The 2015 North Atlantic cold anomaly was largely caused by surface forcing, not by internal variability

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The mid-to-high latitude North Atlantic features cold temperature anomalies on interannual timescales. For example, in 2015 a region of open ocean southwest of Greenland reached a record low temperature relative to the period 1880-2015. Such rapid drops in upper ocean heat content have been linked to impacts on the North Atlantic Oscillation and European climate (e.g. heat waves induced by changing atmospheric circulation patterns). Despite their potential importance for regional climate, the specific mechanisms that induce these interannual cold anomalies are still not well understood. In particular, the relative importance of changes in surface forcing compared with upwelling of deep ocean cold anomalies (i.e. those below 500 m) in establishing the 2015 cold anomaly is a topic of debate.

Here we use an observationally-constrained ocean model in adjoint mode to calculate the sensitivities of upper ocean heat content to local and remote surface forcing. Adjoint methods allow us to quantify the relative contributions of wind stress and net heat flux in producing the 2015 cold anomaly. Wind stress contributes to the cold anomaly via both (1) strengthening surface latent and sensible heat losses and (2) inducing changes in ocean circulation. Net heat flux contributes to the cold anomaly by inducing heat loss in both local and upstream waters. We also use adjoint methods to calculate (1) the source waters that contributed to the cold anomaly and (2) regions that may have contributed to the cold anomaly by inducing changes in synoptic-scale ocean circulation. Furthermore, we examine the large-scale context by calculating the sensitivities of subpolar gyre heat content to surface forcing and the ocean state. Our results illustrates that surface forcing, particularly the extreme heat loss event in the winter of 2013-2014, played a dominant role in producing the 2015 cold anomaly. This raises the possibility that long-term variability in extreme heat loss events south of Greenland may be connected to long-term variability in the NAO and European climate.