Using mixed layer heat budgets to determine the drivers of the 2015 North Atlantic cold anomaly

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1 Introduction

In 2015, while most of the global ocean experienced warmer than average surface temperatures, the subpolar North Atlantic instead experienced a record cold anomaly. Previous studies have linked the anomaly to increased surface heat loss associated with the North Atlantic Oscillation (NAO) and East Atlantic Pattern (EAP). Re-emergence has also been shown to be important in sustaining temperature anomalies over consecutive years. We computed mixed layer budgets in the ECCOv4-r4 state estimate (1992-2017, nominal resolution 1°) to further understand the drivers.

2 Methods

Mixed layer budgets were computed and averaged over the cold blob region (black box in Fig. 1). Temperature variability is dominated by surface fluxes and vertical diffusion. Lateral induction and horizontal diffusion are negligible throughout the year.

$$\frac{\partial T_m}{\partial t} \approx \underbrace{\frac{Q_{net} - q(h_m)}{\rho_0 c_p h_m}}_{\text{Surface flux}} - \underbrace{\boldsymbol{u_m} \cdot \nabla T_m}_{\text{Advection}} - \underbrace{\frac{\partial h_m}{\partial t}\frac{\Delta T}{h_m}}_{\text{Entrainment}} - \underbrace{\boldsymbol{u_m} \cdot \nabla h_m \frac{\Delta T}{h_m}}_{\text{Lat. induction}} + \underbrace{\frac{K_z}{h_m}\frac{\partial T}{\partial z}}_{\text{Vert. diffusion}} + \underbrace{\kappa \nabla^2 T_m}_{\text{Hor. diffusion}}$$

3 Cold anomaly in ECCOv4

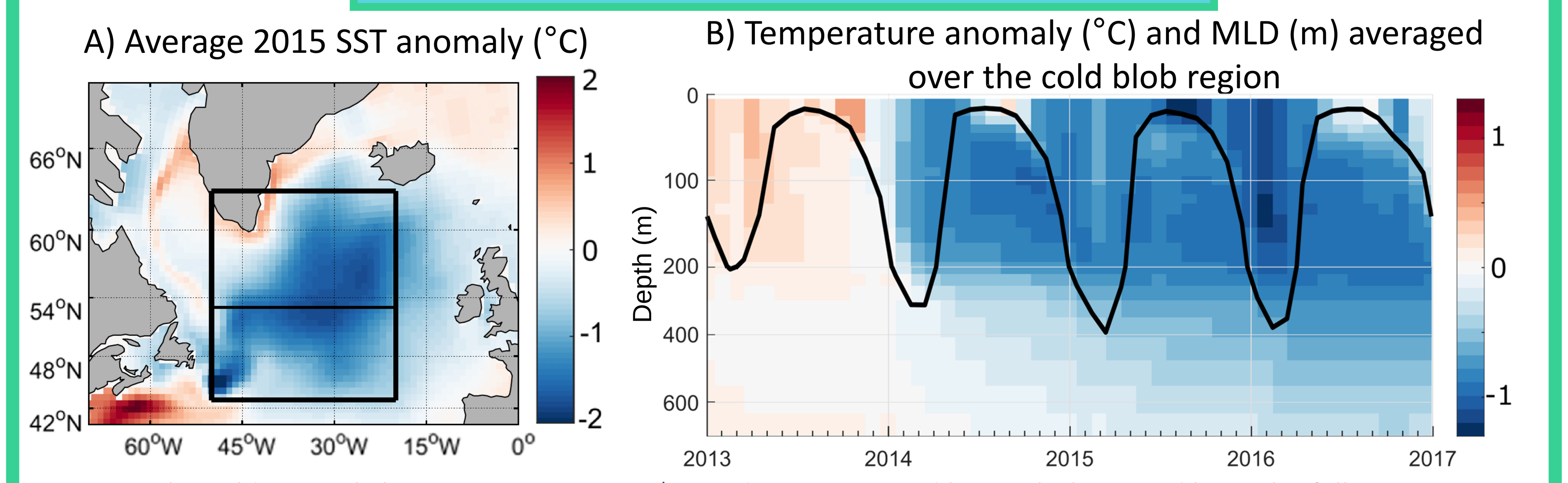


Fig 1. The cold anomaly begins in winter 2013/14 and is sequestered beneath the mixed layer the following summer. Re-emergence of the anomaly from beneath the mixed layer can be seen as the mixed layer deepens.

4 Temperature budget anomalies

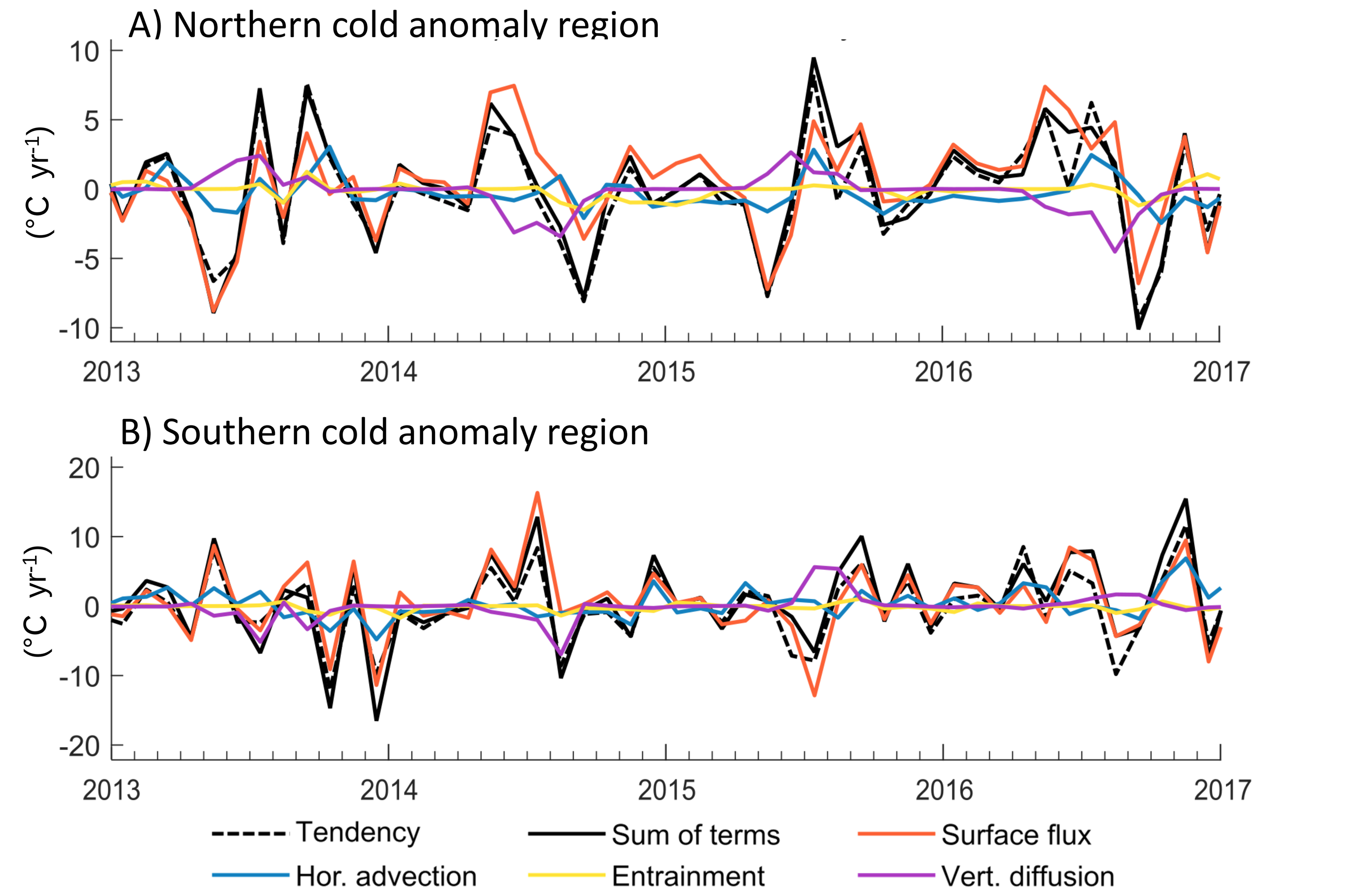


Fig 2: Anomalies averaged over the north and south of the cold blob region. Strong surface cooling in winter 2013/14 drives the initial cooling, strongest in the north. Re-emergence of the cold anomaly is then due to vertical diffusion in summer/autumn, followed by entrainment as the mixed layer deepens. Weaker than average surface warming in summer leads to the strongest cold anomaly in August 2015.

5 Surface flux anomalies

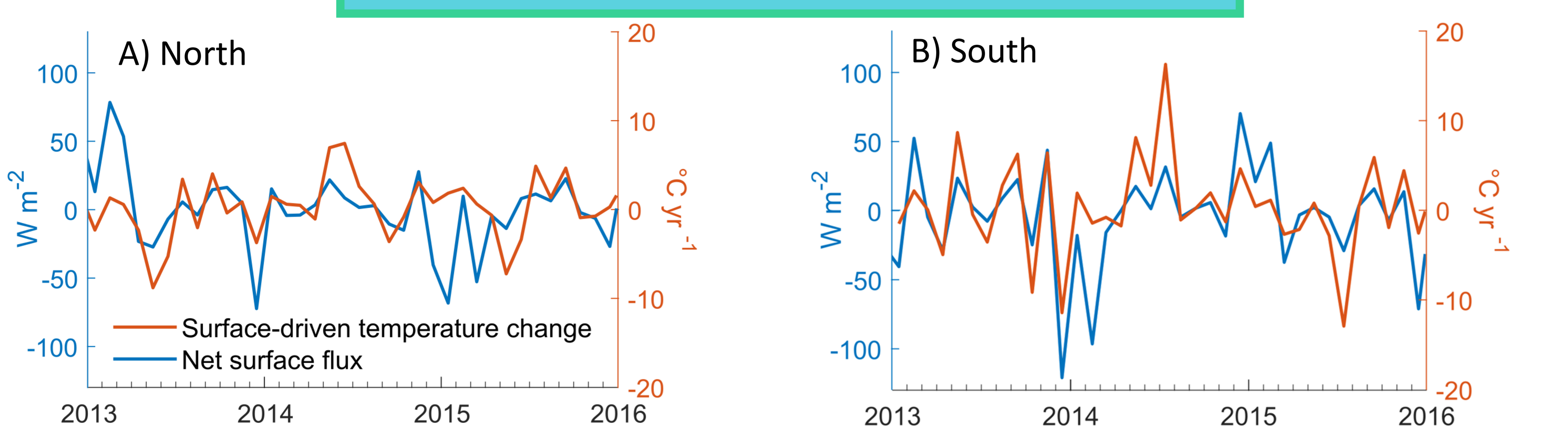
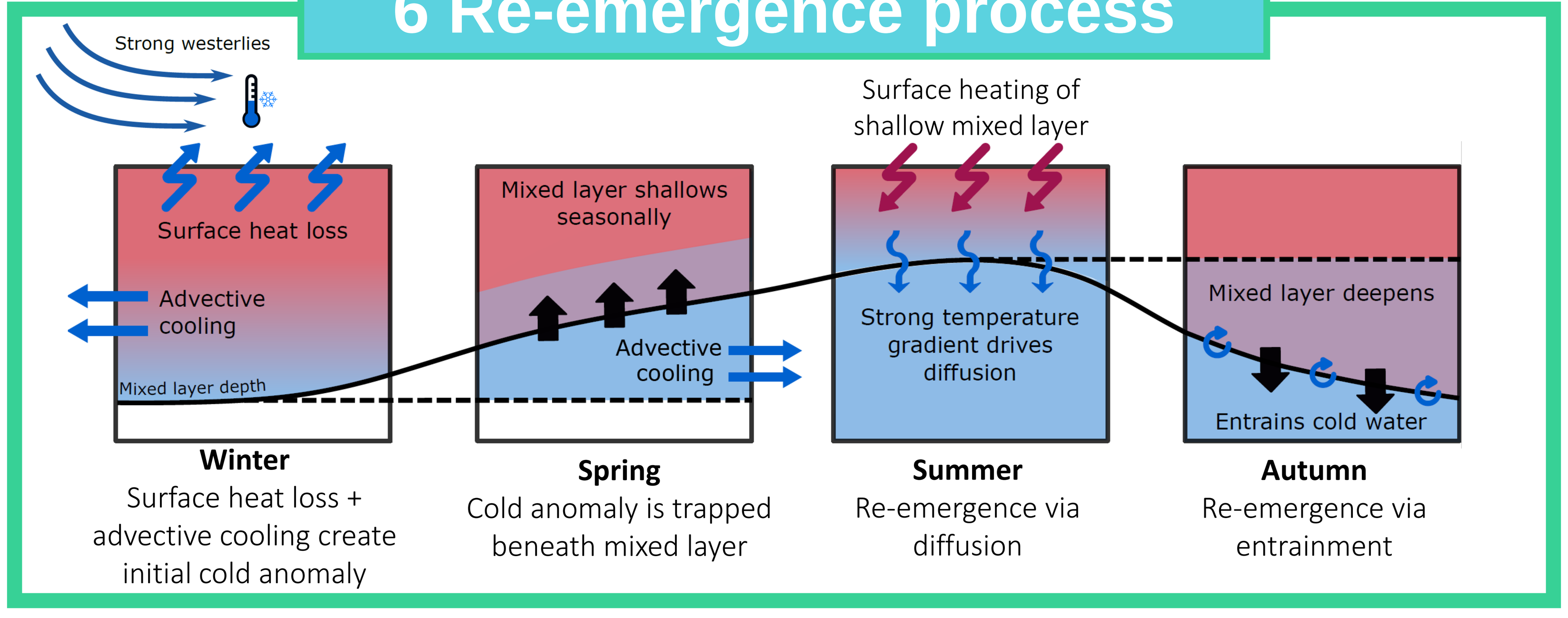


Fig 3: Surface-driven cooling of the mixed layer is controlled by the net heat flux and MLD. Strong cooling in December 2013 (red) is due to a strong net flux out of the ocean (blue), and greater in the south due to shallower mixed layers. In winter 2014/15, a strong net surface flux in the north has a limited effect on mixed layer temperature due to anomalously deep mixed layers.

6 Re-emergence process



6 Strong temperature gradients driving diffusion

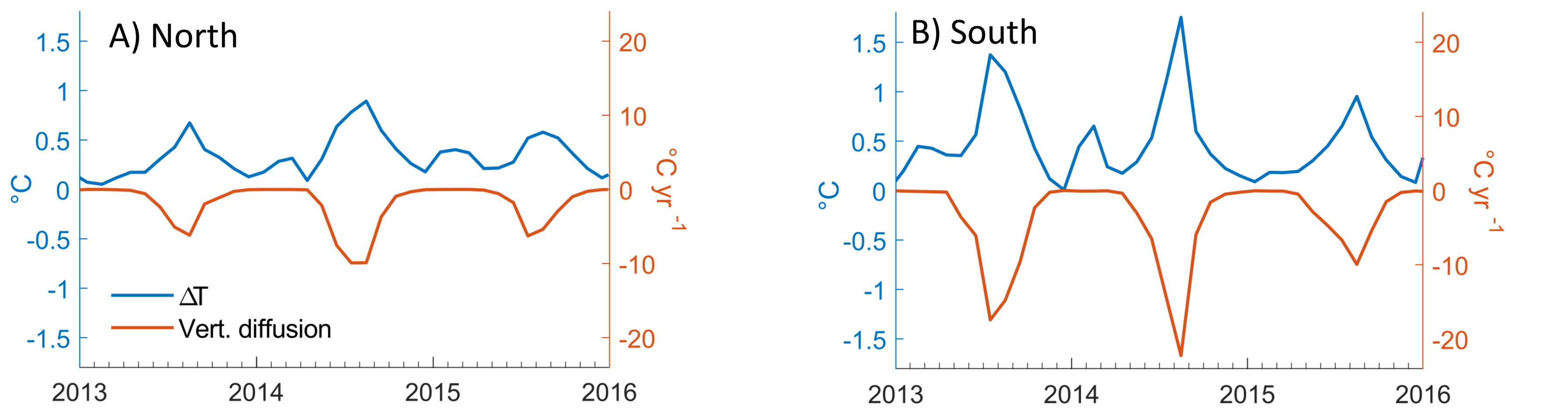
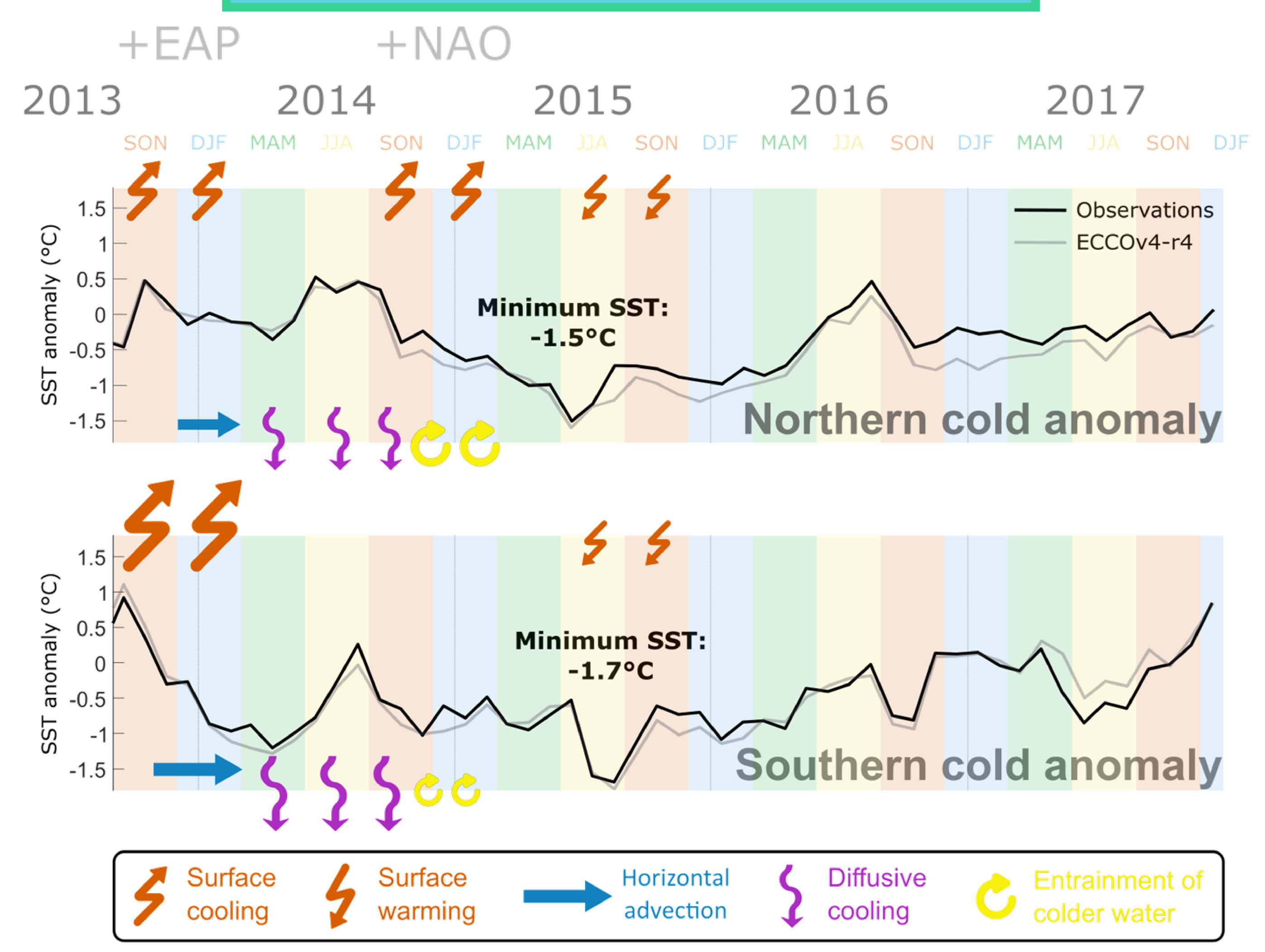


Fig 4: A strong temperature gradient across the mixed layer base (blue) in summer/autumn 2014 leads to strong diffusion, driving re-emergence of the anomaly. In the north, 60% of re-emergence is due to diffusion, with the rest due to entrainment, while in the south, 80% is due to diffusion.

8 Summary



Strong surface cooling in the winter of 2013/14, associated with anomalous winds accounts for 75% of initial cooling in the cold blob region.

Re-emergence of the cold anomaly the following year is driven by 70% vertical diffusion due to a strong temperature gradient across the base of the mixed layer, before weaker entrainment drives the remaining 30% .

Strong surface cooling in the winter of 2014/15 associated with the positive NAO, had little impact on the average mixed layer temperature due to deep winter mixed layers.

7 Spatial patterns in surface forcing

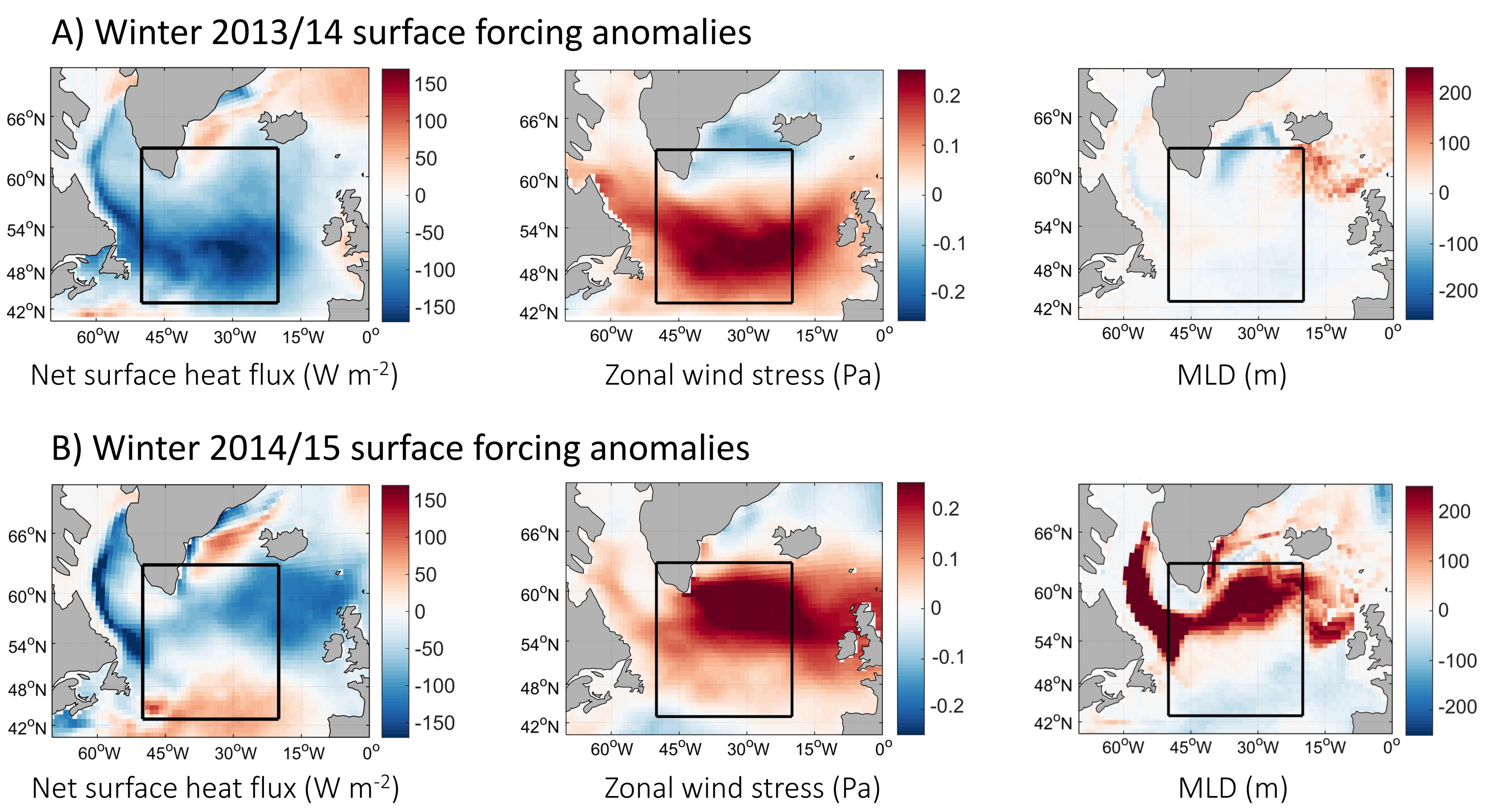


Fig 5: Strong correlation occurs between anomalies in net surface heat flux and zonal wind speed. In winter 2013/14, patterns in surface cooling in the south match those in zonal wind stress. In winter 2014/15, strong surface fluxes in the north matching zonal wind stress anomalies occurs simultaneously with anomalously deep mixed layers, explaining the lack of mixed layer cooling.

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