Local and remote causes of the recent North Atlantic cold anomaly: an adjoint sensitivity study

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Abstract

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 intense 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 suggest 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.

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an adjoint sensitivity study

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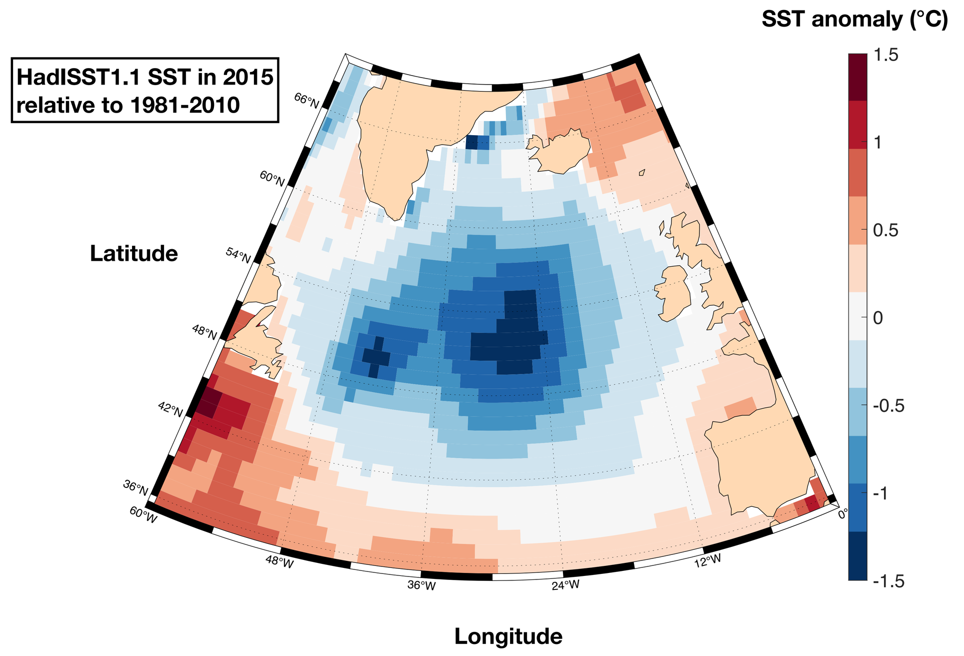
BACKGROUND: North Atlantic cold anomalies are associated with large-scale circulation changes and European heat waves. What creates and sustains these interannual cold anomalies? Here we examine a particular cold anomaly from 2014-2015.



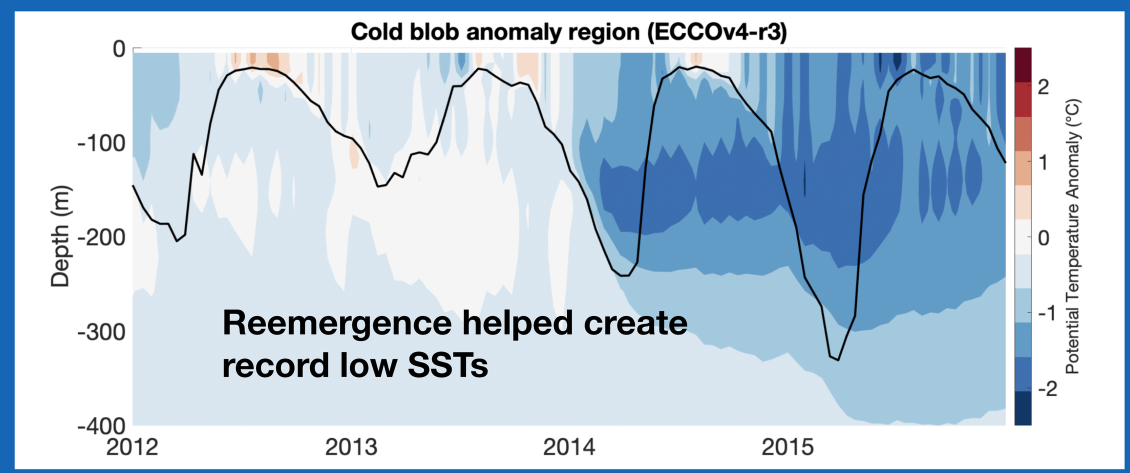
MODEL AND METHODS

- Model: the ECCOv4-r3 state estimate
- Calculated heat budget in control volume (white box above, top 500m)
- Performed adjoint reconstruction of temperature

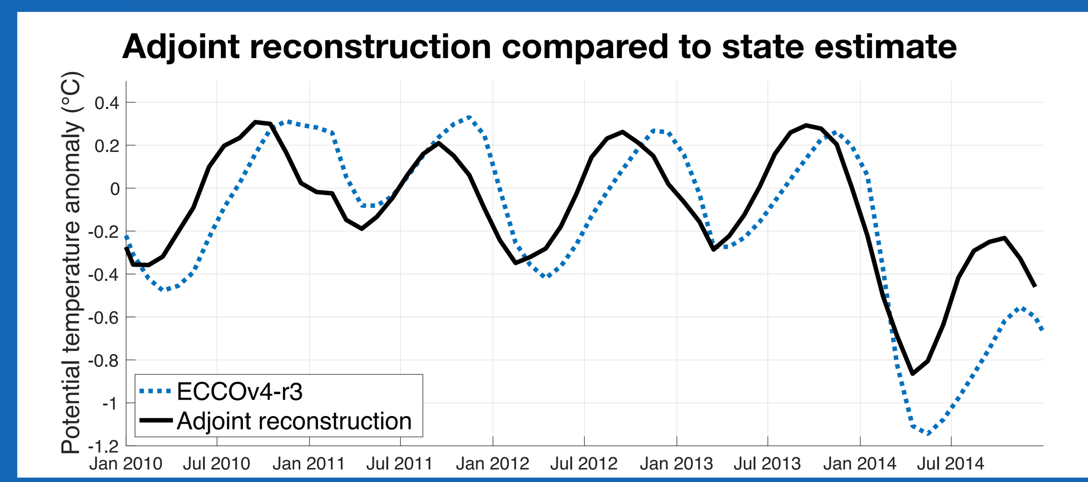
RESULTS

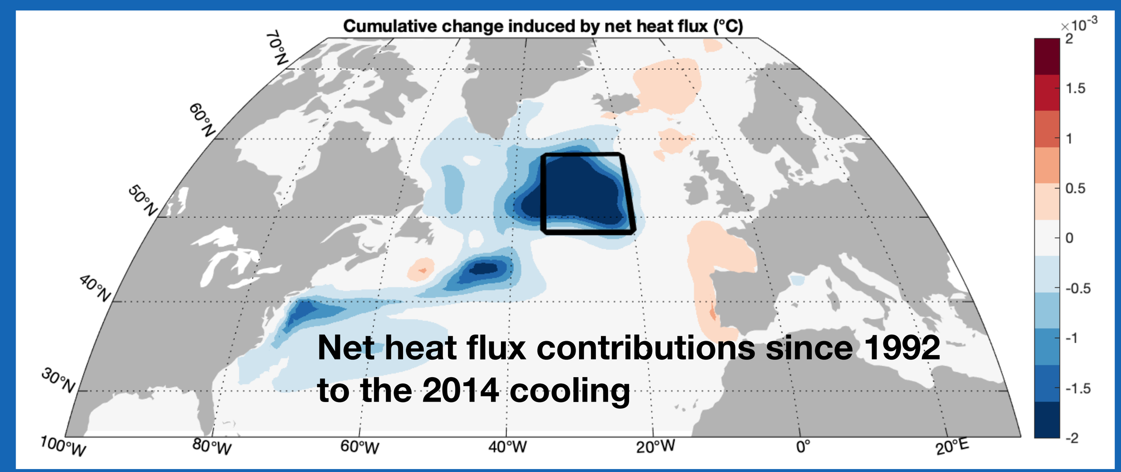
- Reemergence signature:
  - intense ocean heat loss in winter 2013-2014 created especially cold subpolar mode water that became isolated from the atmosphere when the mixed layer shoaled in spring
  - another round of intense heat loss in winter 2014-2015 brought this cold anomaly back up to the surface, contributing to record low SSTs in 2015
- Adjoint reconstruction:
  - we can reconstruct ~80% of the 2014 interior cold anomaly (top 500 m) using *only* heat flux and wind stress. (Note that this reconstruction only includes linear changes induced by the forcing)

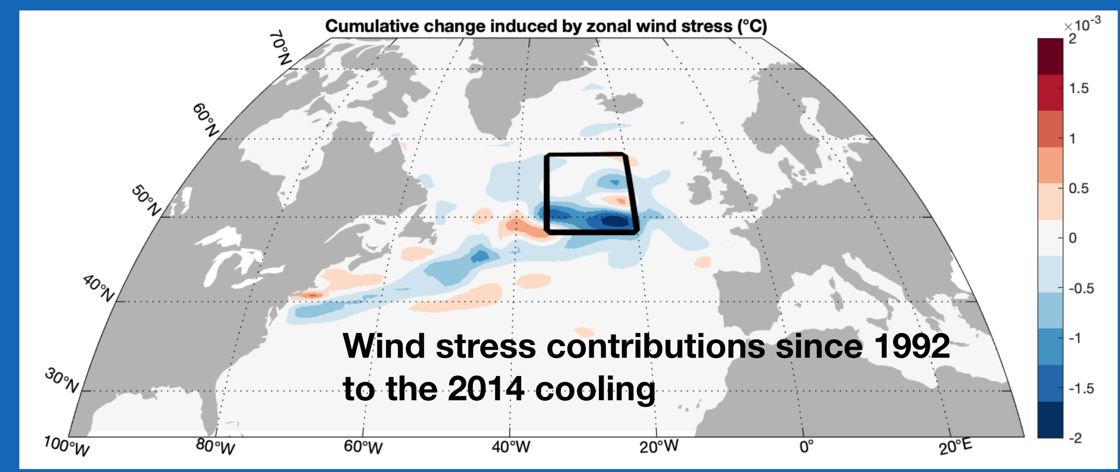
Record low sea surface temperatures in the North Atlantic caused by successive winters with extreme heat loss

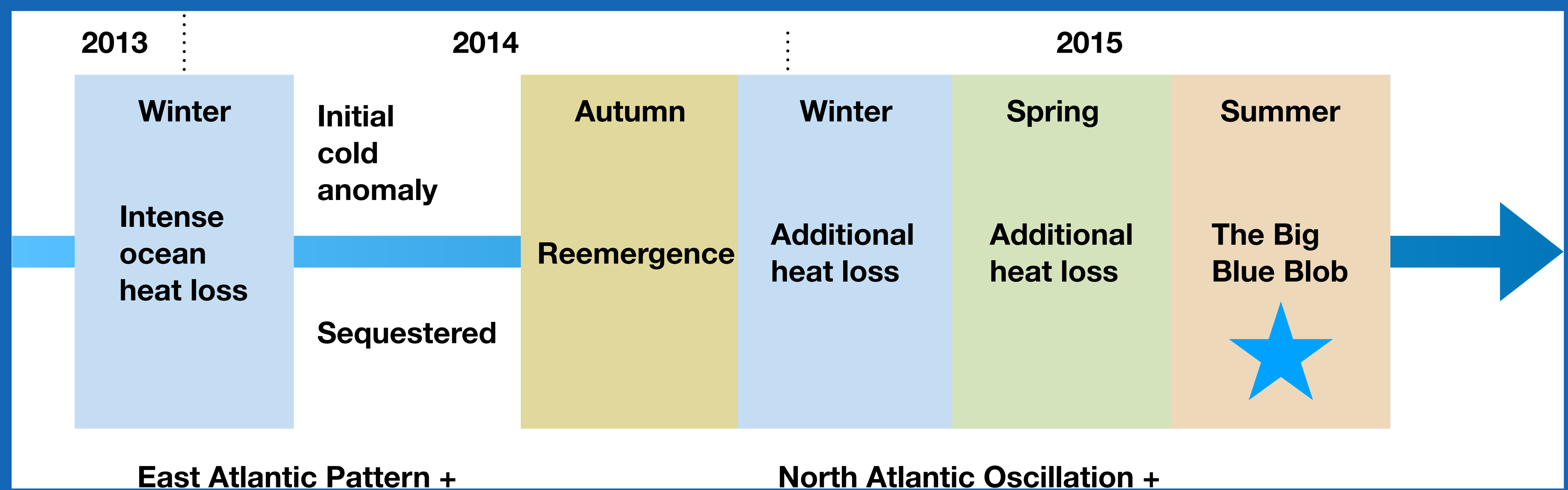


We can reconstruct ~80% of the 2014 temperature drop using only linear heat flux and wind stress impacts









Adapted from Josey et al. (2018)

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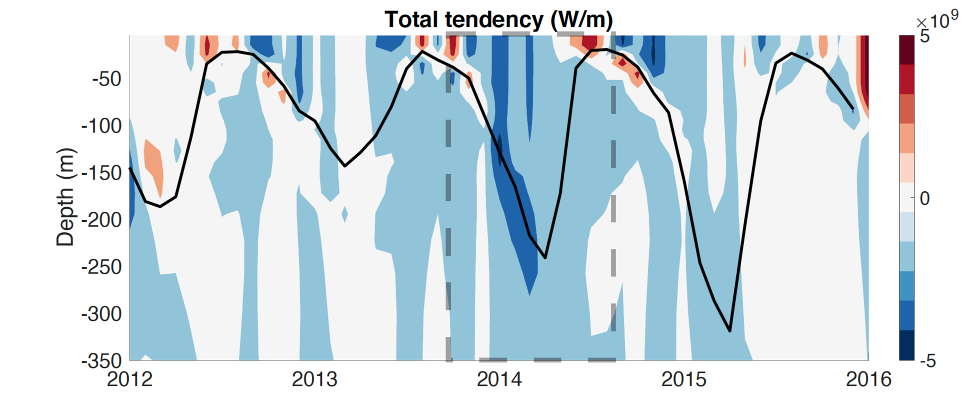
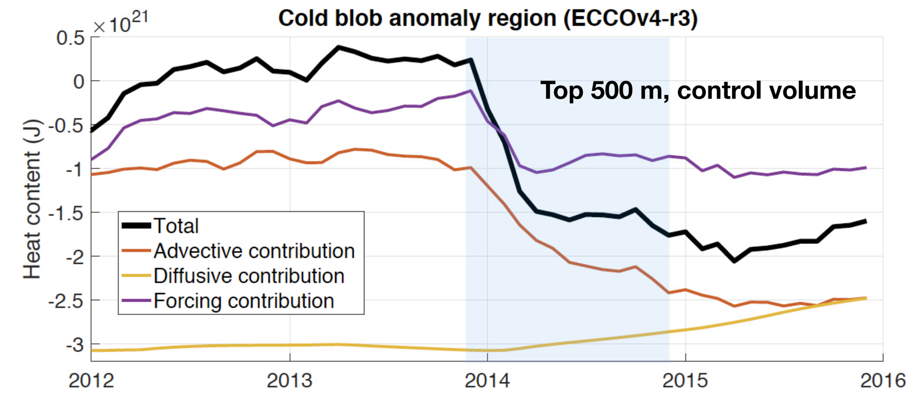
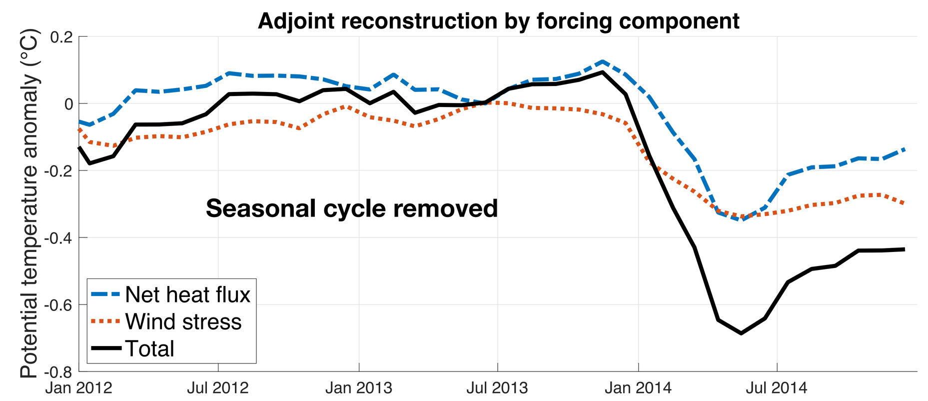


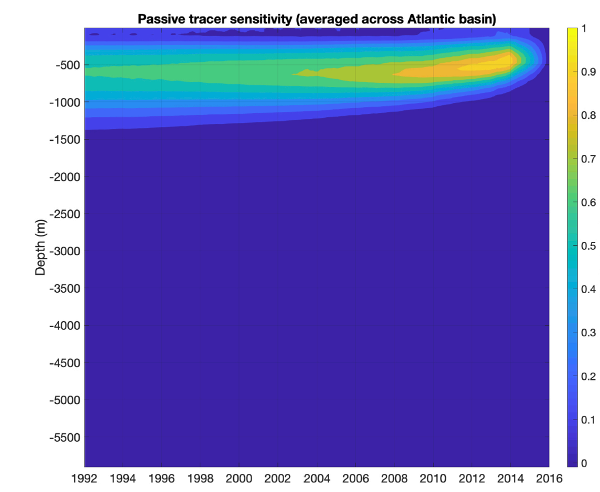
Note how the cooling follows the base of the mixed layer in 2014



The heat budget in the control volume shows the relative magnitudes of forcing and advection in establishing the initial 2014 cold anomaly



Reconstruction shows the relative roles of heat flux and wind stress (not just local - these signals are integrated over the global ocean)



The source waters for the top 500 m are largely from the top 1000 m

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