A Positive Feedback between the North Atlantic Warming Hole and Jet Stream

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Introduction

A persistent cooling trend in the subpolar North Atlantic known as the “Cold Blob” or “North Atlantic Warming Hole” (NAWH) appears in sea surface temperature (SST) observations since 1870. While there have been many studies of the mechanisms and impacts of the NAWH, the extent to which it interacts with the atmosphere and potential feedbacks has not received enough attention. We identify a positive feedback in which SST gradients amplify the jet stream via the thermal wind relation, which leads to stronger surface winds and cooling by latent heat flux. This response and associated mechanisms are in stark contrast with that deduced from a previous study using a lower resolution atmospheric model.

Experiment and Methods

Model Set-up: CESM2.0 model framework with (CAM6) (Kay et al., 2015; Danabasoglu et al., 2020) at 1° resolution and HadISST (Rayner et al., 2003) used for CESM2 with prescribed SST

Experiment 1: forced by monthly climatology from HadISST (1° horizontal spatial resolution), averaged from 1870-2019 repeated 45 times, and all other sources of forcing, including carbon dioxide, held constant at 2000-year levels.

Experiment 2: same as experiment as one, but the cooling trend, also found with HadISST, was subtracted from modern climatology.

Atmospheric Response: Experiment 2- Experiment 1 isolates atmospheric response strictly due to the Cold Blob with modern climatology everywhere else.

Cold Blob: linear SST trend field in units ° C per century using HadISST (1870-2019) removing a basin-wide median trend (0.49C per century, calculated from 55S–60N), disregarding 2000-2005 for model "spin up," leaving 2005-2045 data to analyze

Seasonal Mean Value: Calculated during the boreal wintertime (DJF), when the jet stream is at its strongest, from 2005-2045 and with GHG levels held constant at the year 2000

Data

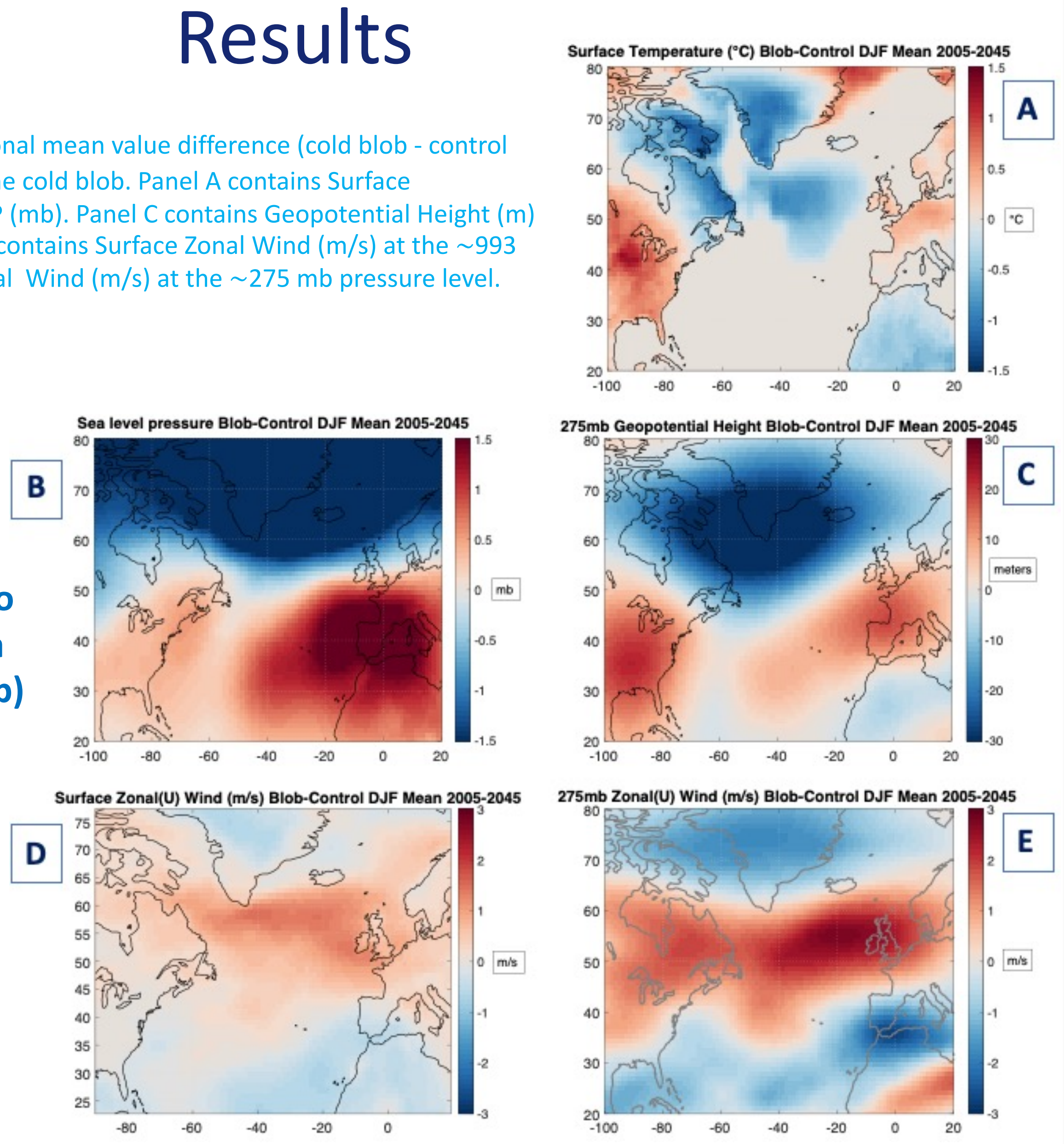
HadISST: **Observed SST** Rayner et al.,2003

CESM2.0 with CAM6: **Model Framework** Kay et al., 2015 & Danabasoglu et al., 2020

Cheyenne: **Model output stored**

Results

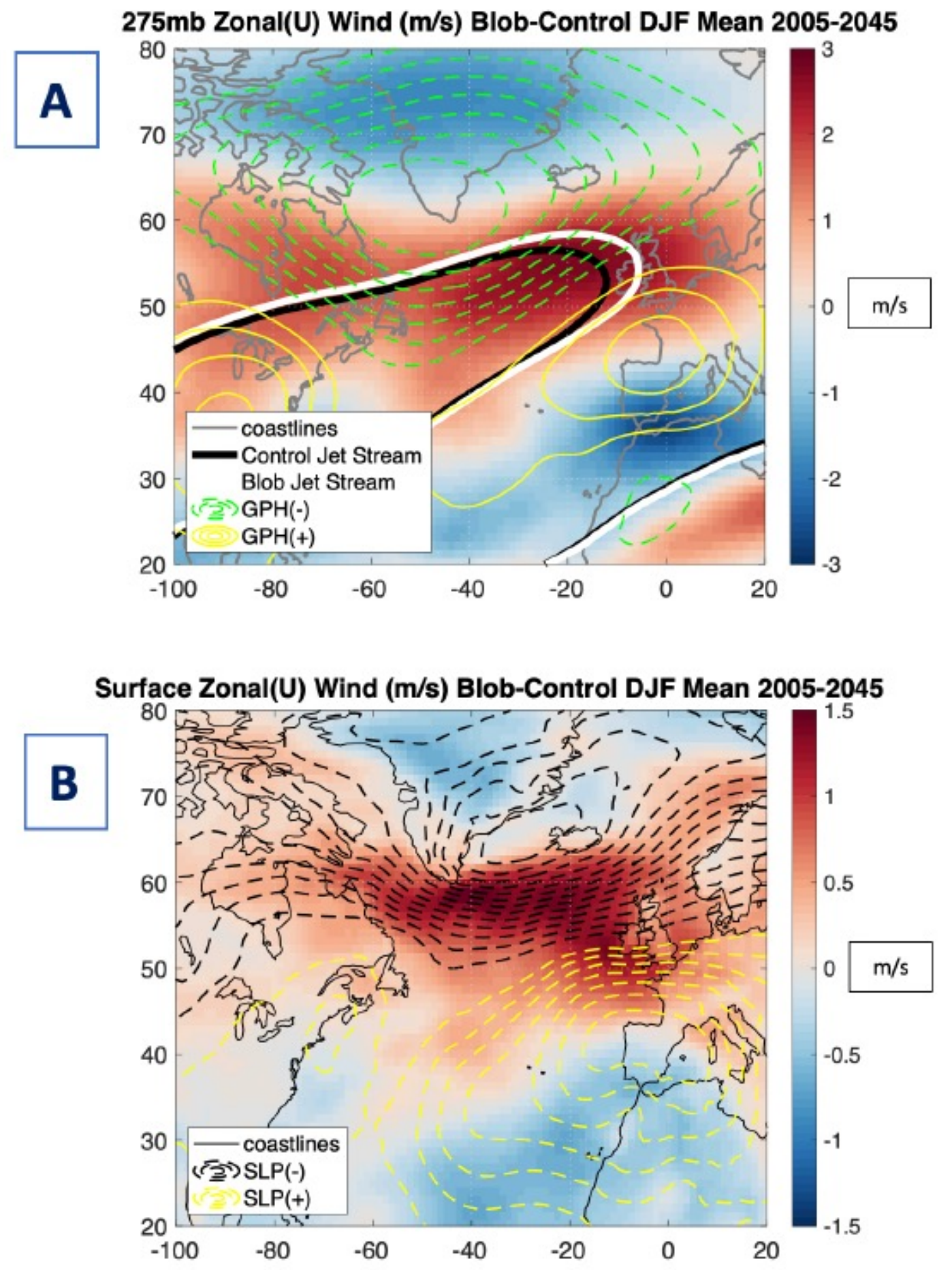
Figure 1. All data represents the seasonal mean value difference (cold blob - control experiment) isolating the response to the cold blob. Panel A contains Surface Temperature (° C). Panel B contains SLP (mb). Panel C contains Geopotential Height (m) at the ~275 mb pressure level. Panel D contains Surface Zonal Wind (m/s) at the ~993 mb pressure level. Panel E contains Zonal Wind (m/s) at the ~275 mb pressure level.



Key points:

- →Anomalous SST’s in the cold blob region have a maximum of ~1° C
- →Anomalous surface low to the North (~1.5mb) and a high to the south (~1.5mb)
- → Anomalous upper level low to the North (~30m) and a high to the south (~15m)
- →Westerly wind increases at the surface (~1.5 m/s) and at the height of the jet stream (~2.8 m/s)

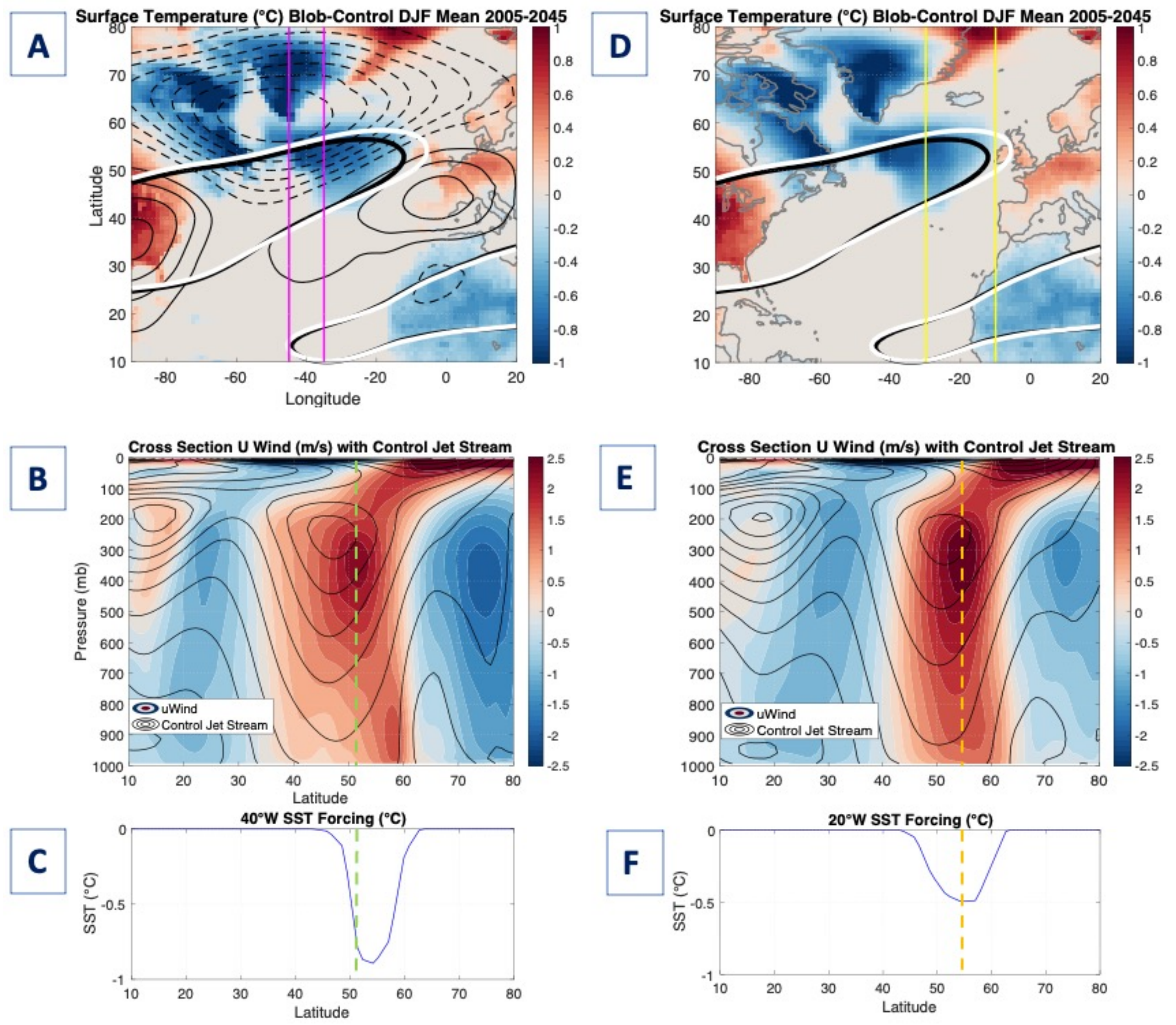
Figure 2. Panel A contains the geopotential height (m) and the zonal wind (m/s), as well as the control experiment jet stream, and the cold blob experiment jet stream at ~275 mb. The Jet Stream contours contain a threshold of $\geq 25\ m/s$. Panel B contains the SLP (mb) and zonal wind (m/s) at the surface (~993 mb).



Key points:

- → When cold blob is present jet stream becomes elongated and stretches to the East by ~8°
- → Upper level and surface level pressure anomalies are in an opposite position to what was found at lower resolution in Karnauskas et al. 2021

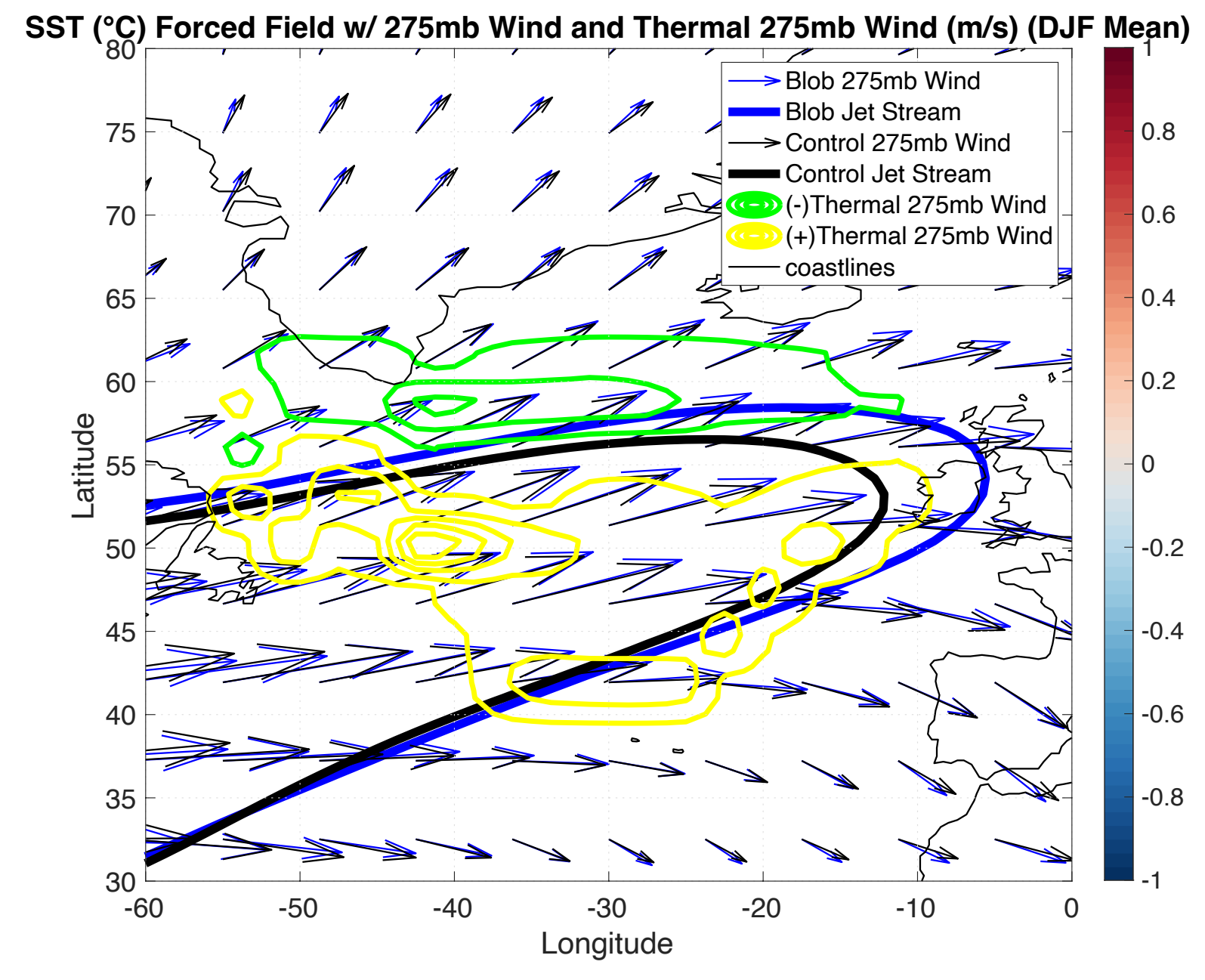
Figure 3. Panels A and D contain the Surface Temperature (° C) and the control and cold blob experiment jet streams at ~275 mb. The lines indicate the cross-section range found in Panels B (magenta) and E (yellow). Panels B and E contain the cross-section of the zonal wind (m/s) response with height (35W-45W and 10W-30W), location of the control jet steam (contours), and maximum increase in zonal wind (green and orange dashed lines). Panel C and F show SST Forcing of the cold blob along 40W and 20W and indicates the maximum zonal wind speed increase (green and orange dashed lines).



Key points:

- → Trickle down impact on zonal wind from the level of the jet stream to the surface can be seen in Panels 3B and 3E
- → The strongest zonal wind acceleration is in line with the thermal wind forcing in Panel B, but shifted to the NE in Panel E.

Figure 4. Sea Surface Temperature forced field overlayed with wind vectors showing control (black) and cold blob (blue) 275 mb wind, and jet stream contours $\geq 25\ m/s$. Contours show negative thermal 275mb wind between -0.25 and -5.0 m/s (green) and positive thermal 275mb wind between 0.25 and 5.0 m/s (yellow).

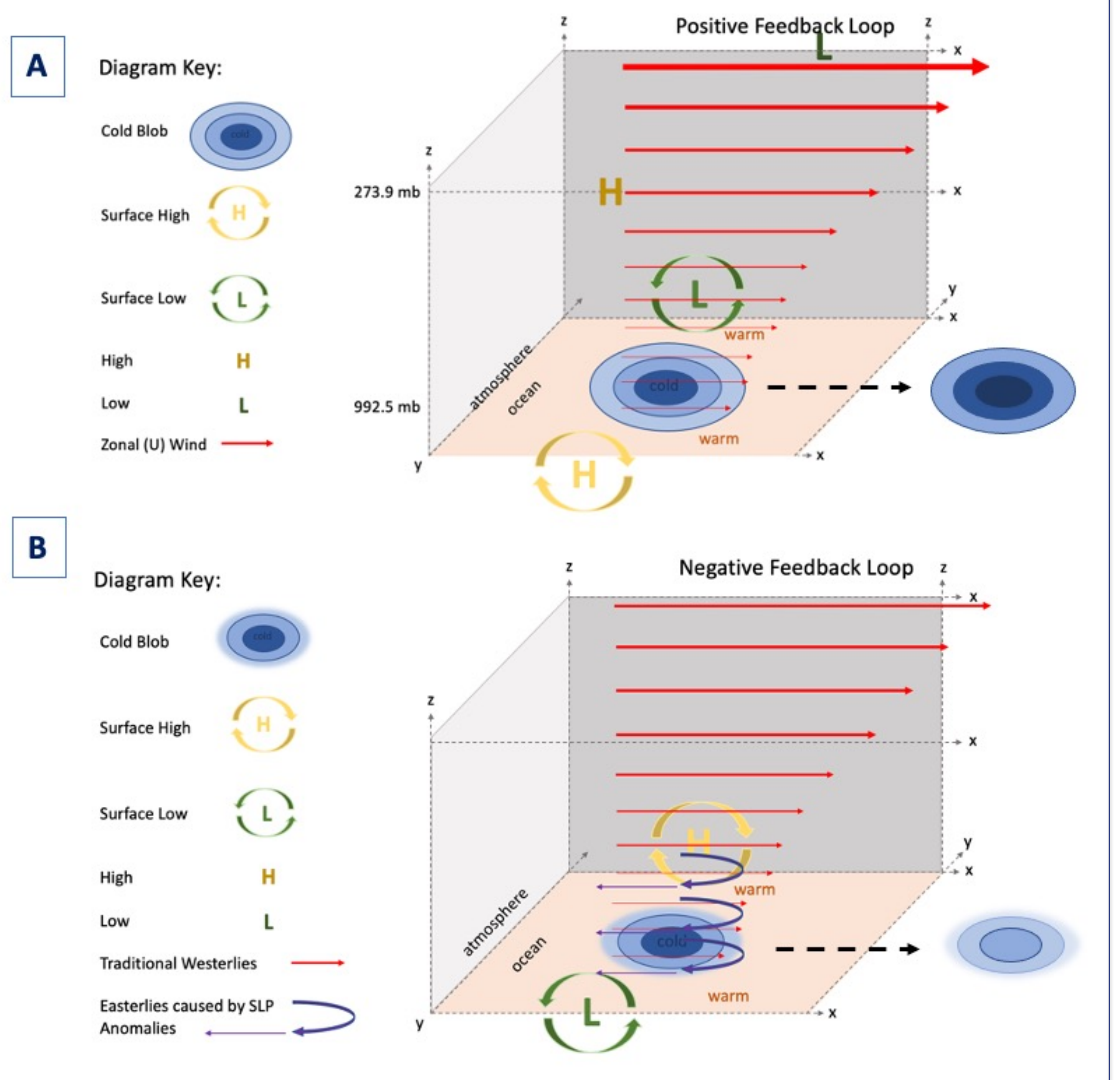


Key points:

- → The mean flow of the jet stream advects the thermal wind driven anomaly eastward
- → Justifies why the thermal wind forcing is shifted to the North East rather than at the center of the jet stream contour in Panel 3E.

Mechanism

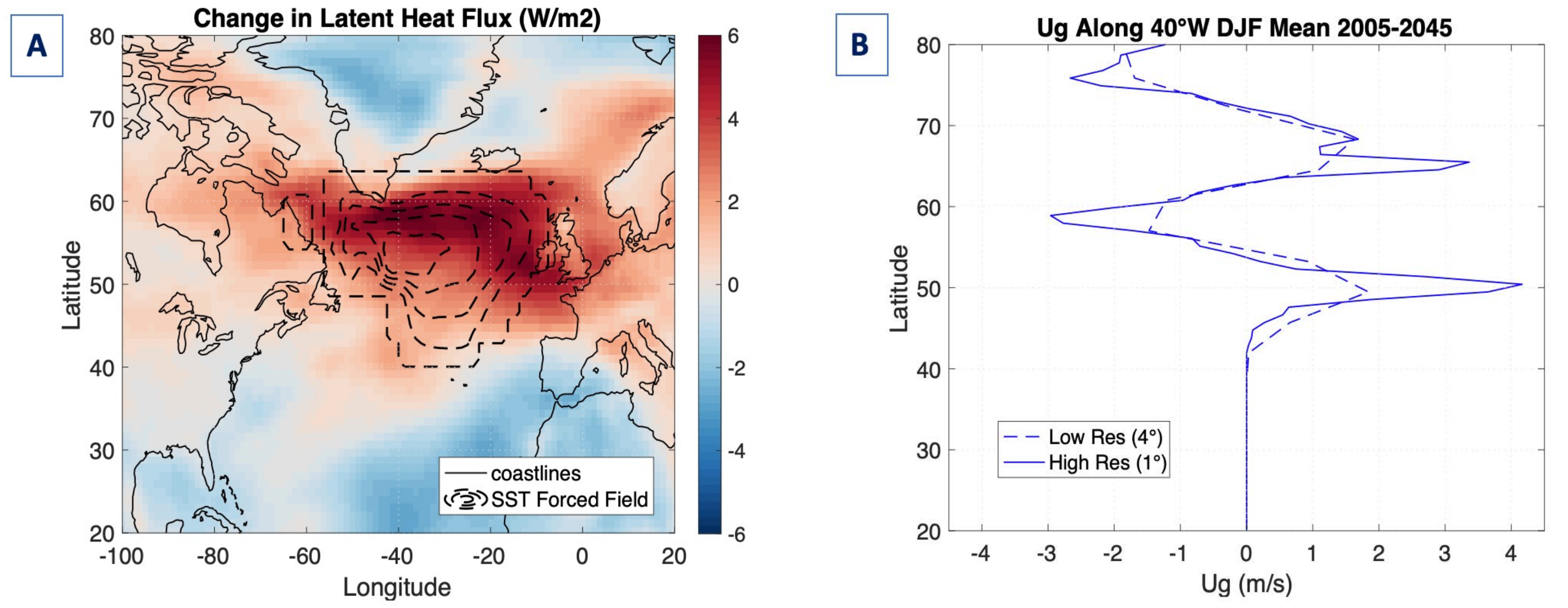
Figure 5. Panel A is an idealized diagram to illustrate the proposed positive feedback loop ultimately leading to an enhanced cold blob. Panel B is an idealized diagram to illustrate the negative feedback loop used to describe Karnauskas et al. 2021 results ultimately leading to a weakened cold blob. Diagram keys are provided for both Panel A and Panel B.



Key points:

- → The 1° AGCM well resolves the horizontal temperature gradient, and thus, the thermal wind relation creating an opposite SLP anomaly structure than previously seen with lower resolution
- → Increased westerlies trickle from the “Top down” instead of “Surface up”

Figure 6. Panel A shows the change in latent heat due to only the change in surface zonal winds using the simple bulk formula $\Delta Q_{LH} = \rho L_V C_{LH} \Delta W_{10m} \Delta q$. The SST forced field is also included (contour) to show the placement of the cold blob in relation to the increase in latent heat flux. Panel B shows the increase in geostrophic zonal mean DJF wind along 40W in our high resolution (1°) experiment versus the identical experiment run at lower resolution (4°).



Key points:

- → When recreating the identical experiment at a lower resolution the thermal wind relation is not realized and the resulting zonal wind increase is much weaker (~1m/s) than at higher resolution (~ ±3 m/s) seen in Panel 6B.
- → There is an increase in latent heat flux with the increased surface westerlies in the cold blob region furthering the positive feedback hypothesis.

Conclusions

The resolved thermal wind relation seen at a 1° resolution enhances the jet stream which then generates an anomalous high to the South and a low to the North by triggering a geostrophic adjustment. What occurs at the ~275 mb pressure level then trickles downward, “top down,” towards the surface causing corresponding sea level pressure anomalies and stronger surface westerlies. The enhanced surface westerlies increase latent heat flux in the cold blob region creating a positive feedback that may explain its persistence. This study indicates the necessity of a higher resolution model in this region to capture the air-sea interaction at play.

References:

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