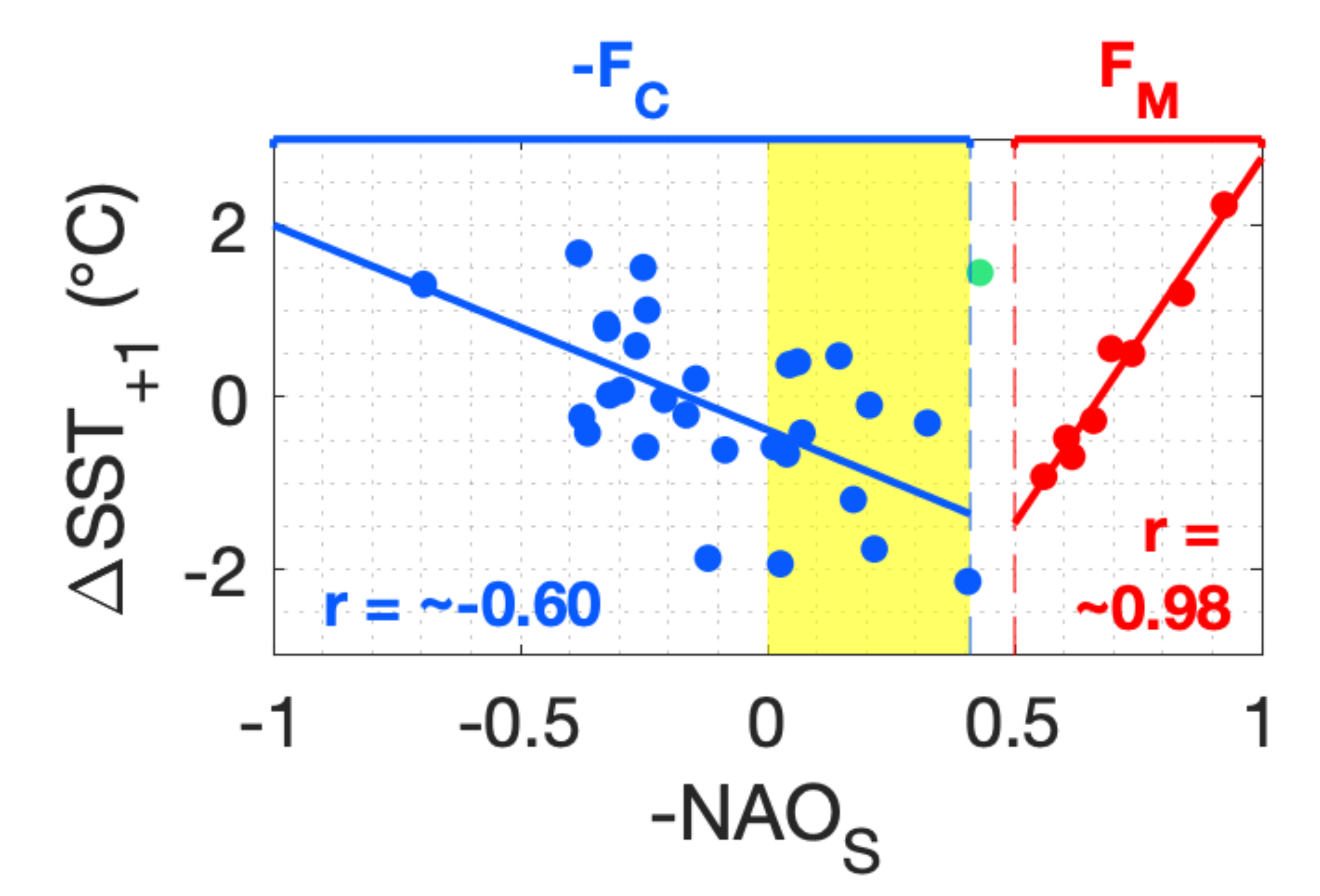
National Oceanography Centre

Marine Physics and Ocean Climate

Arctic pacing of North Atlantic climate variability through freshwater exports

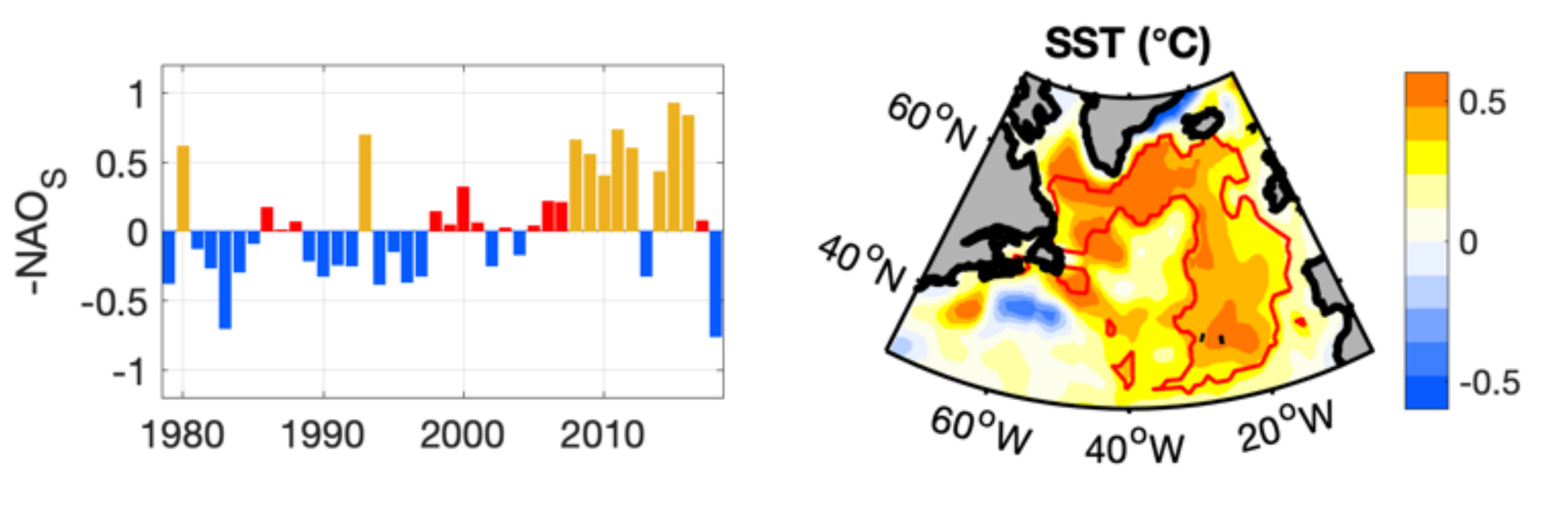
M. Oltmanns, P. Holliday, B. Moat

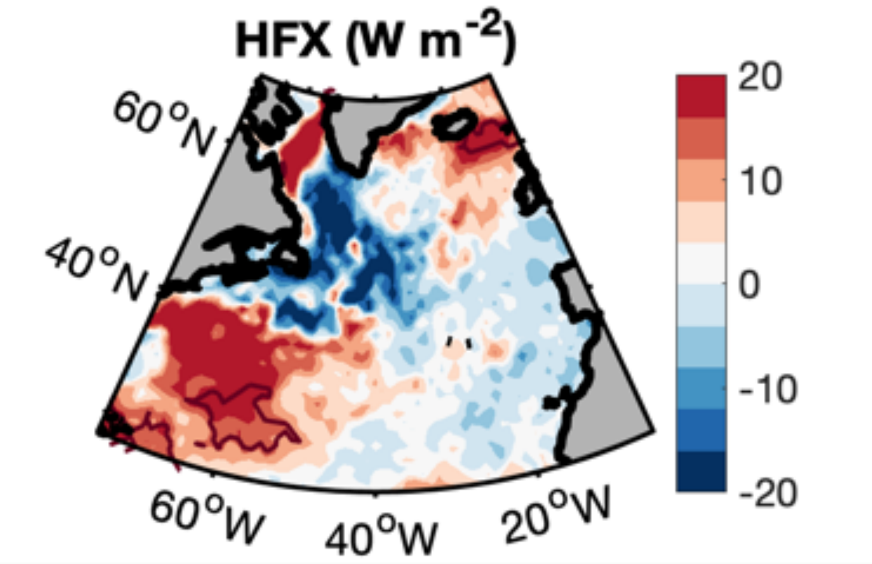
What happens in the absence of strong freshwater events?



The summer NAO serves as indicator for freshwater variations. Both a high and a low summer NAO are followed by increased fresh and cold anomalies in the subsequent winter. Reduced fresh and cold anomalies occur in the central NAO range.

In the absence of freshwater events, there is an increased buoyancy-driven northward surface flow.

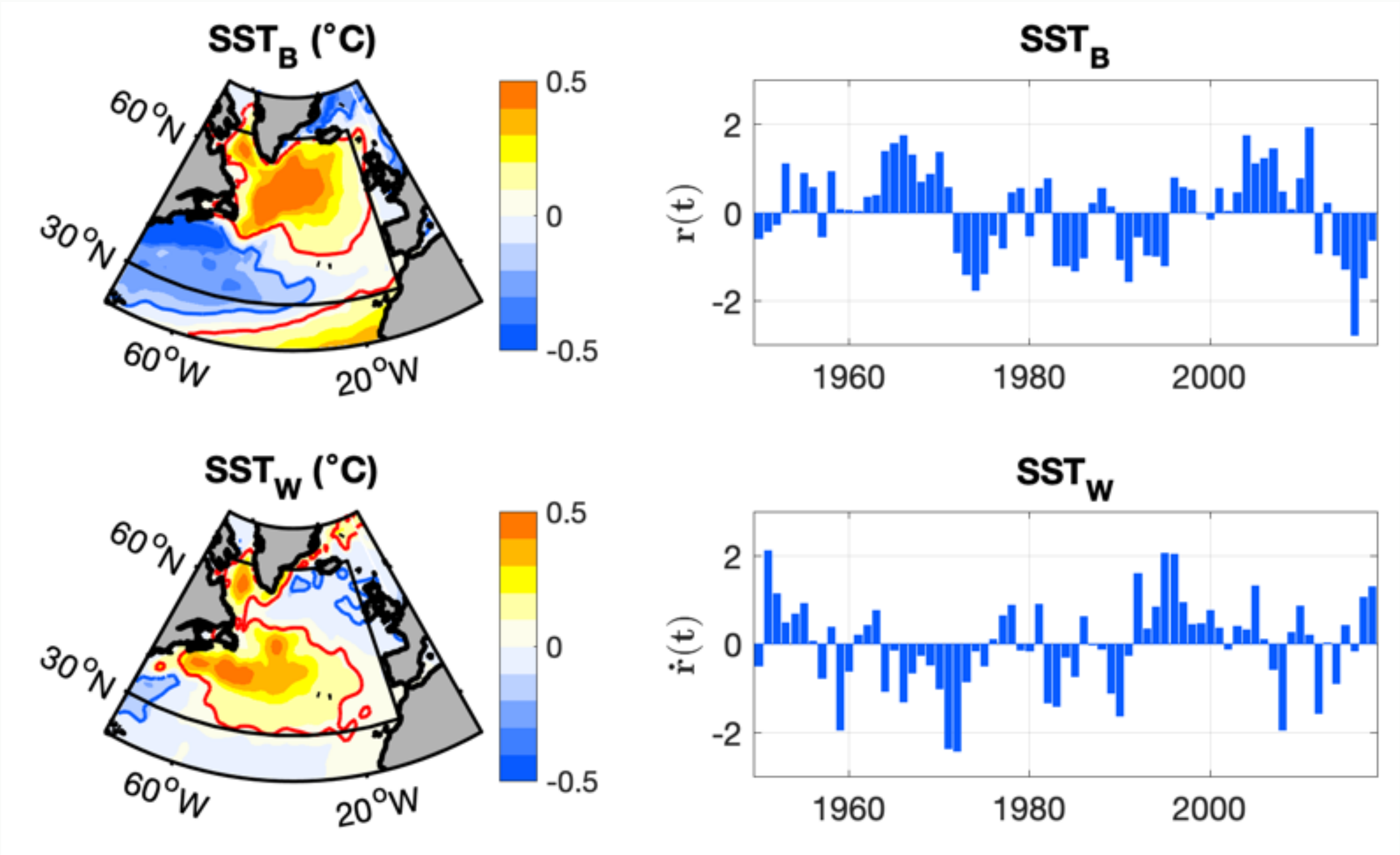




Increased ocean heat loss in the subpolar region leads to densification and downward mixing of surface water, drawing in more warm water from the south.

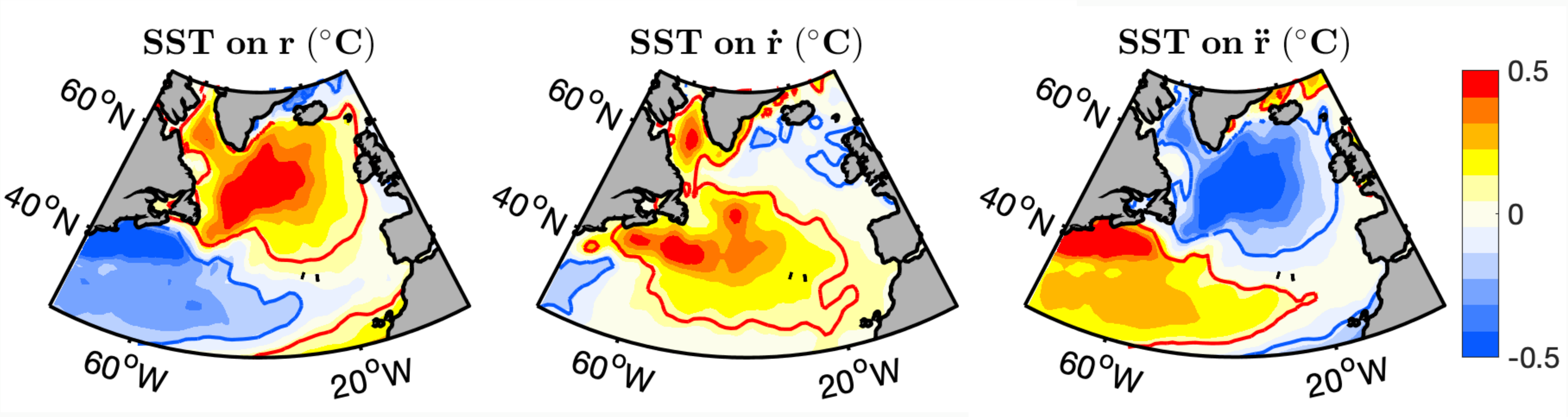
Derived from a heat budget; Composites are based on SST from NOAA and ERA5 atmospheric data

How does the warm anomaly evolve?



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

The two SST patterns form a cycle.

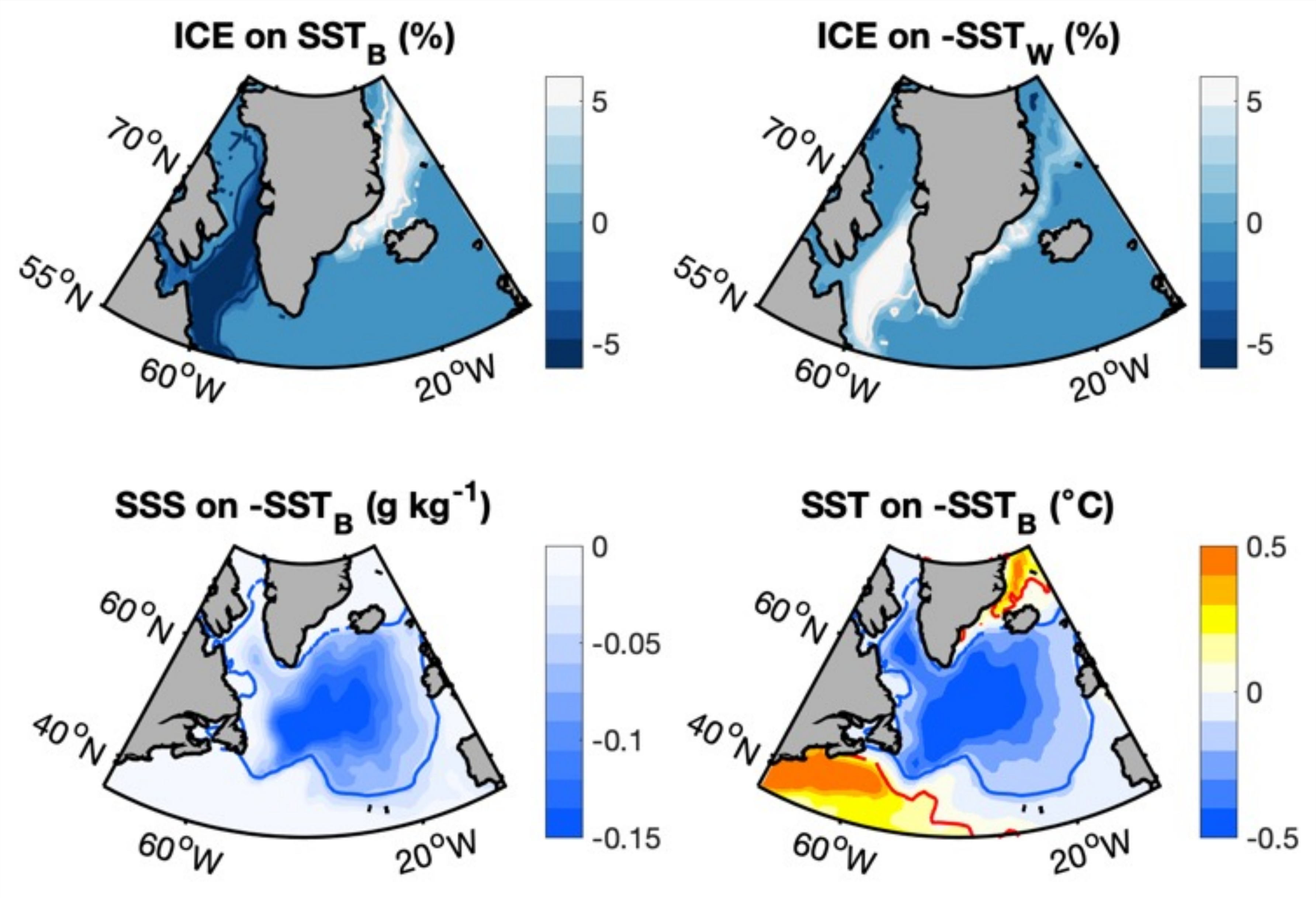


$$SST(x,y,t) = r(t) \cdot SST_B(x,y) + s(t) \cdot SST_W(x,y) + SST_R(x,y,t)$$

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

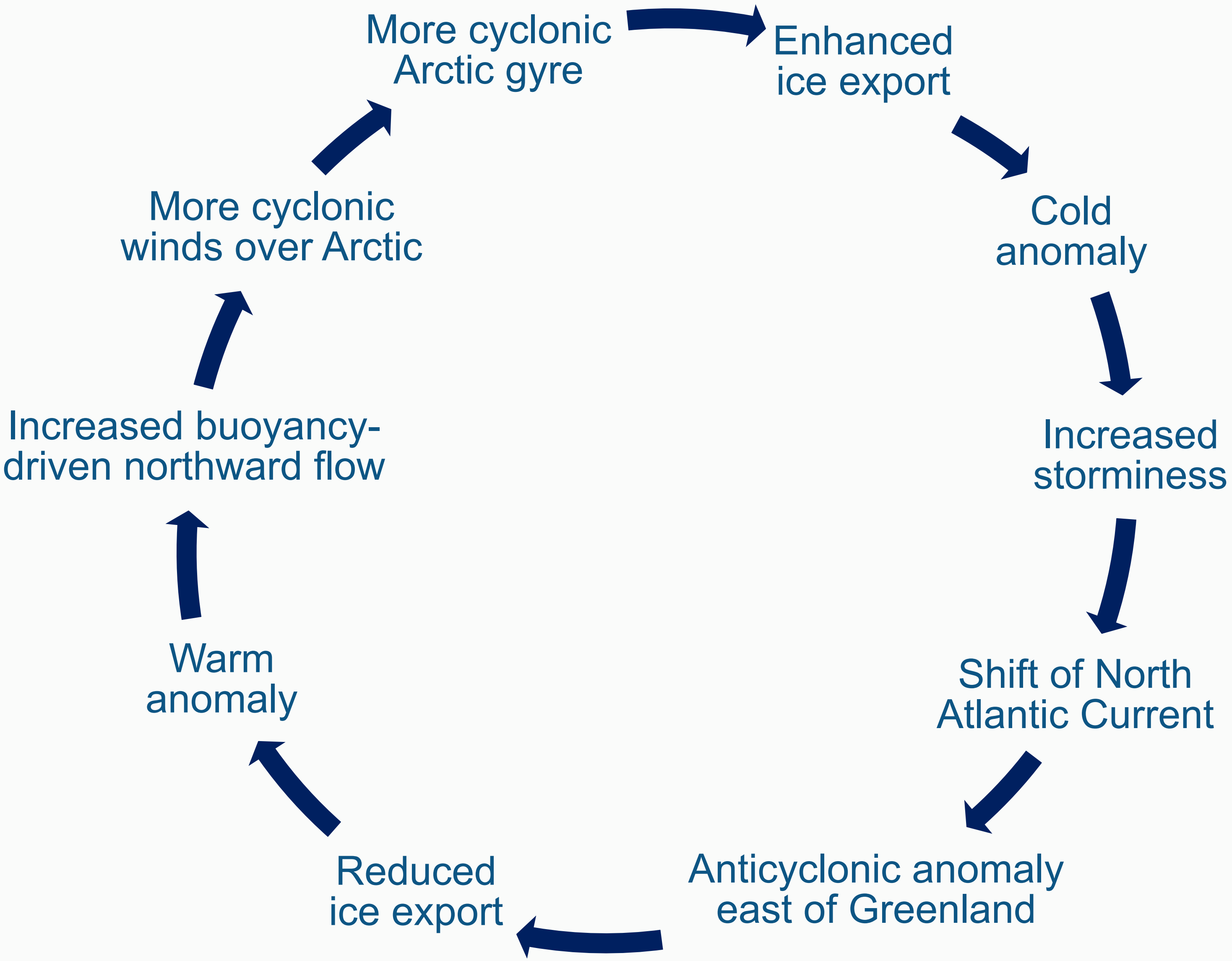
The cycle consists of two orthogonal modes, is most pronounced on decadal timescales and explains over 50% of the subpolar SST variance.

The cycle is associated with enhanced Arctic sea ice export.



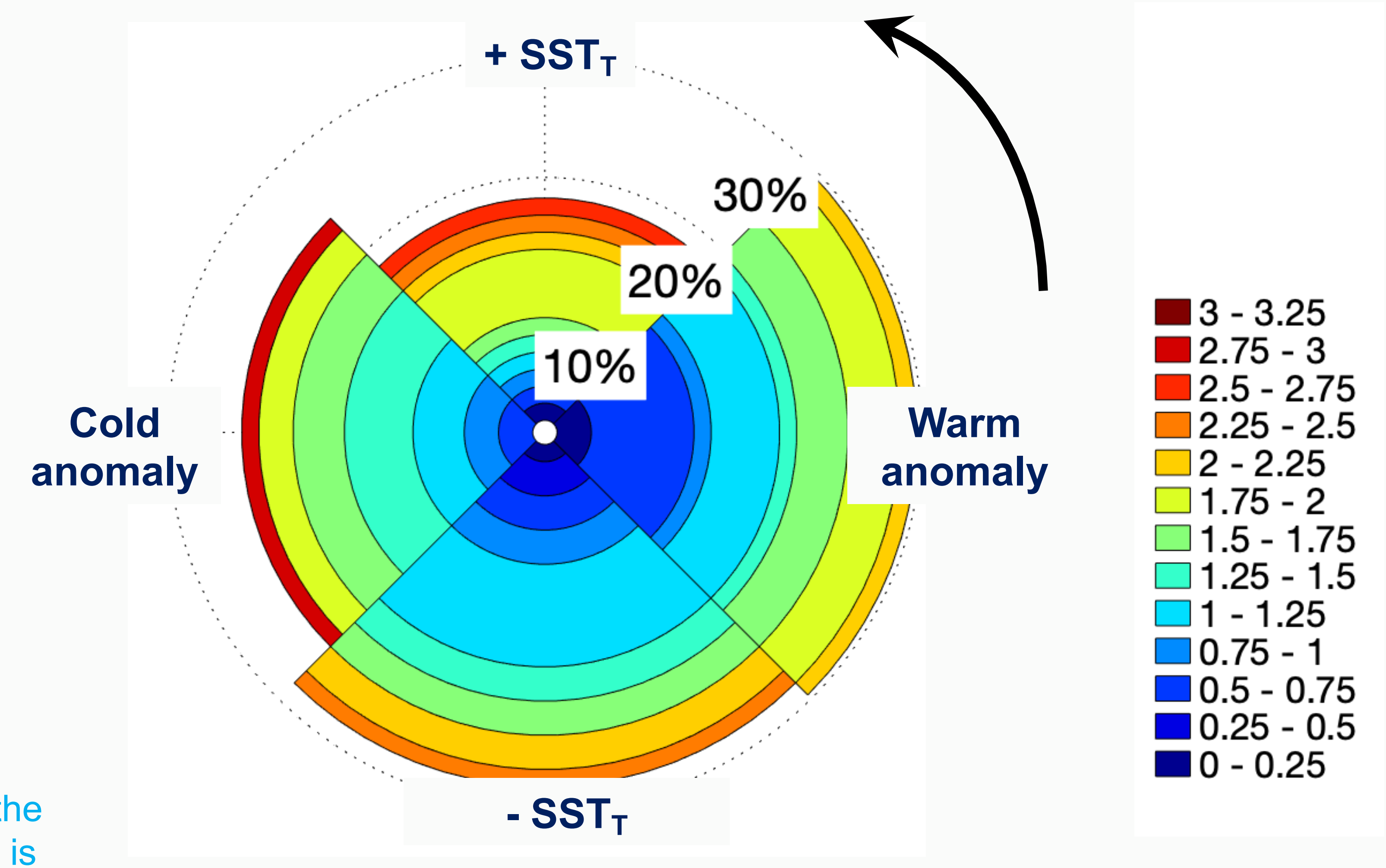
Based on ice concentration data from NOAA, 1979 – 2020, and Hadley SST, 1950 – 2020

This (idealised) cycle is dynamically linked through ocean and atmosphere feedbacks.



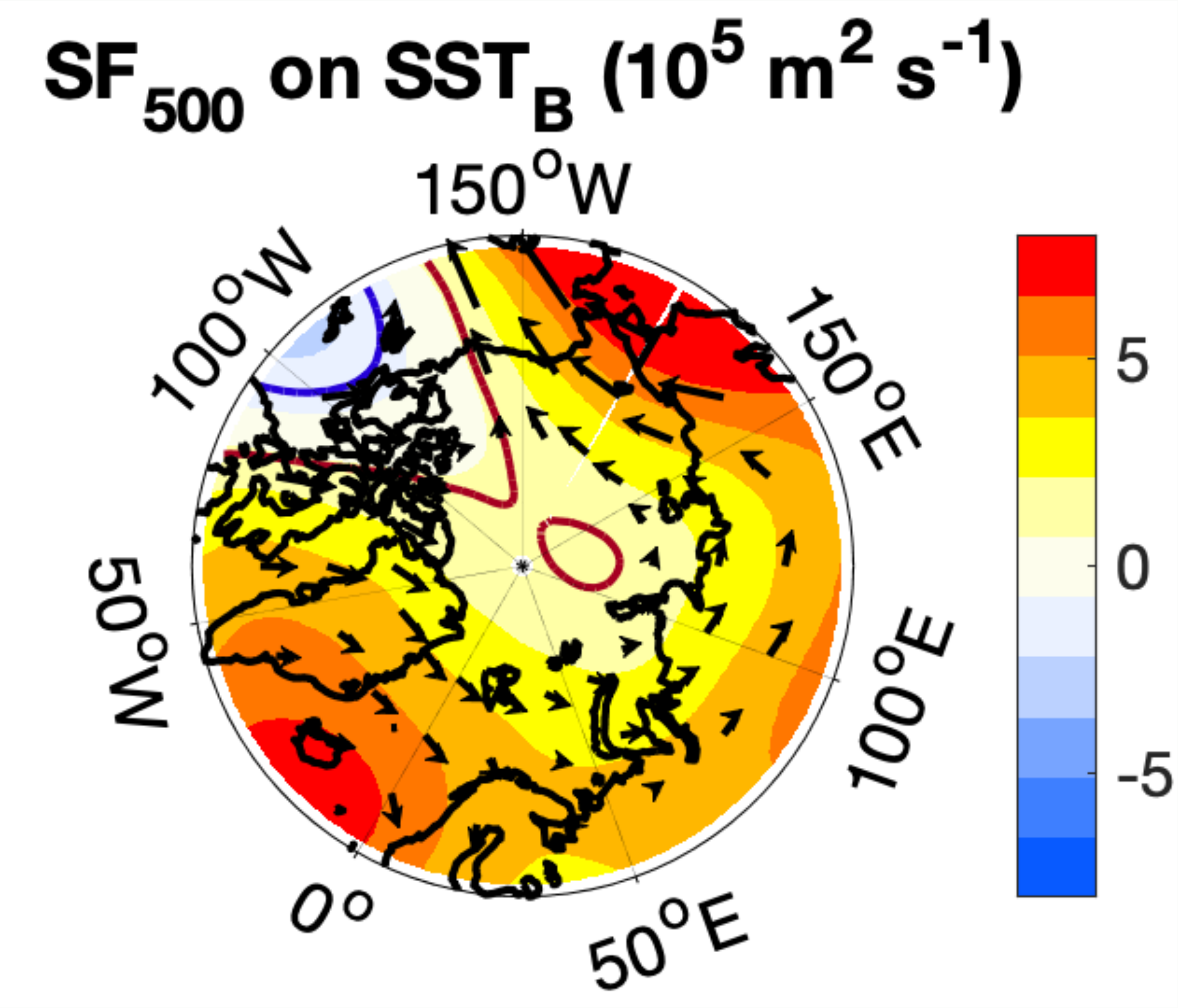
Cassou et al., 2004; Deser et al., 2007; Ferreira & Frankignoul, 2005; Gulev et al., 2013; Kushnir et al., 2002; Kwok et al., 2013; Marshall et al., 2001; Oltmanns et al., 2020; Proshutinsky and Johnson, 1997; Proshutinsky et al. 2015; Ricker et al., 2018; Zhang et al., 2019

The warm anomaly stage forms the slowest link in the cycle.



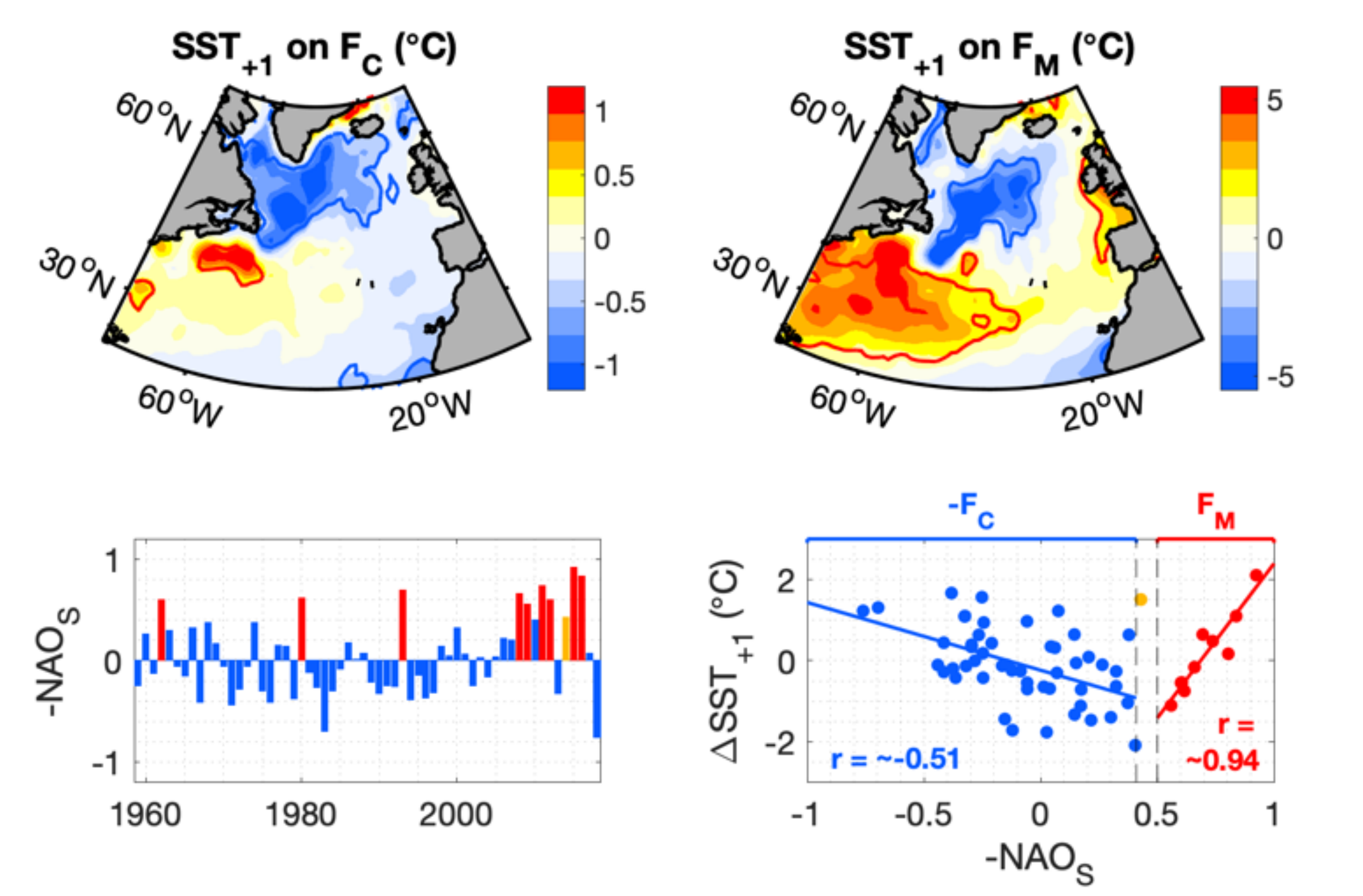
Polar histogram, obtained by converting to polar coordinates; the colour refers to the radius, which is the strength of the cycle.

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



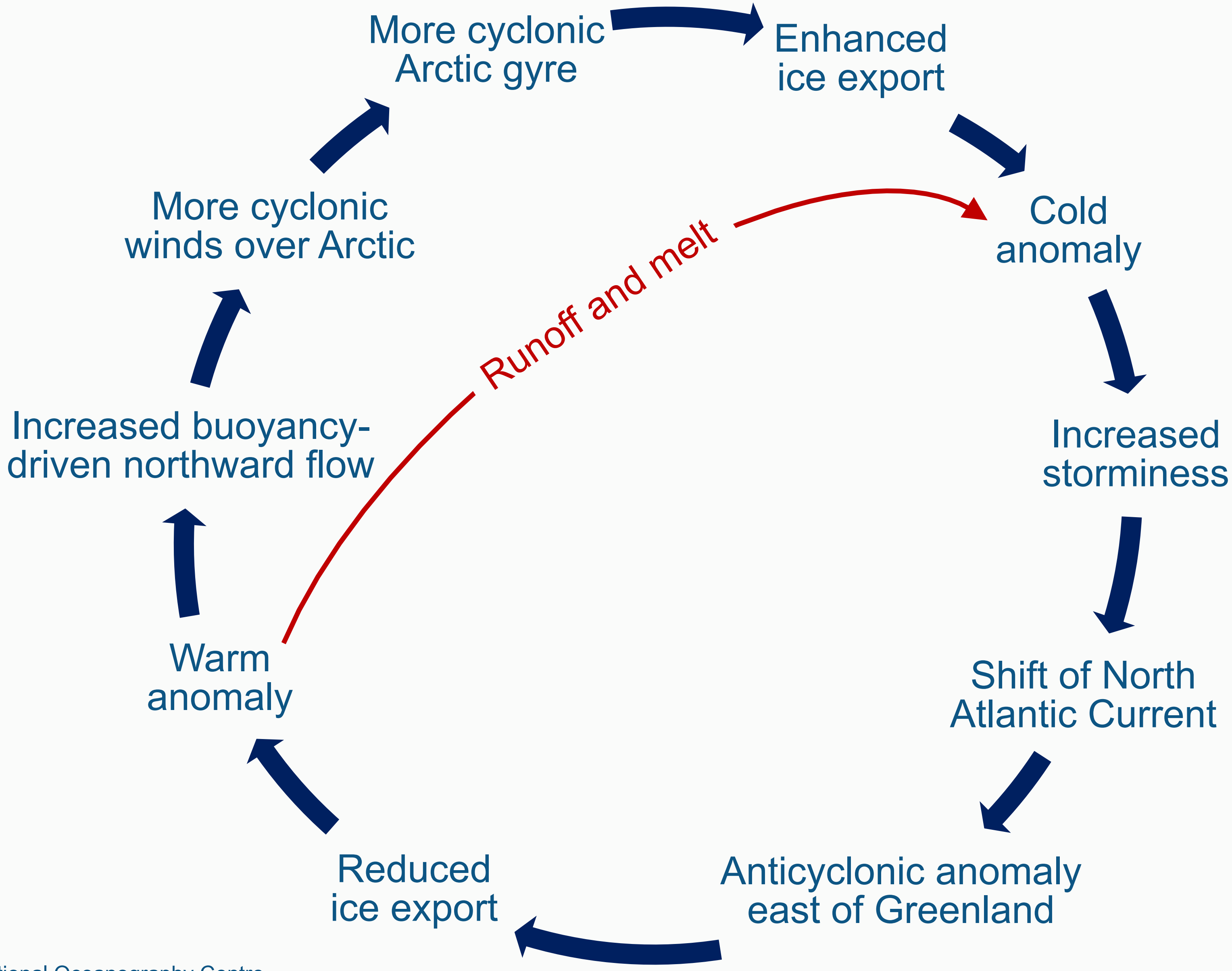
Streamfunction at 500 hPa, based on 50 SST-forced simulations with ECHAM5 over 40 years.

In recent years, a new cold anomaly emerged from it, even though it was not its turn.



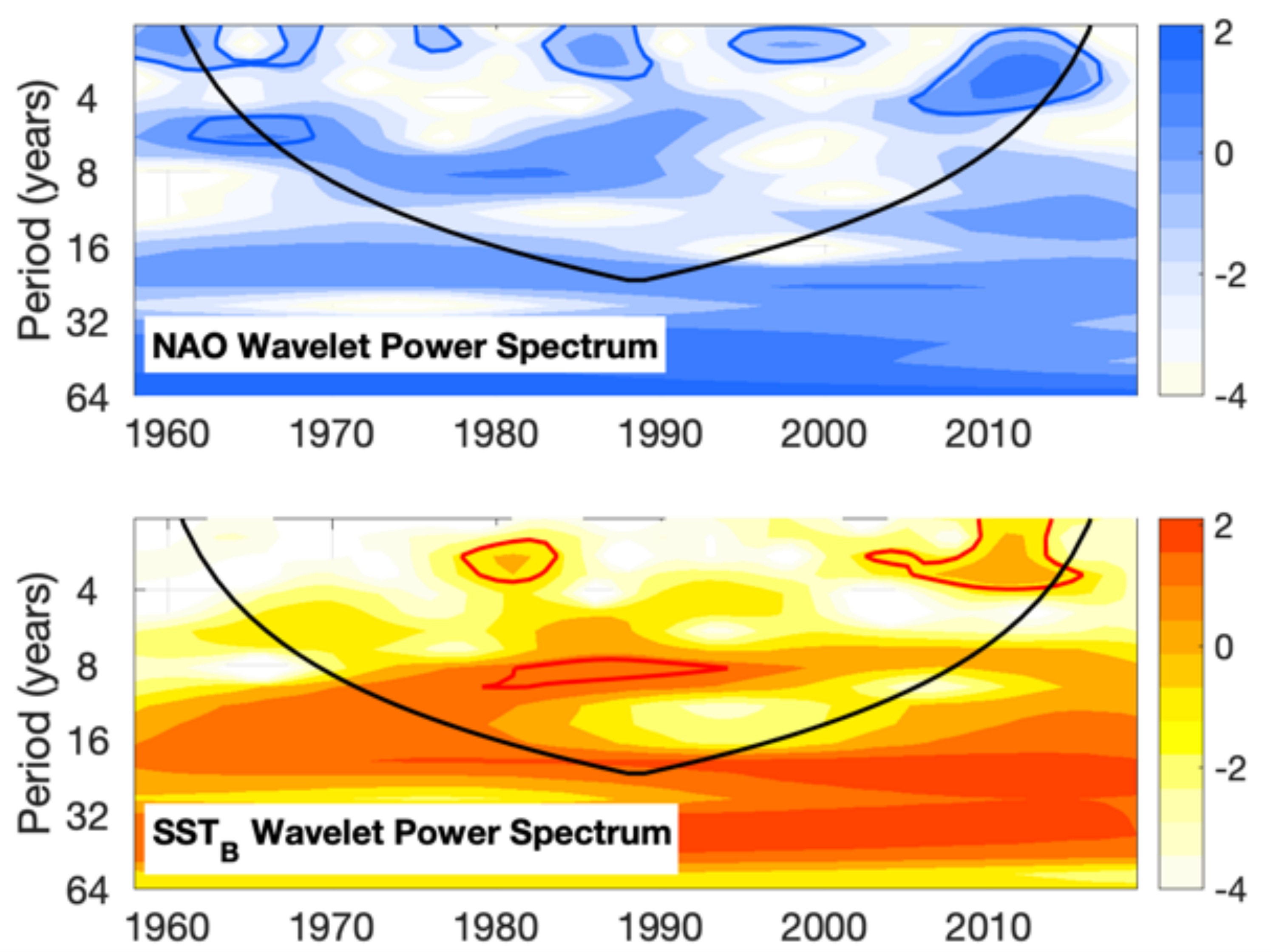
NAO from NOAA; SST from Hadley; red years indicate a new freshening mechanism; blue years comply with the cycle.

The cycle took a shortcut.



Cassou et al., 2004; Deser et al., 2007; Ferreira & Frankignoul, 2005; Gulev et al., 2013; Kushnir et al., 2002; Kwok et al., 2013; Marshall et al., 2001; Oltmanns et al., 2020; Proshutinsky and Johnson, 1997; Proshutinsky et al. 2015; Ricker et al., 2018; Zhang et al., 2019

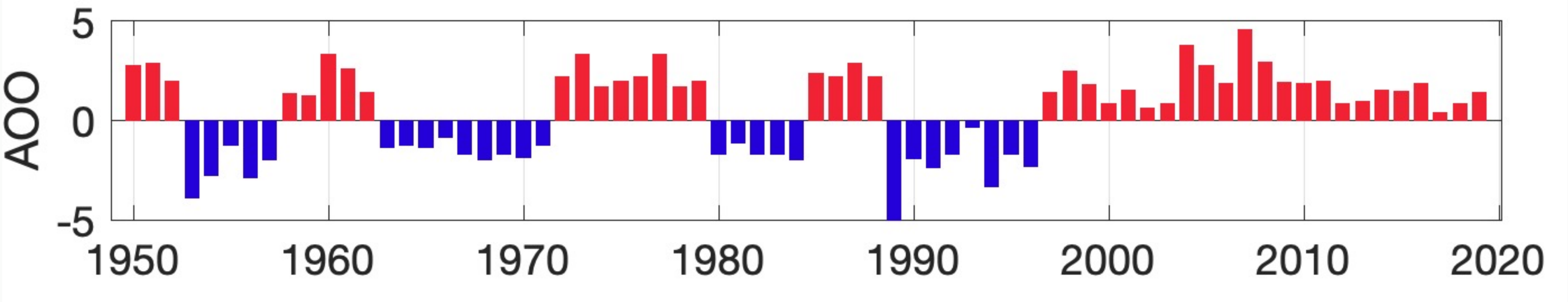
The shortcut has accelerated the cycle from decadal to interannual timescales.



Morlet wavelet with NAO from NOAA and Hadley SST

The Arctic gyre has now been in an anti-cyclonic regime for over 20 years, resulting in the accumulation of freshwater.

Proshutinsky et al., 2020; Wang et al., 2018, 2021



Obtained from the Beaufort Gyre exploration project

The persistent anti-cyclonic regime has resulted in a large accumulation of freshwater.

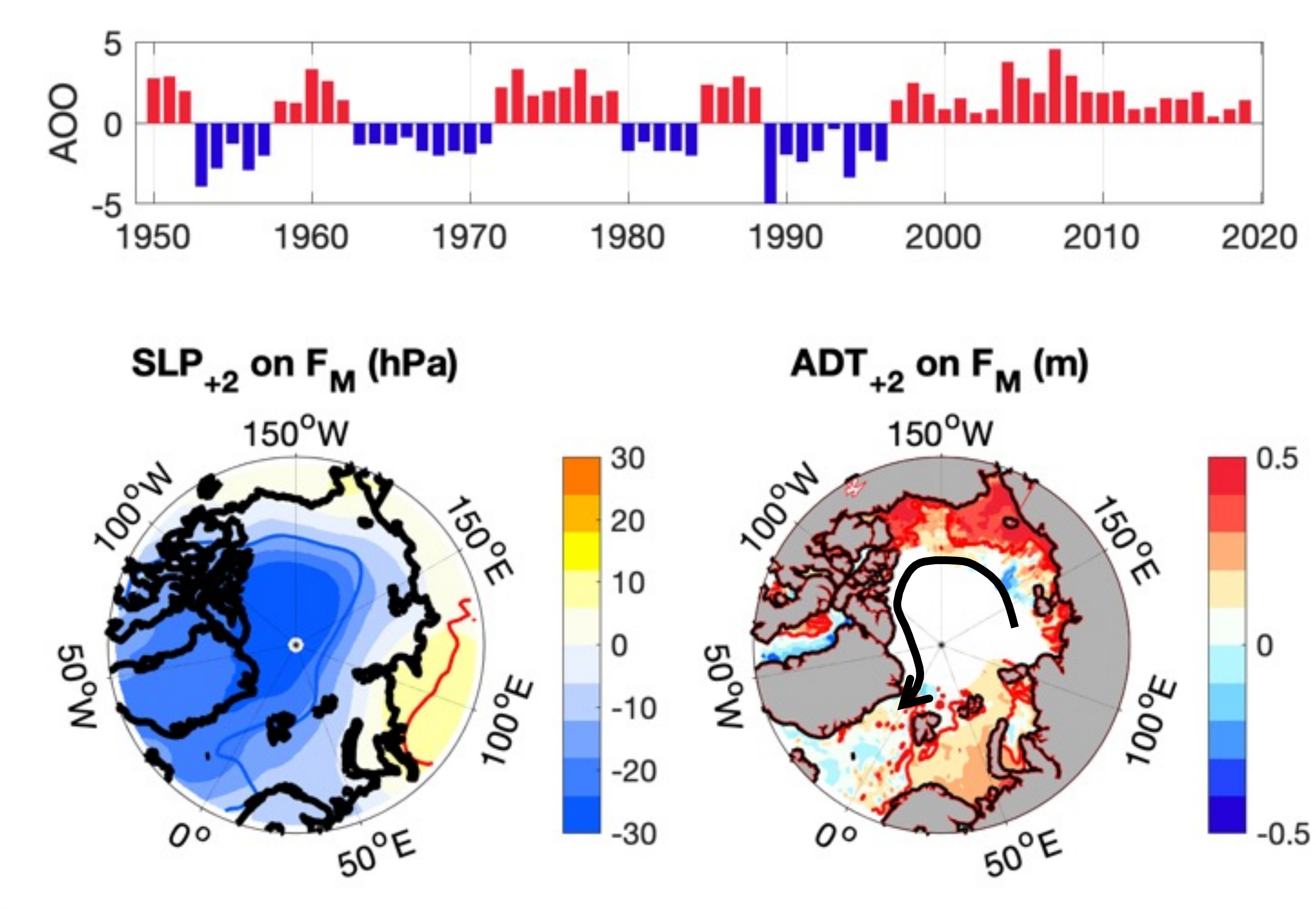
Proshutinsky et al., 2020; Wang et al., 2018, 2021

Conclusion

- Ice and freshwater exports from the Arctic participated in a cycle that explains a substantial part of North Atlantic variability.
- Over recent years, a new cold anomaly mode has interfered with this circulation-driven freshwater cycle.
- The interference has led to an acceleration of the cycle in the North Atlantic and a weakening and accumulation of freshwater in the Arctic.

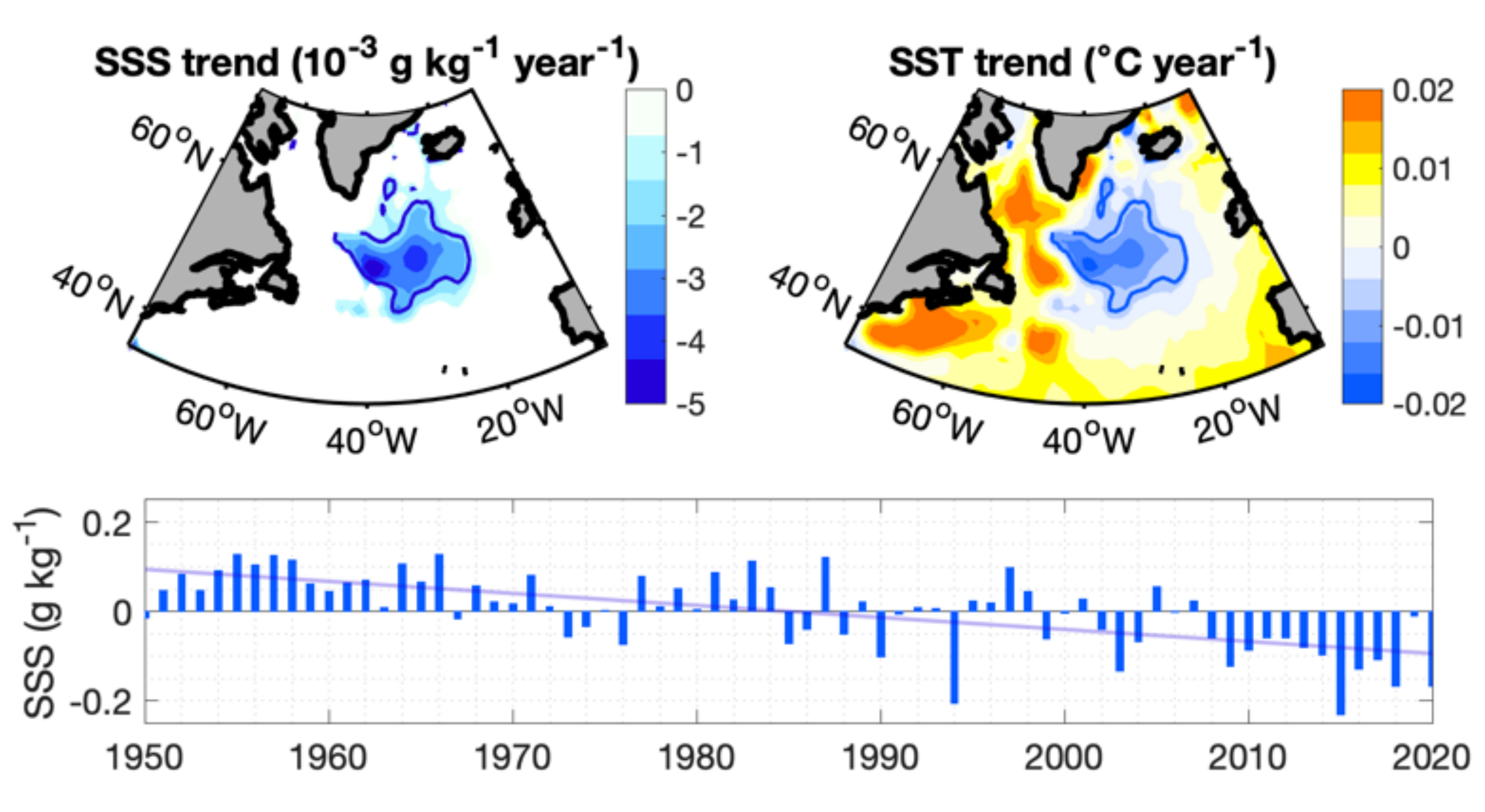
Oltmanns et al., in prep.

After melt-driven freshwater events there is a also more cyclonic Arctic gyre.



Regressions in summer with SLP from ERA5 and ADT from Copernicus

The freshening trend will amplify future, runoff-driven cold anomalies, potentially resulting in stronger feedbacks and a shift in the Arctic gyre circulation.



Thank you

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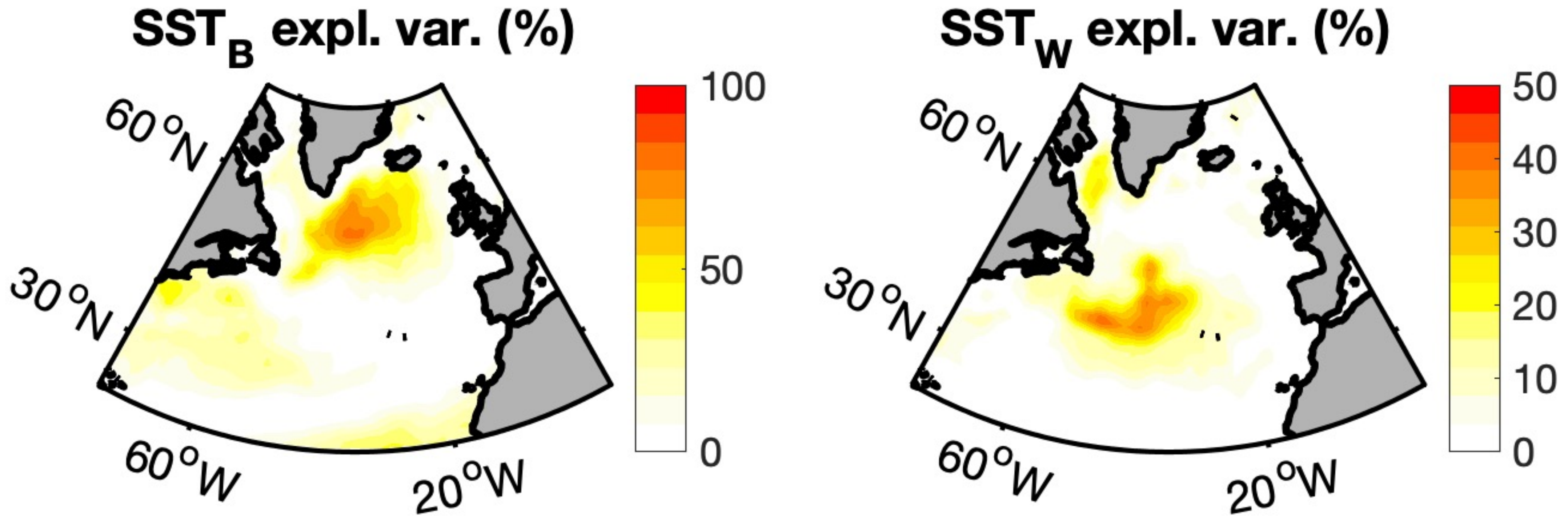
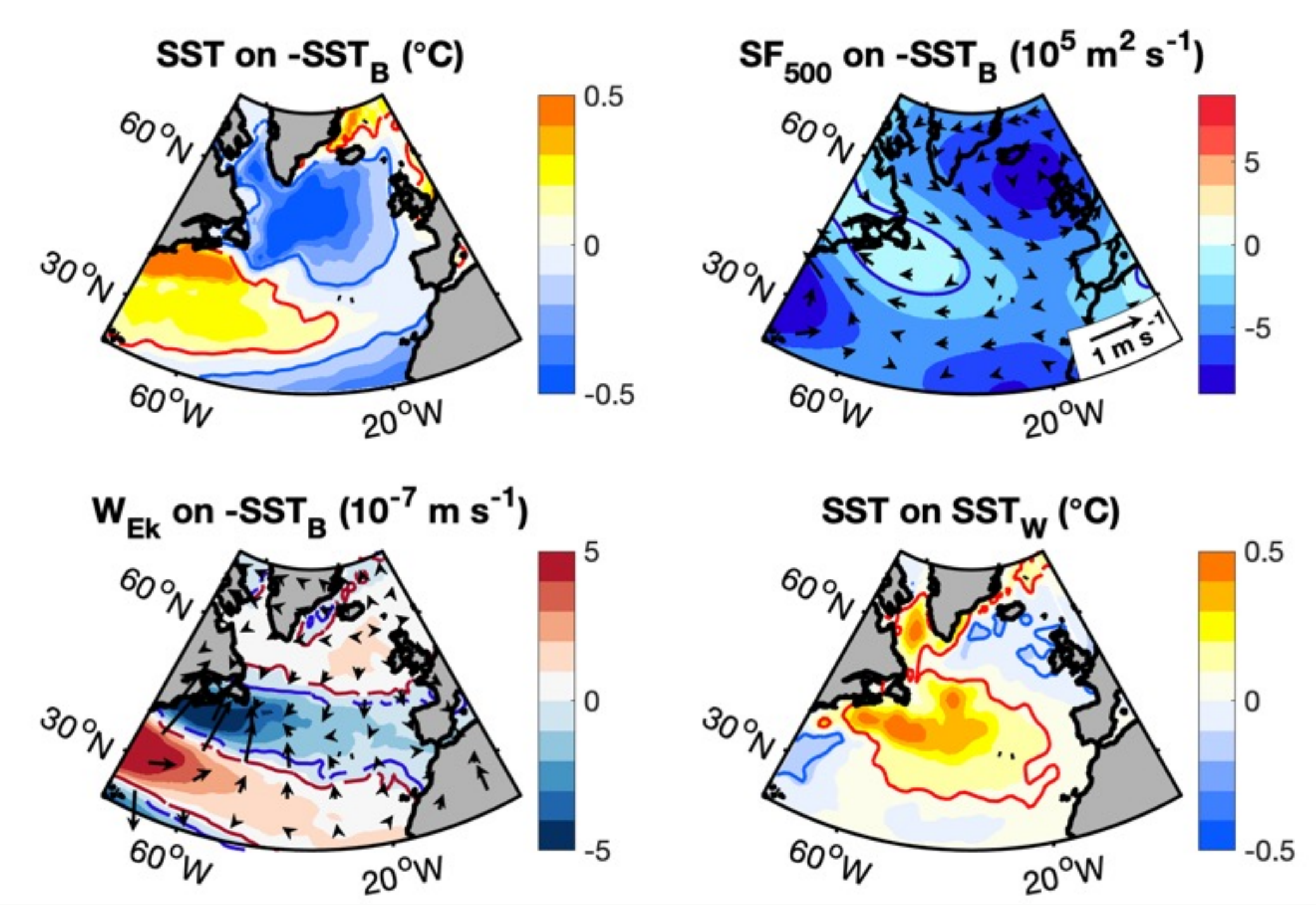
The cycle explains over 50% of the SST variance in the subpolar region.



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 streamfunction at 500 hPa; the arrows show the simulated winds;
Ekman pumping was calculated from the resulting wind stresses.