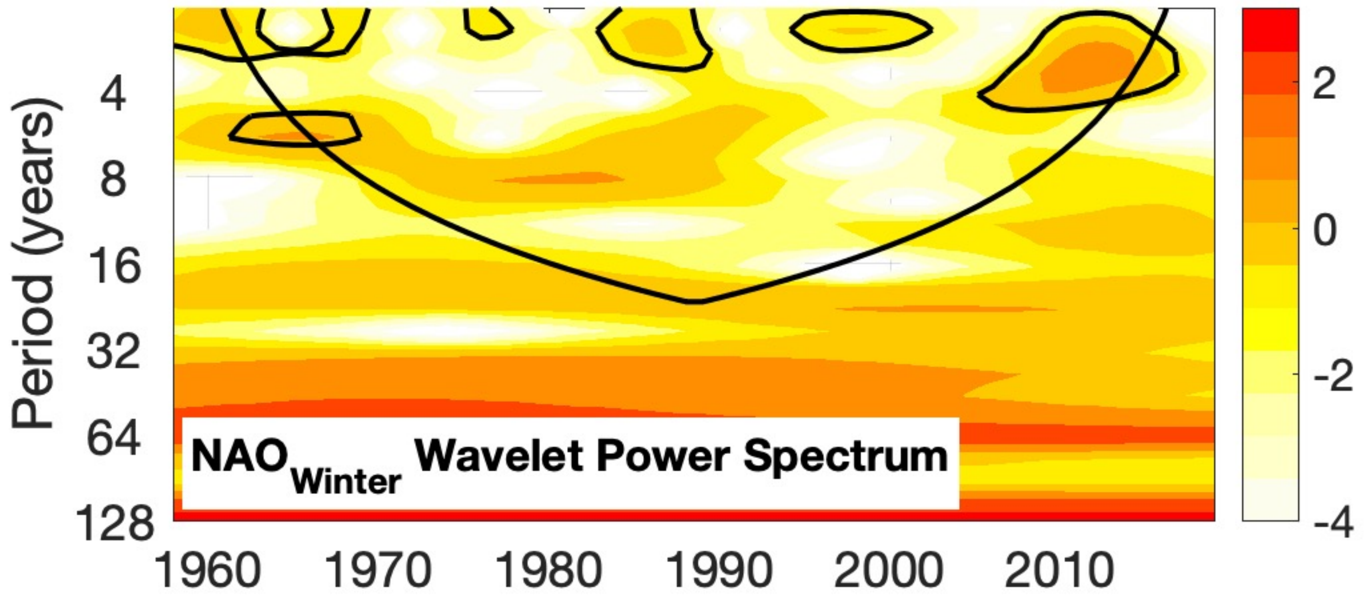
Since the freshwater trend pattern is highly correlated with the natural freshwater pattern, it interferes with the cycle.



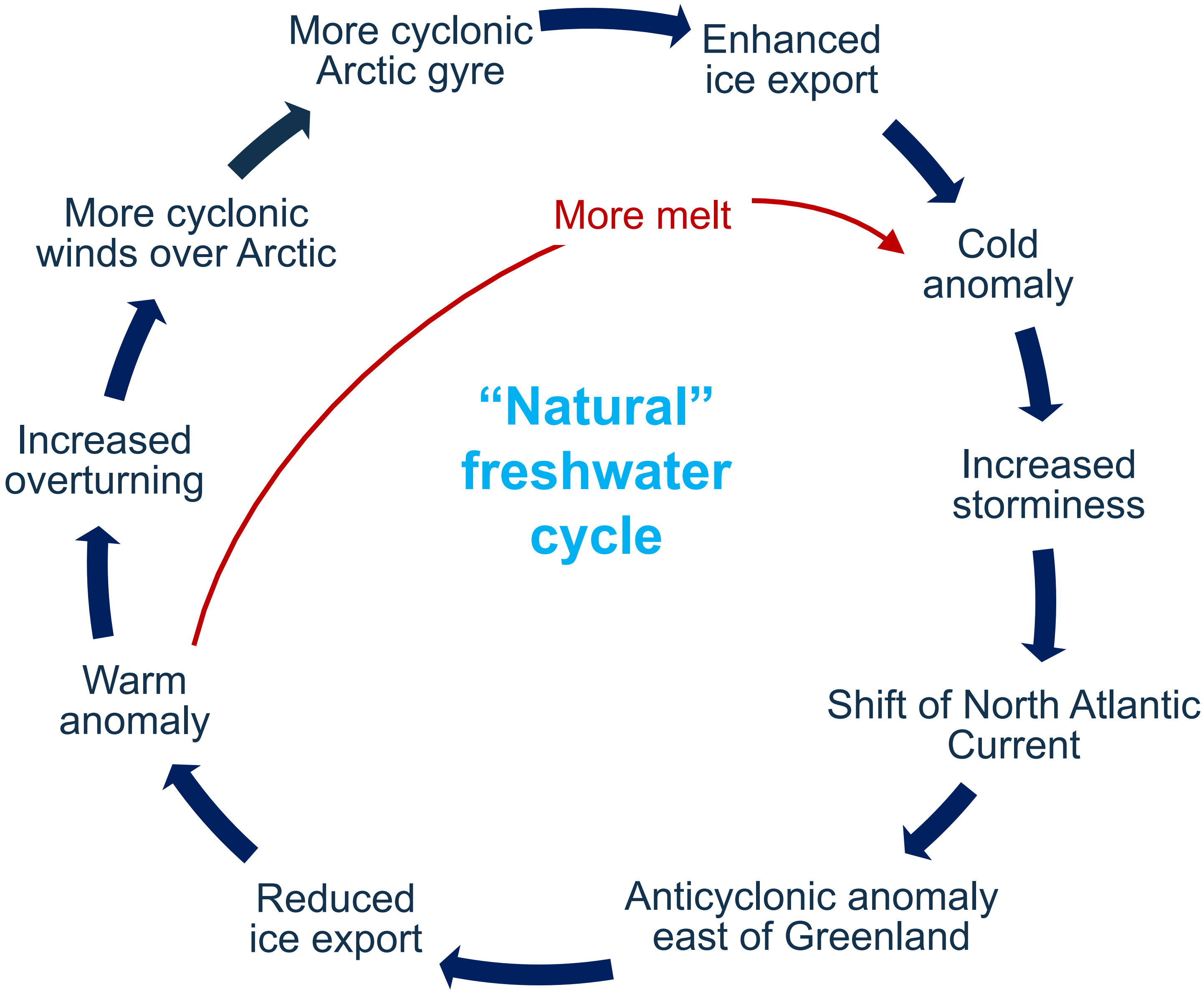
The circulation-driven freshening has buffered the melting.

The interference with melting has increased the frequency and amplitude of the freshwater cycle.

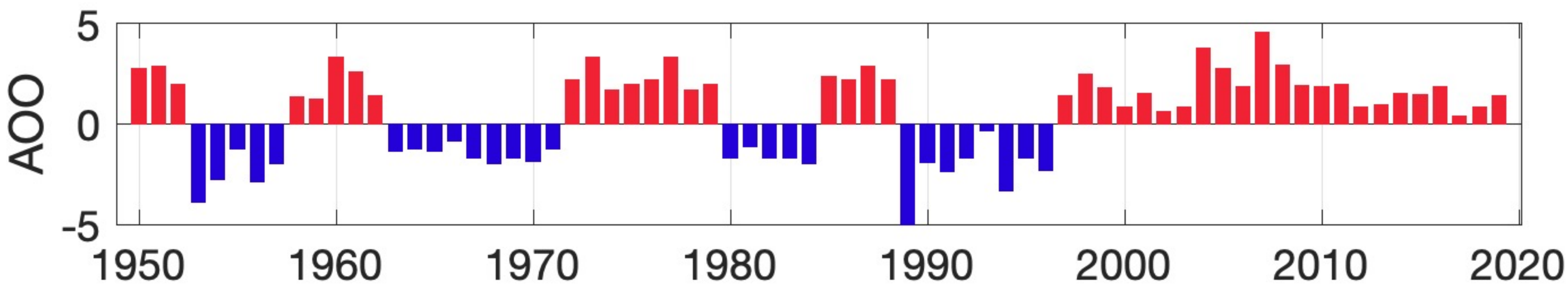




Increased melting has lead to a shortcut, skipping steps.



The Arctic gyre has been in an anti-cyclonic regime and accumulated freshwater for over 20 years.



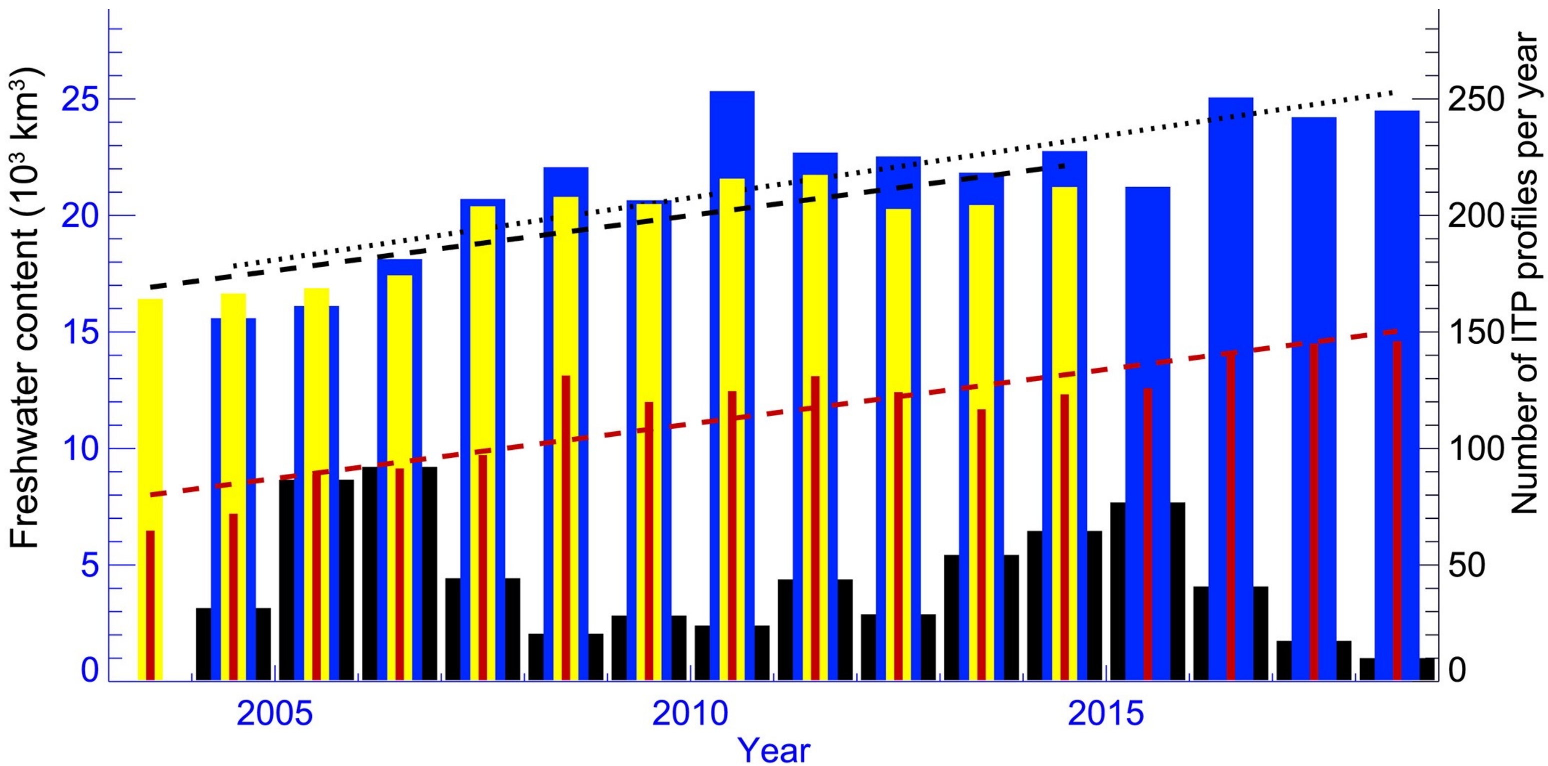
Obtained from the Beaufort Gyre exploration project

Anti-cyclonic regime (pos. AOO):
Freshwater accumulates in the Arctic.

Cyclonic regime (neg. AOO):
Freshwater is released.

Proshutinsky and Johnson, 1997; Proshutinsky et al., 2015; 2019

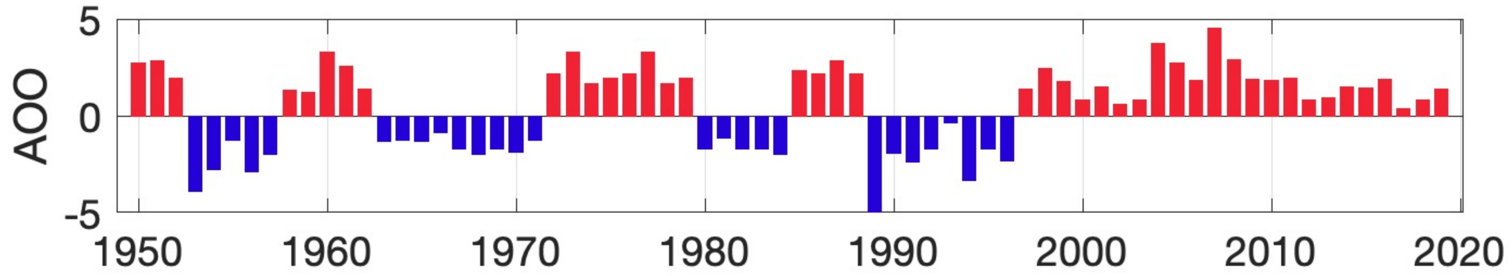
The Beaufort gyre has now been anticyclonic for over 20 years and accumulated freshwater.

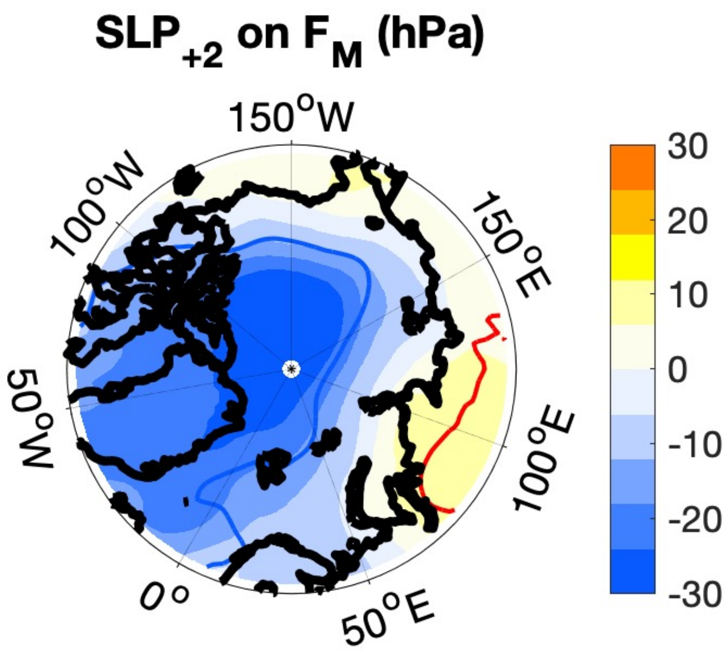


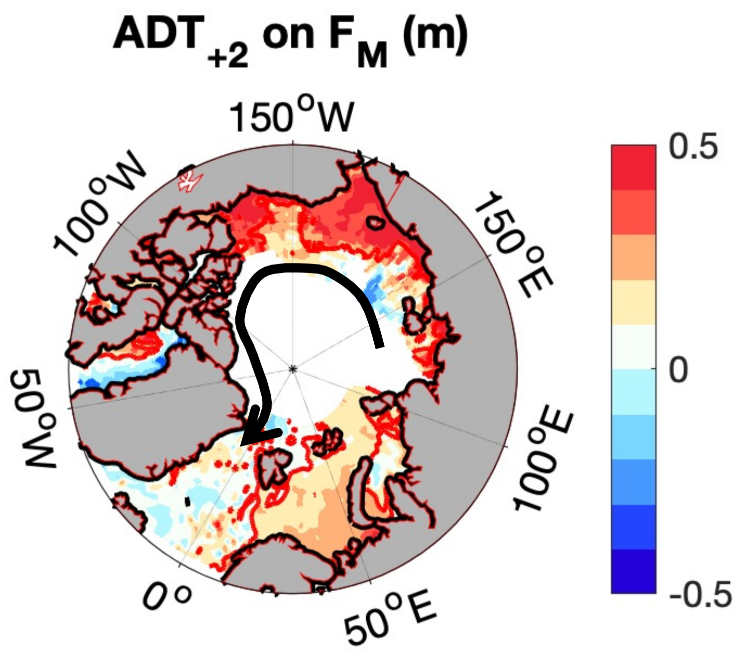
From 2003 to 2018, the freshwater content increased by ~40%.

Proshutinsky et al. 2019

Melt-induced events give rise to a more cyclonic Arctic gyre.







Regressions in summer with SLP from ERA5 and ADT from Copernicus

Conclusion

- Freshwater is a key driver of the North Atlantic climate variability.

  Oltmanns et al. 2020; Oltmanns et al. in review

- Melting has interfered with the circulation-driven oscillation, leading to more intense and more frequent extremes.

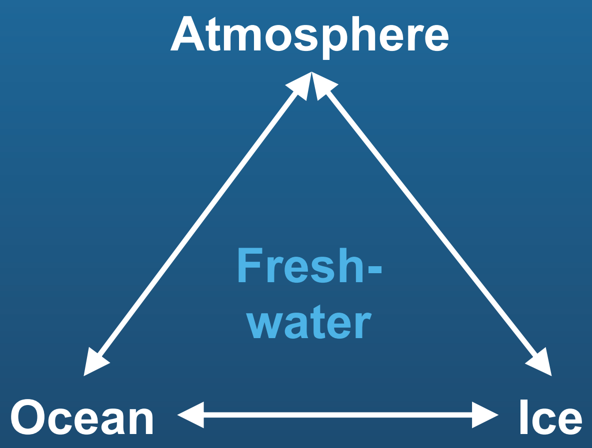
  Oltmanns et al. in prep.

- There is now an increasing chance of a large Arctic freshwater release.

  Oltmanns et al. in prep.

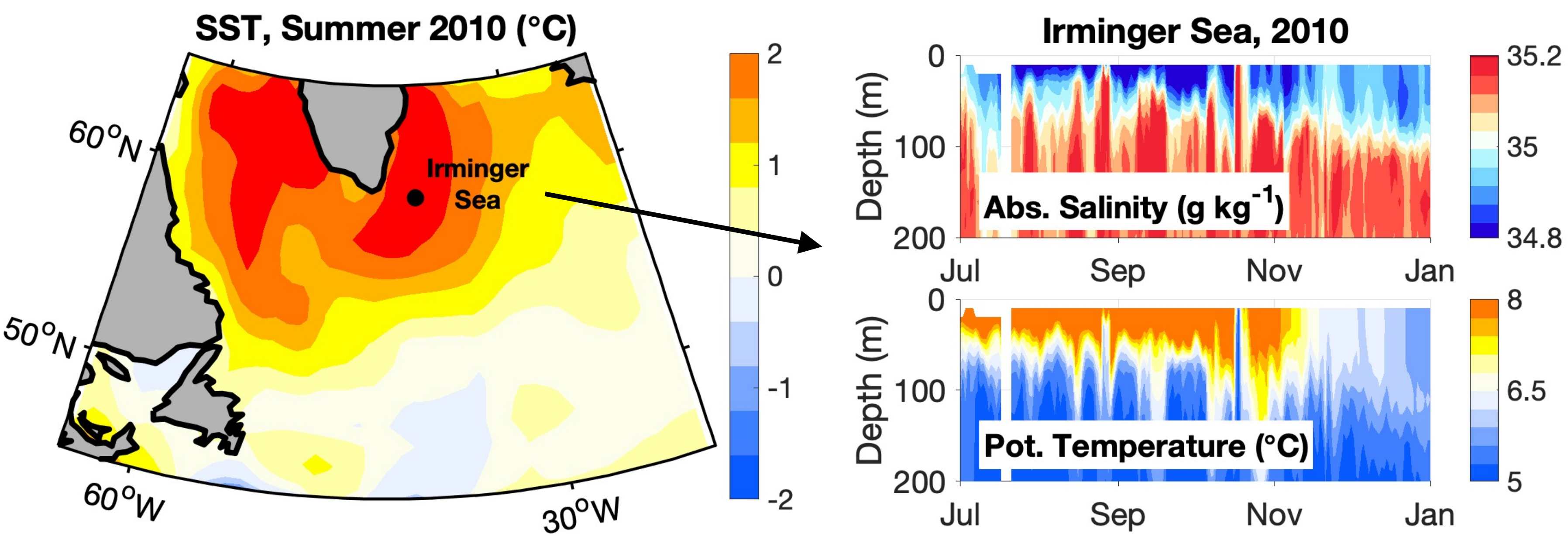
National Oceanography Centre

Thank you



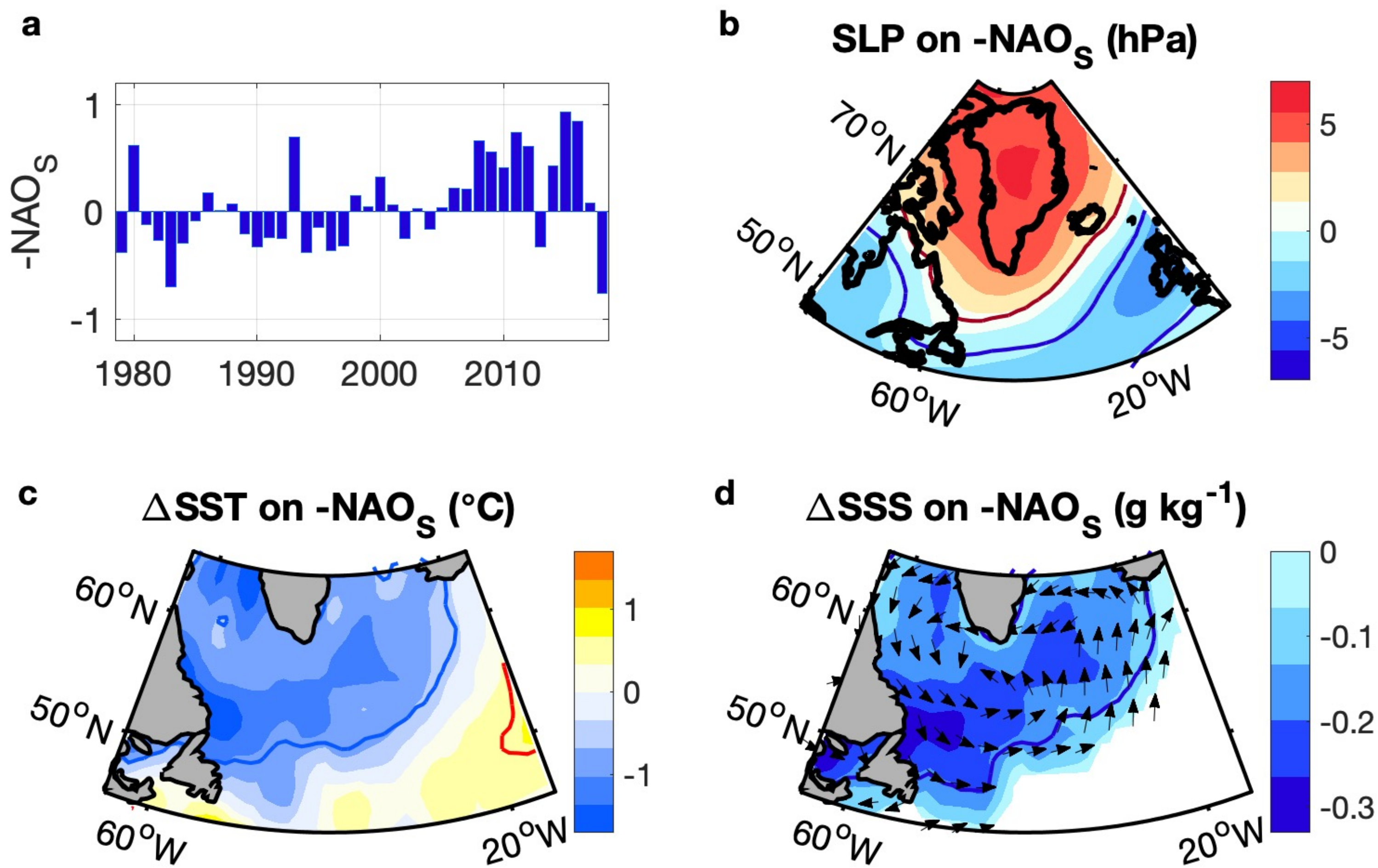
Supplementary Slides

Large freshwater events inhibit vertical mixing leading to changes in the ocean and, in turn, atmospheric circulation.



SST from NOAA; mooring observations from the Irminger Sea

Freshwater determines the temperature that the water is required to have, before it can be mixed down.



Regressions with SLP from ERA5, SST from NOAA and SSS from surface mass balance; ΔSST refers to the cooling rate from summer to winter; ΔSSS is the seasonal freshening.

Scaling analysis of the surface mass balance

Griffies and Greatbatch 2012

1. Start with mass conservation:

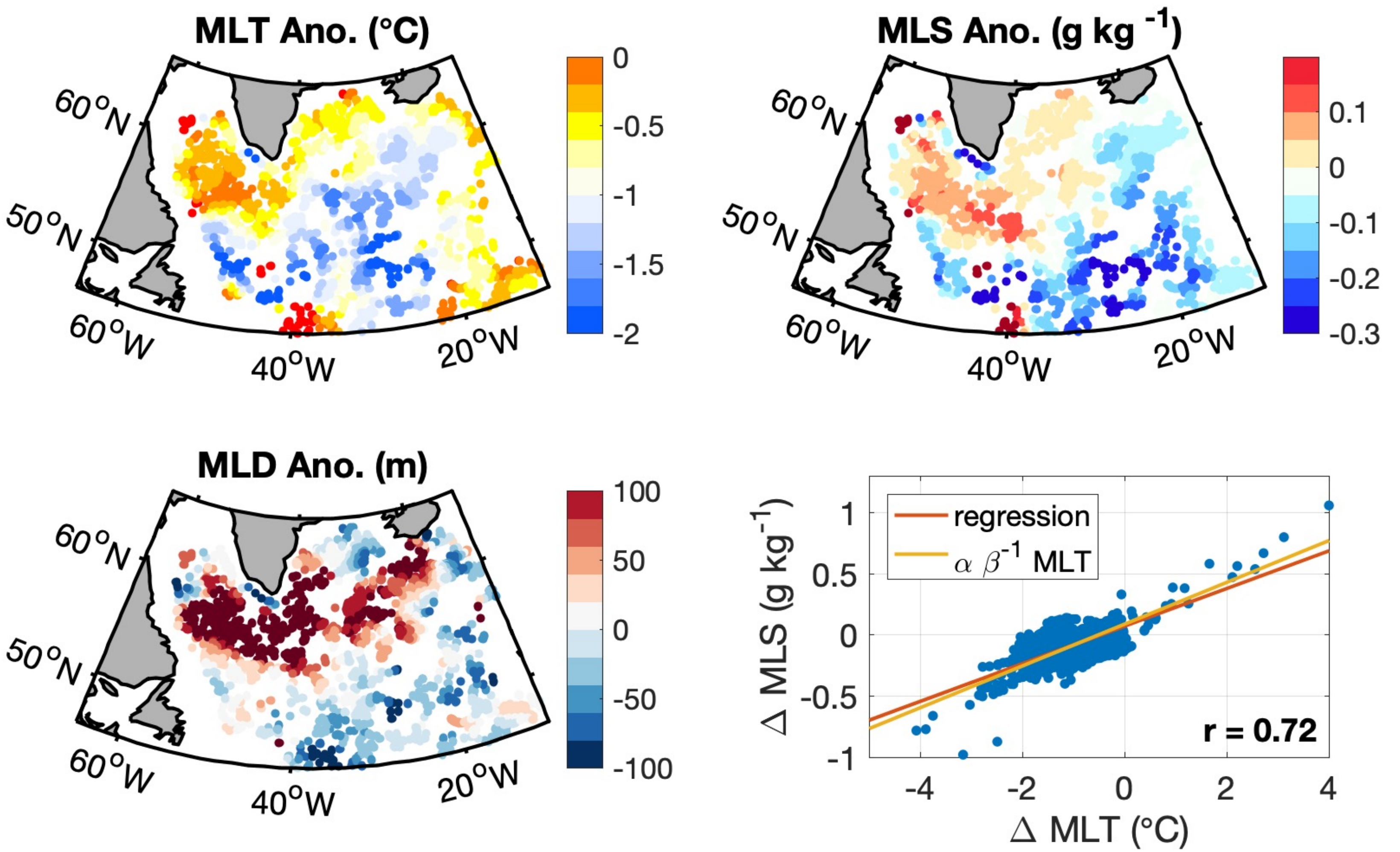
$$\int_{-H}^{0} \left(\frac{\partial \rho}{\partial t} + \vec{u} \cdot \nabla \rho \right) dz = -\frac{B}{g} - M$$

2. Discretise and linearise the equation of state:

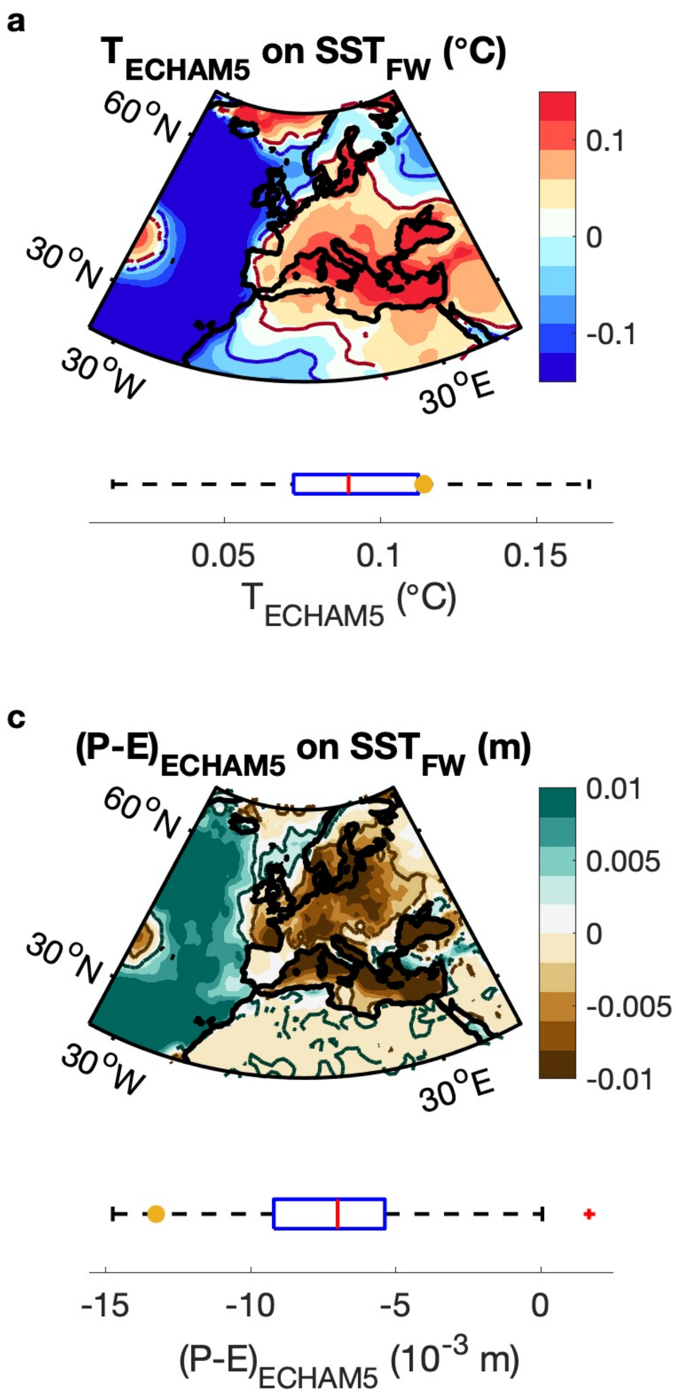
$$\rho \approx \rho_0 [1 - \alpha (T - T_0) + \beta (S - S_0)]$$

3. Regress each term on potential freshwater sources.

In-situ observations support the influence of freshwater on the SST, obtained from the surface mass balance.

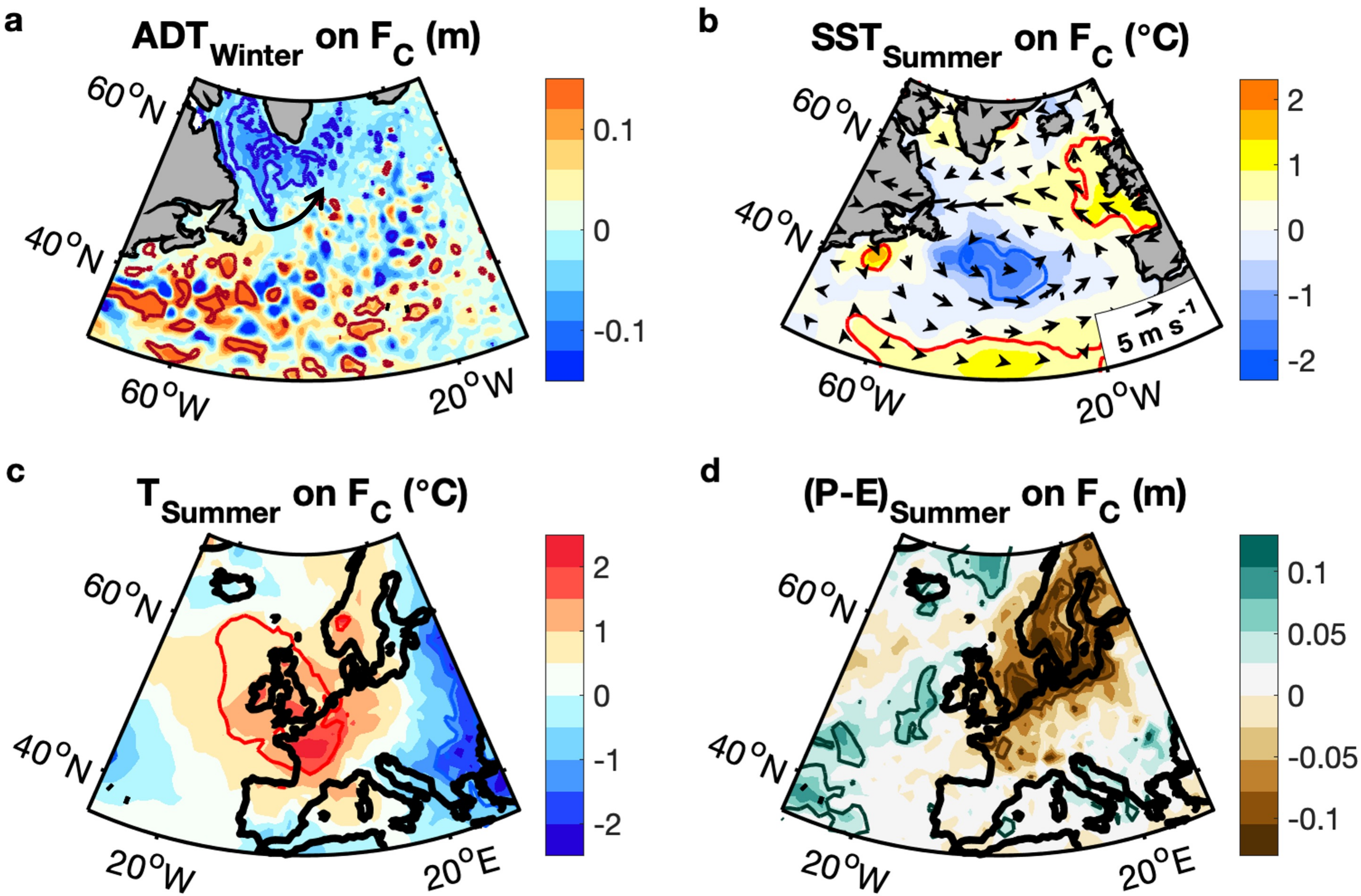


Mixed layer anomalies in the winters of 2015 and 2016, obtained from Holte et al. 2017



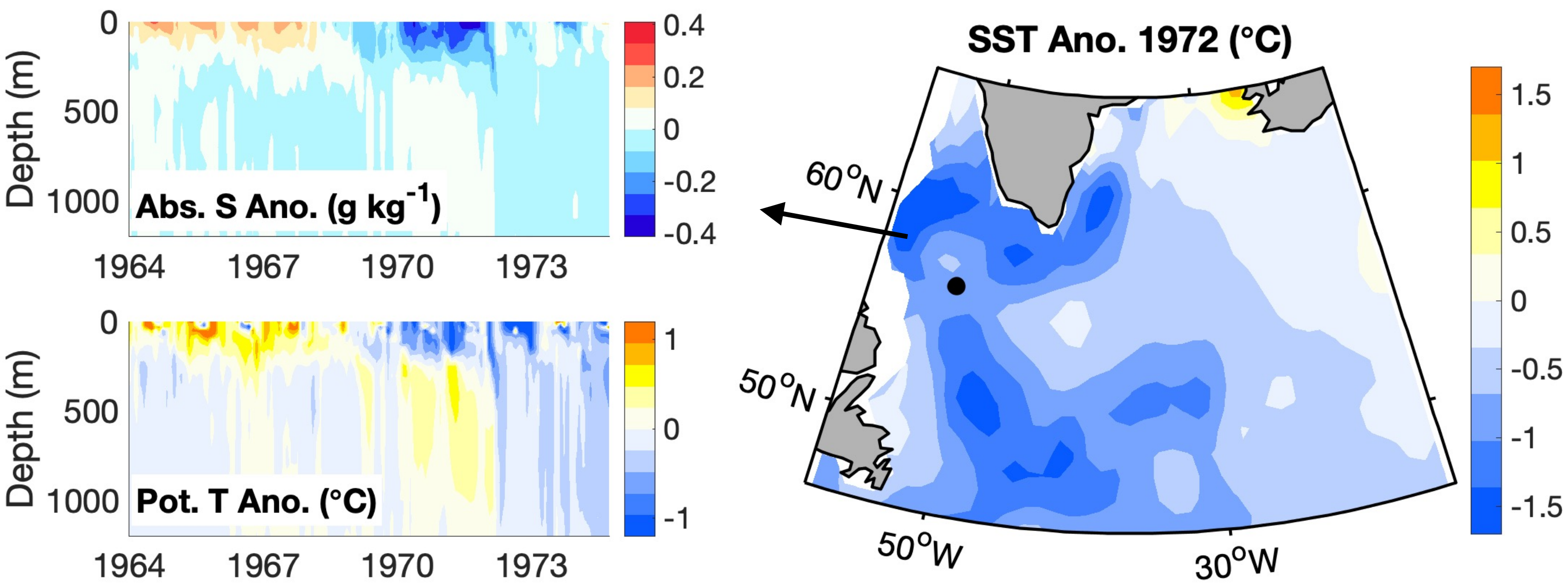
90 SST forced simulations over 40 years confirm the link between the freshwater-induced SST and European summer weather (de-trended).

Circulation-driven events are accompanied by a stronger subpolar gyre circulation and offshore freshwater advection.



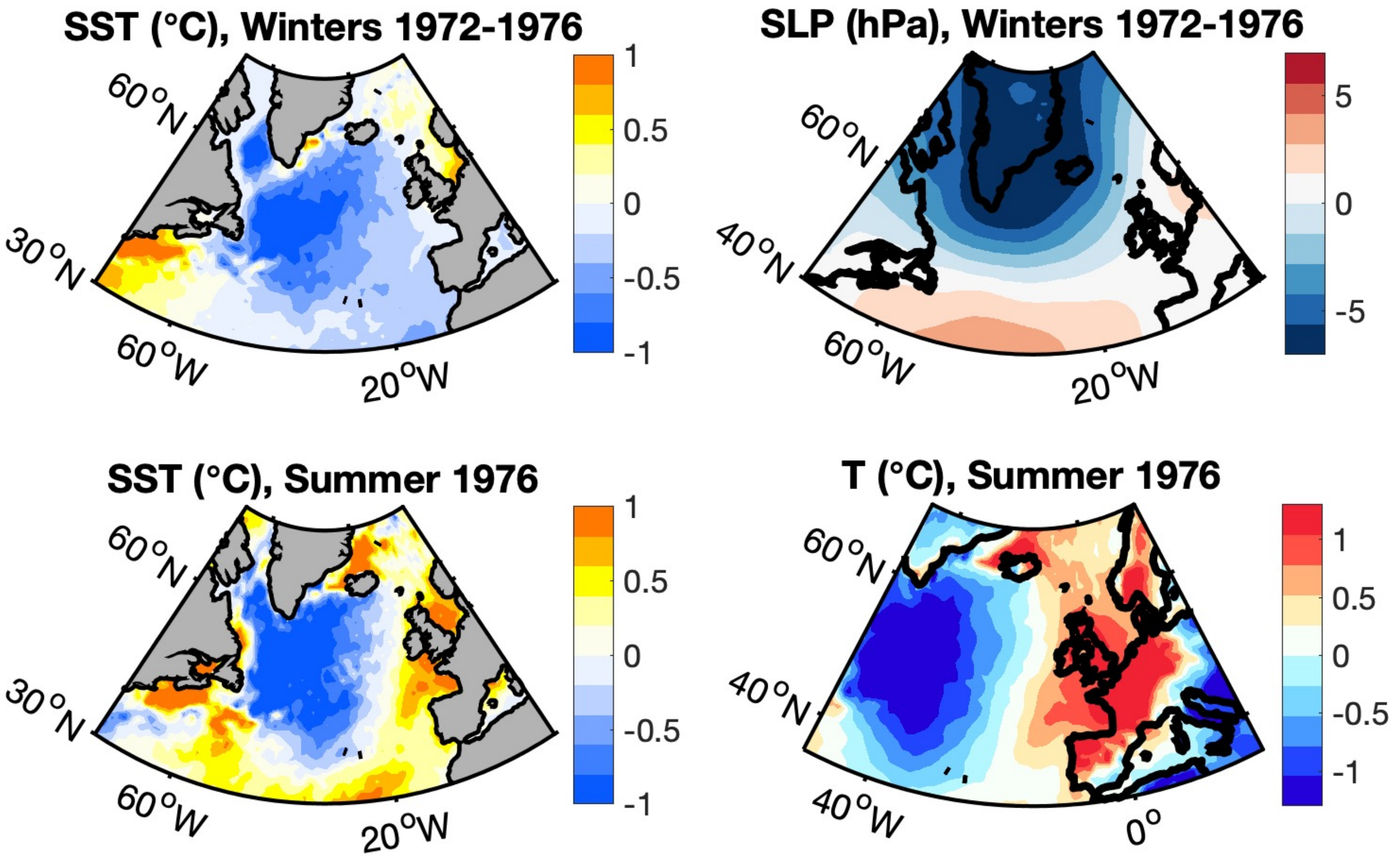
The Great Salinity Anomaly has been attributed to a change in the Beaufort gyre circulation.

Belkin et al. 1998; Haak et al. 2003



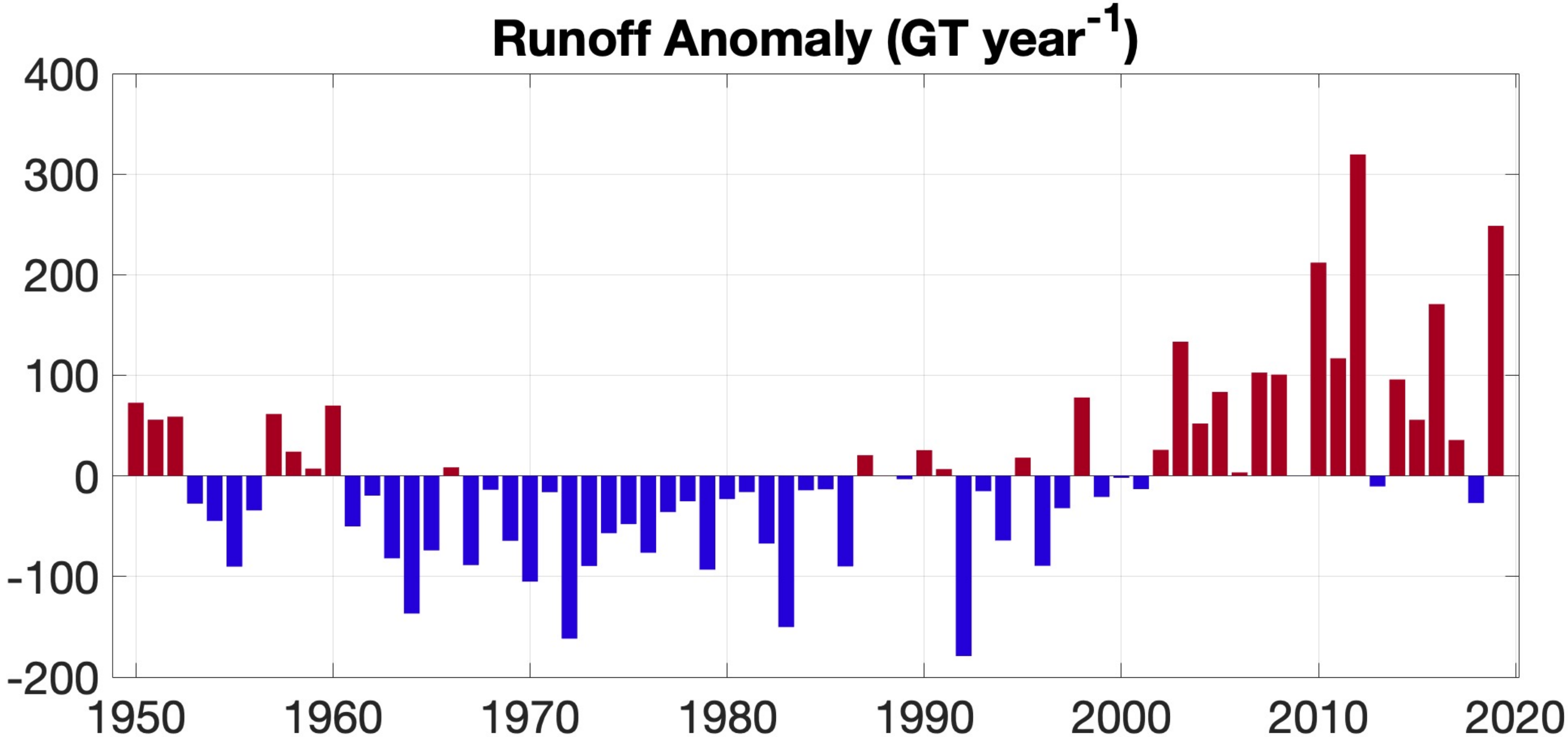
Hydrographic observations from the ocean weather ship Bravo (1964 - 1974); SST from the Hadley Centre (1950 - 2018)

It was associated with extreme winter conditions and followed by an intense summer heat wave over Europe.



Based on ERA5 (1950 – 1979)

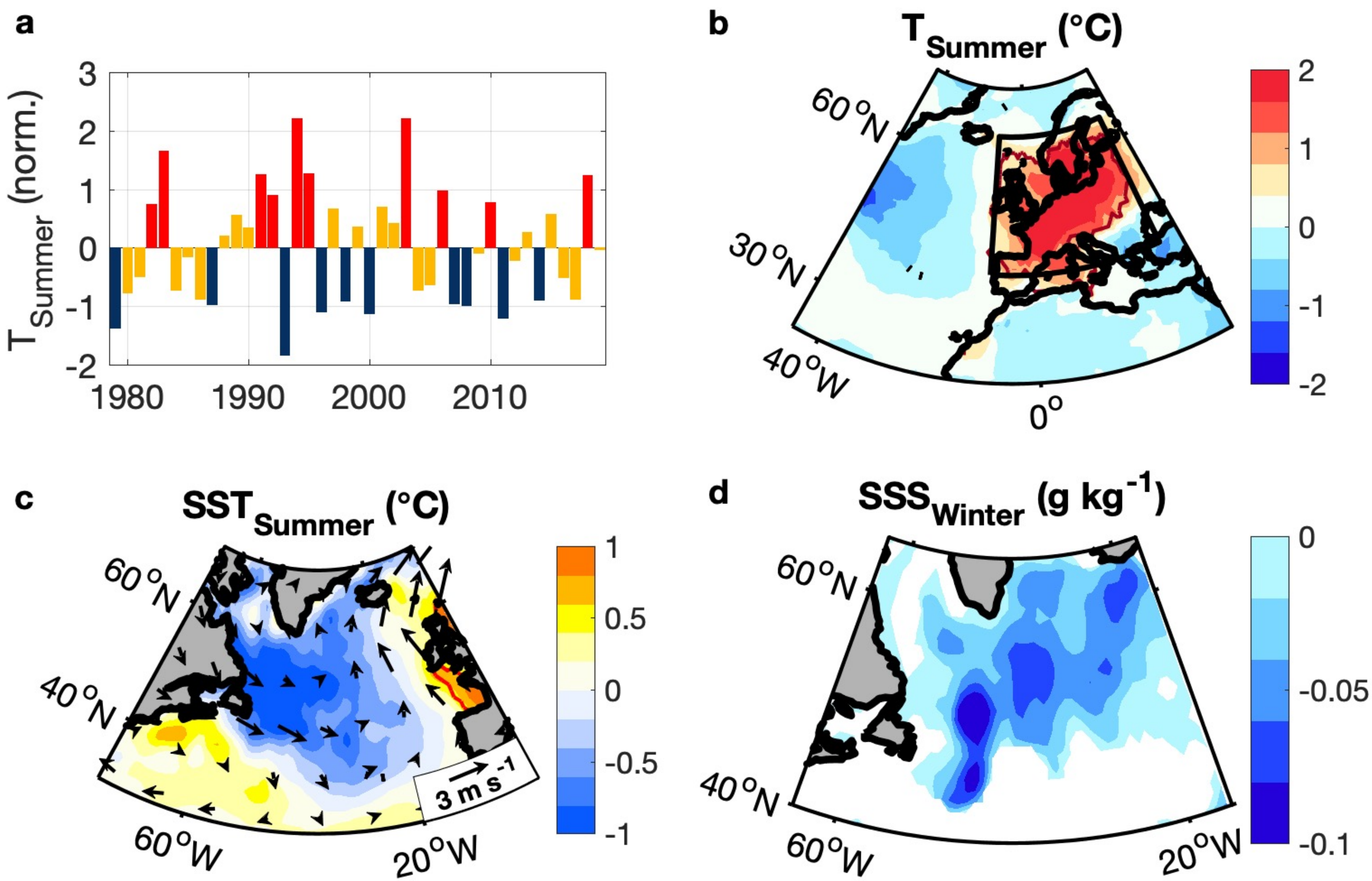
At the time of the Great Salinity Anomaly, Greenland runoff was only ~63% of the average runoff over the last 20 years.



Runoff obtained from MAR

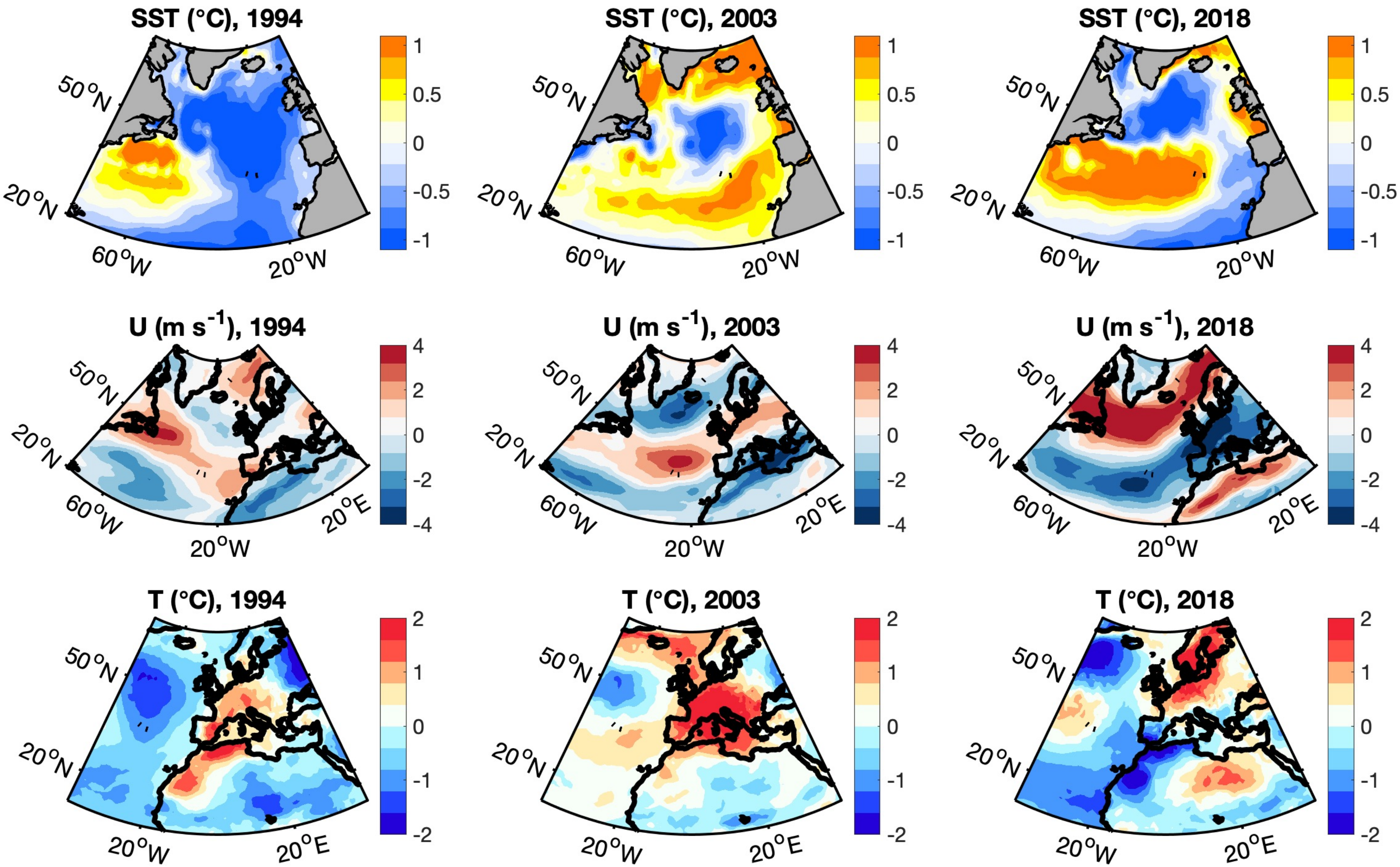
An Arctic freshwater release today would be superimposed on more melt-driven freshening, potentially triggering stronger impacts.

The warmest summers in Europe (de-trended) were preceded by freshwater events.



Composites of the 10 warmest minus 10 coldest summers (after detrending).

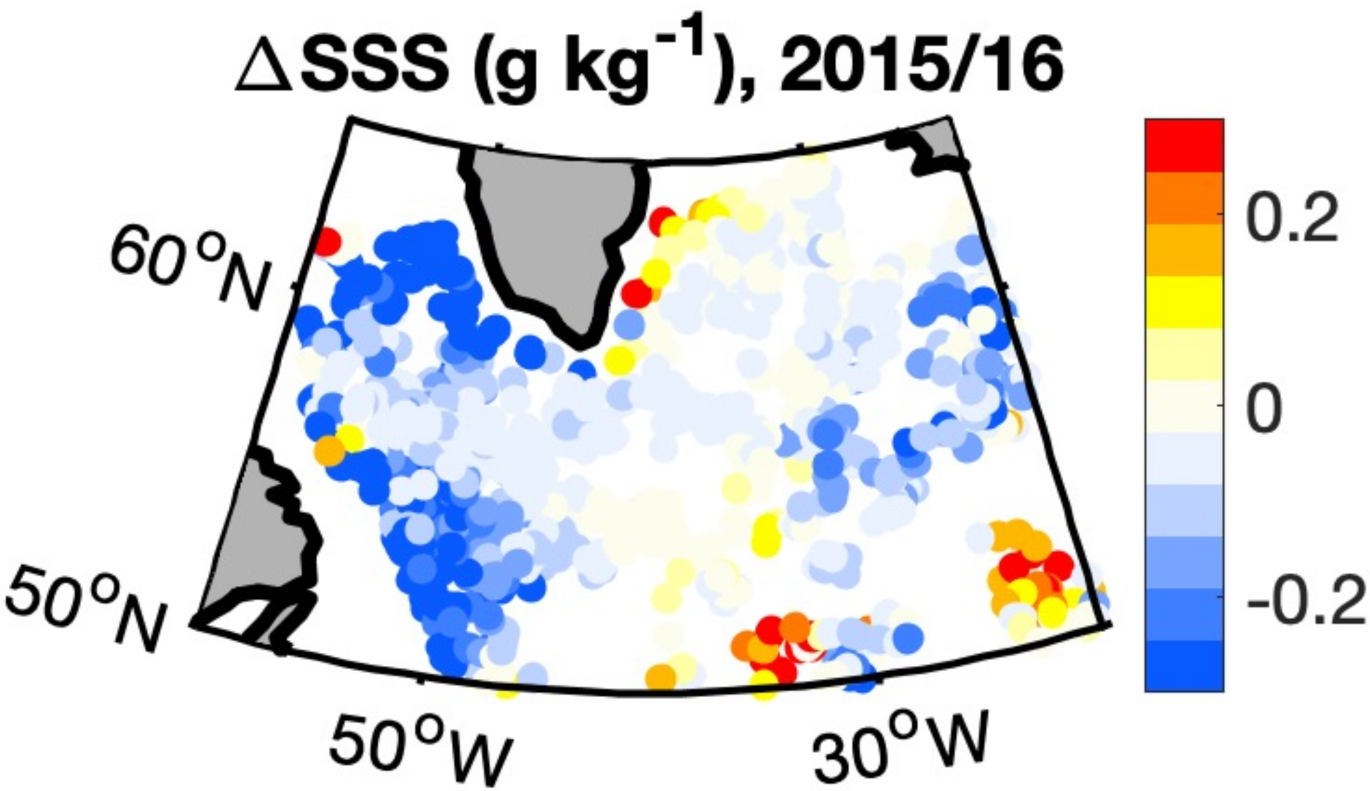
Examples of warm summers after strong freshwater events.



The location of the SST front determines that of the jet stream (shown as ‘U’ at 700 hPa), and in turn, that of the warm anomaly (detrended).

Global climate models tend to have large freshwater biases.

Menary et al. 2015; Heuzé et al. 2017; Liu et al. 2017; Sgubin et al. 2017; Mecking et al. 2017; Wu et al. 2018; Jansen et al. 2020



Comparison of surface freshwater in ECCO with Argo float observations