Hefur blái bletturinn áhrif á veðurfar í Evrópu ?

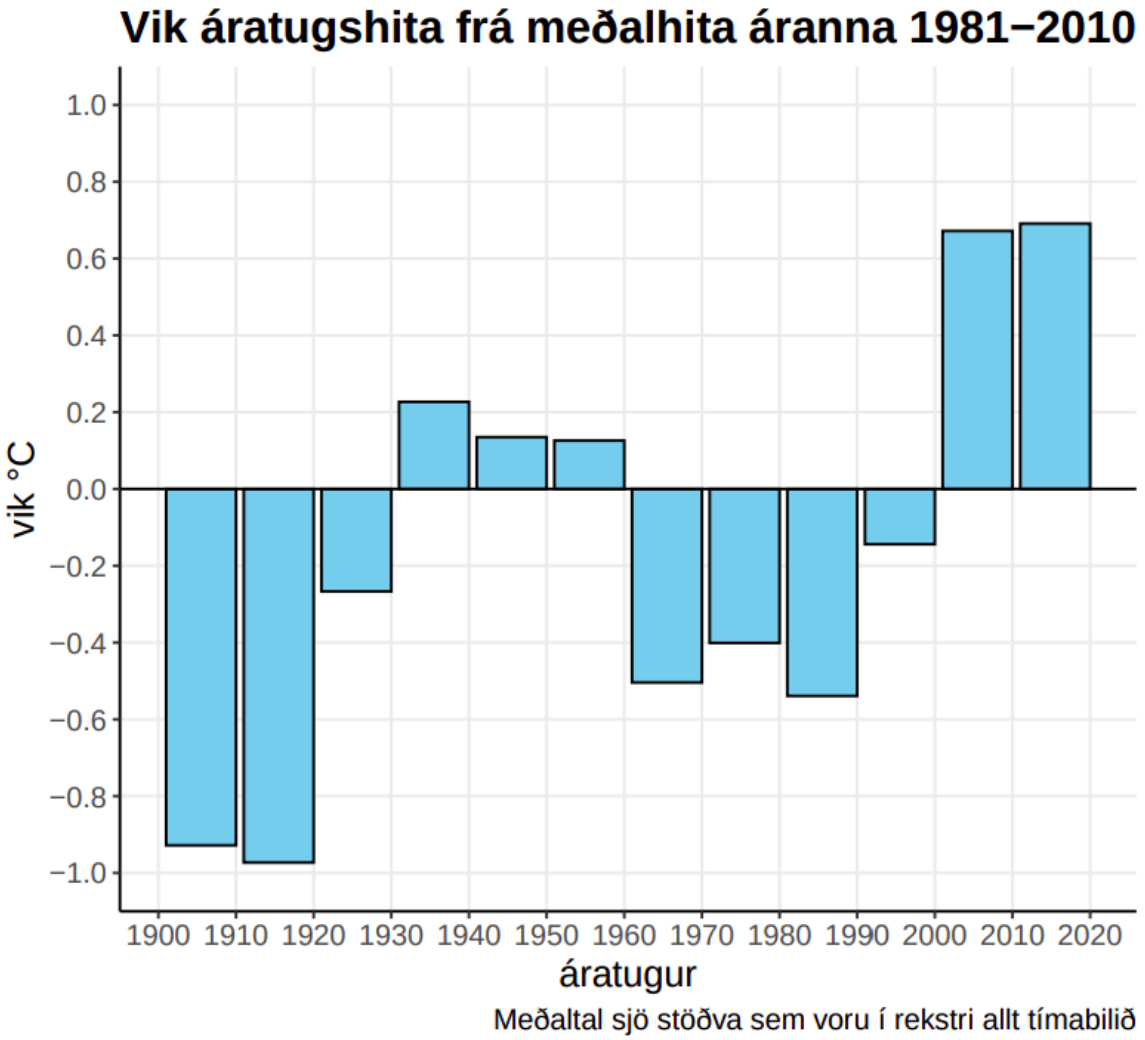
Halldór Björnsson
Veðurstofu Íslands

Byrjum á að velta fyrir okkur áratuga meðaltölum lofthita á Íslandi

Í Vísindaskýrslu 2023 er leitt líkum að því að hlýnun upp úr aldamótum sé að hluta drifin af losun gróðurhúsalofttegunda

En það er þá áhugavert að hlýnun stöðvast eftir 2010.

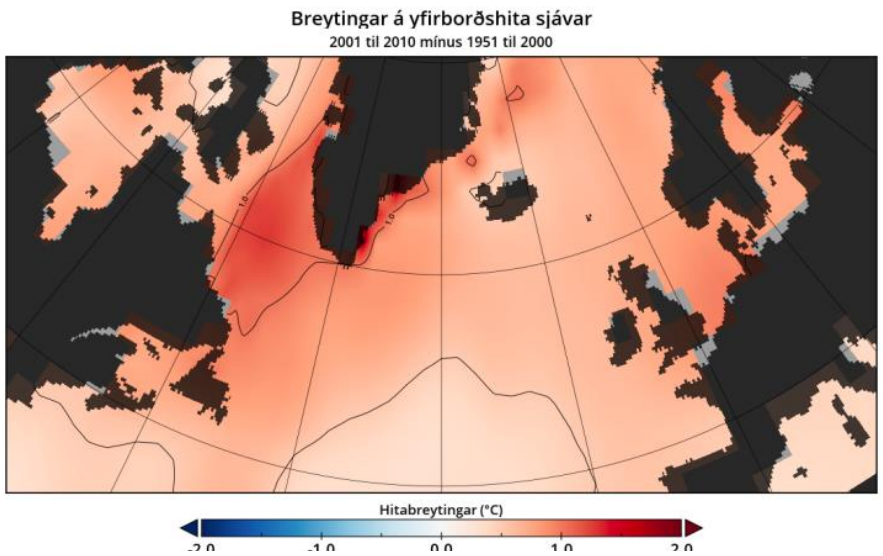
Hvað veldur þessum áratugaveiflum?

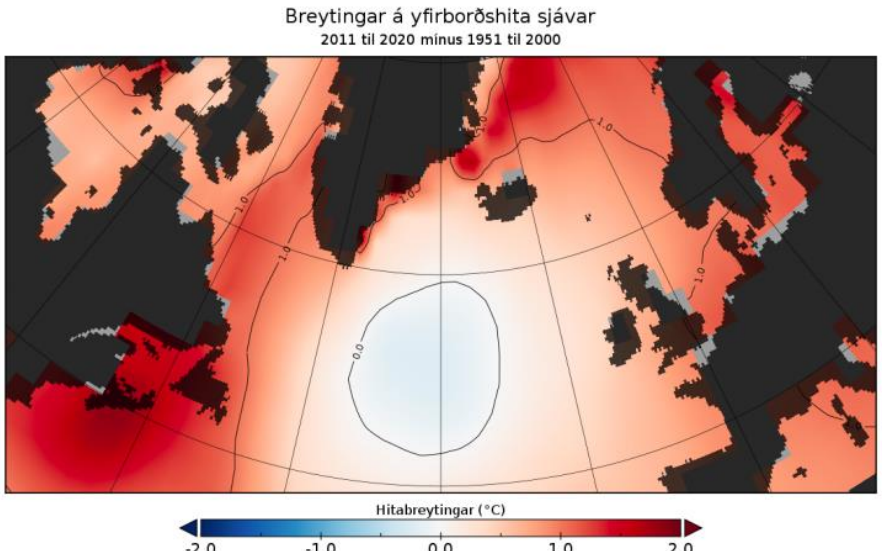


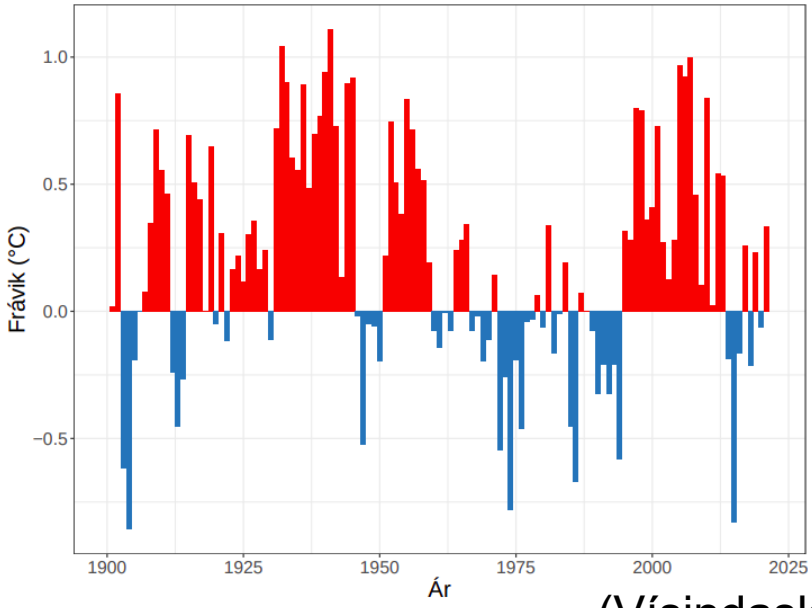
(Kristín B gerði myndina að hugmynd Trausta, Vísindaskýrsla 2023)

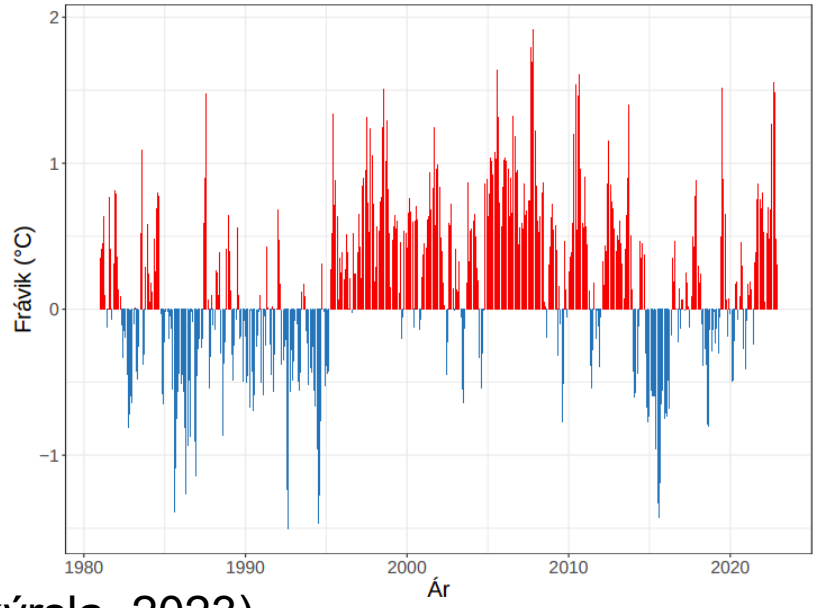
Mynd 2.4: Þróun meðalhita hvers áratugar á Íslandi frá aldamótunum 1900. Sýnd eru vik frá meðaltali áranna 1981–2010. Myndin sýnir gögn frá sjö stöðvum víðs vegar um landið, þ.e. Reykjavík, Stykkishólmi, Akureyri, Grímsey, Stórhöfða, Teigarhorni og Hæli/Árnesi. Þessar stöðvar voru í rekstri allt tímabilið.

Líklegur sökudólgur eru sjávarhitasveiflur, m.a. “NAWH, aka BlueBlob. Blái bletturinn hefur komið og farið á síðustu áratugum









(Vísindaskýrsla, 2023)

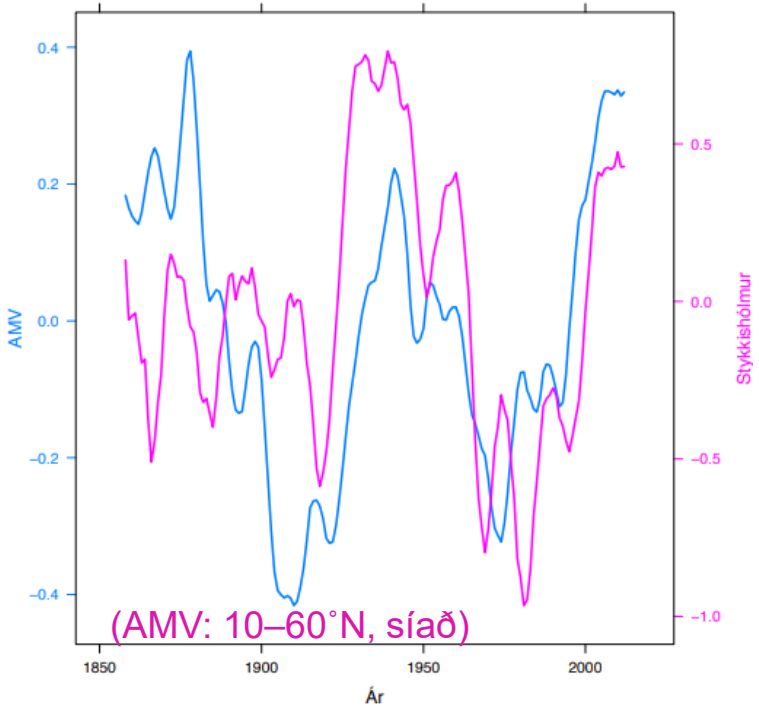
Hiti í Stykkishólmi og á Atlantshafi

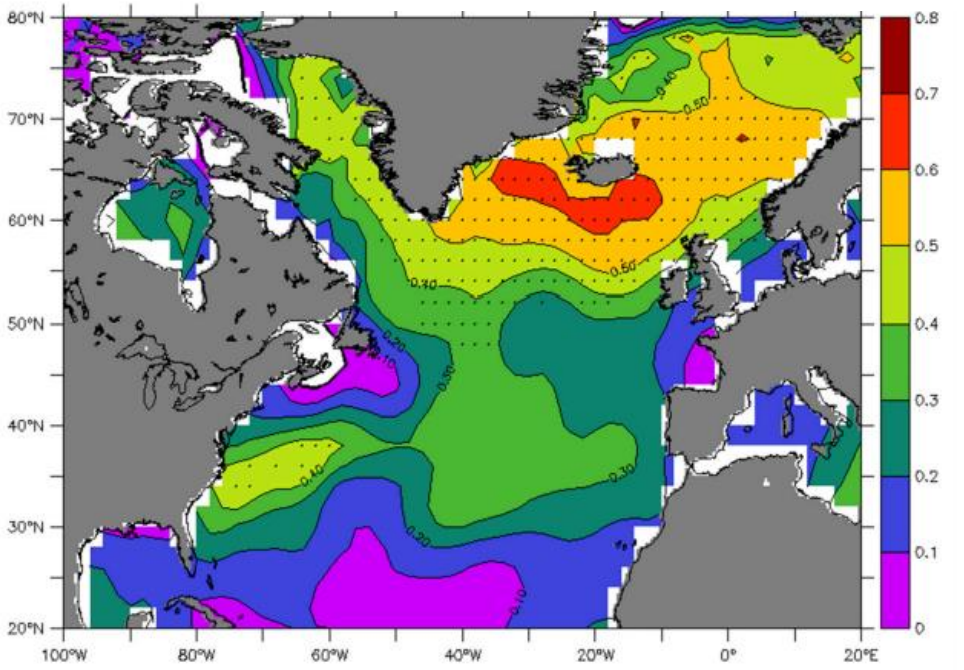
Það er sterk fylgni milli sjávarhita á Norður Atlantshafi og hita á Íslandi

Áratugasveiflur í lofthita á Stykkishólmi og yfirborðshita sjávar á N-Atlantshafi (ERSSTv5)

- AMV vs $T_{Stykkishólmur}$
- $T_{Stykkishólmur}$ vs SST (kort)

- Á báðum myndum hefur langtímaleitni verið fjarlægð úr mæliröðum



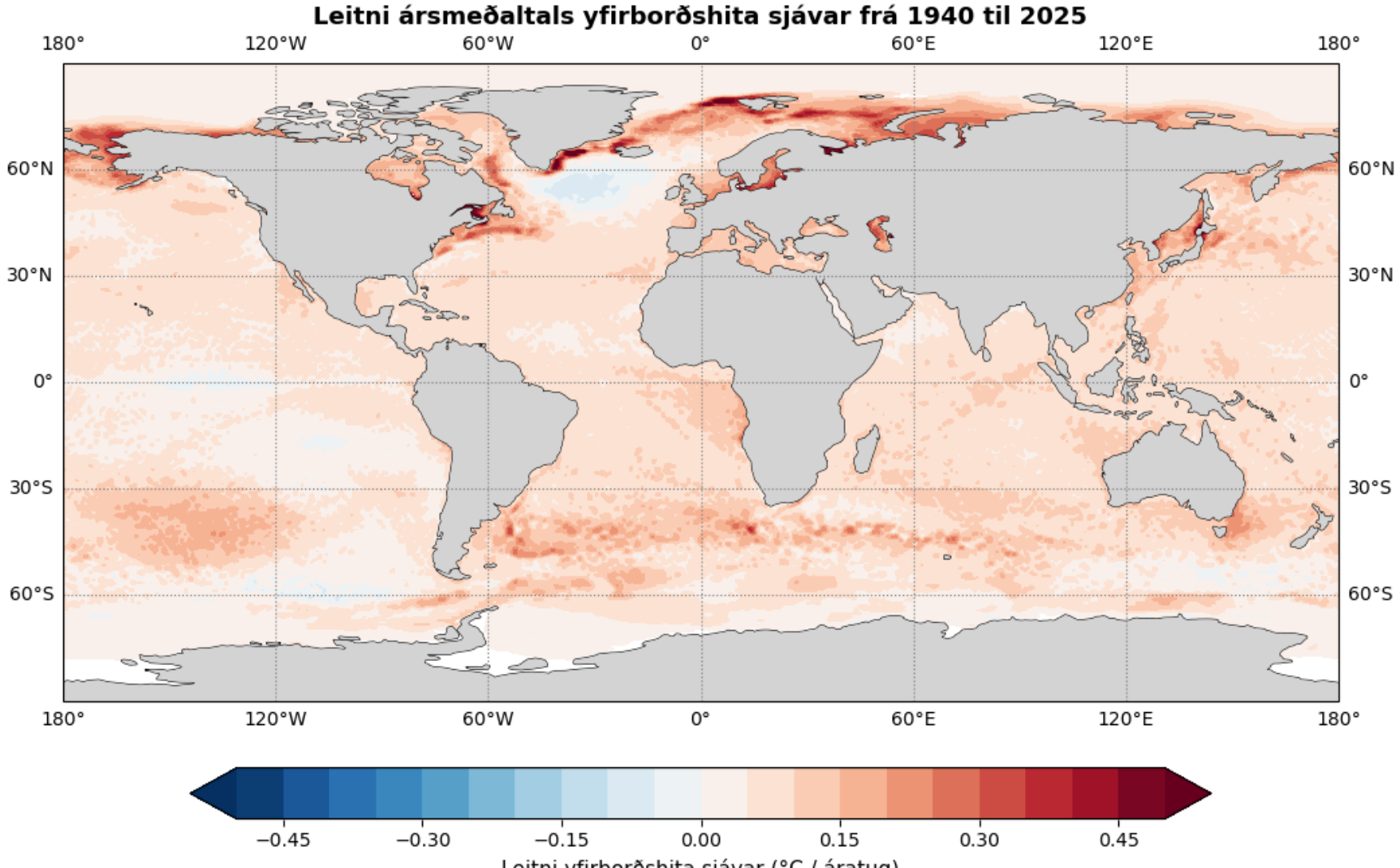


(Vísindaskýrsla, 2018)

En langtímasveiflur?

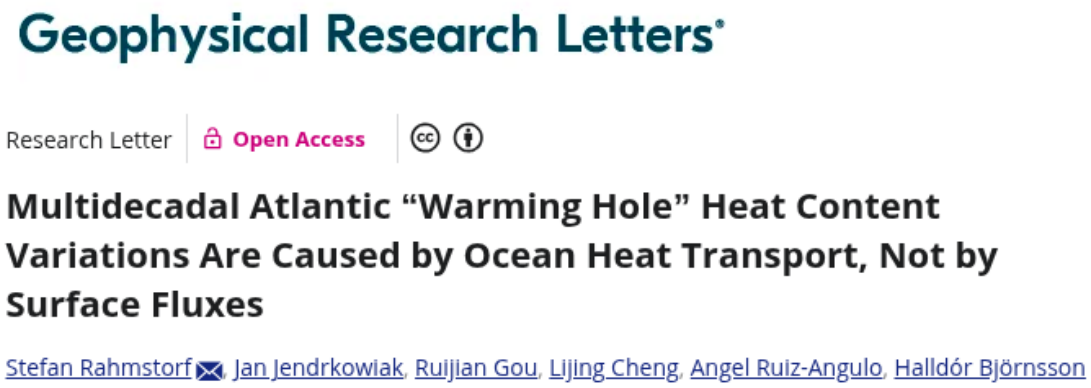
Næsta vangavelta er hvort langtímasveiflur í aðstæðum í sjó séu eitthvað annað fyrirbærir en áratugasveiflur

Eru þær marktækar?

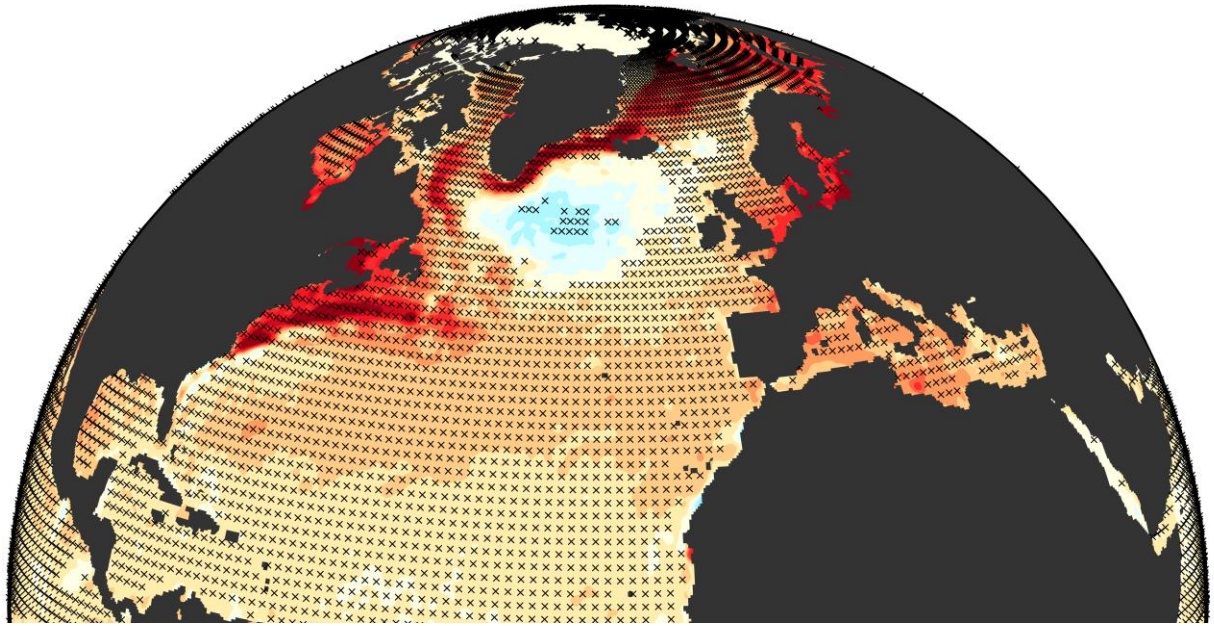


Leitni og marktækni

- Við skrif greinarinnar



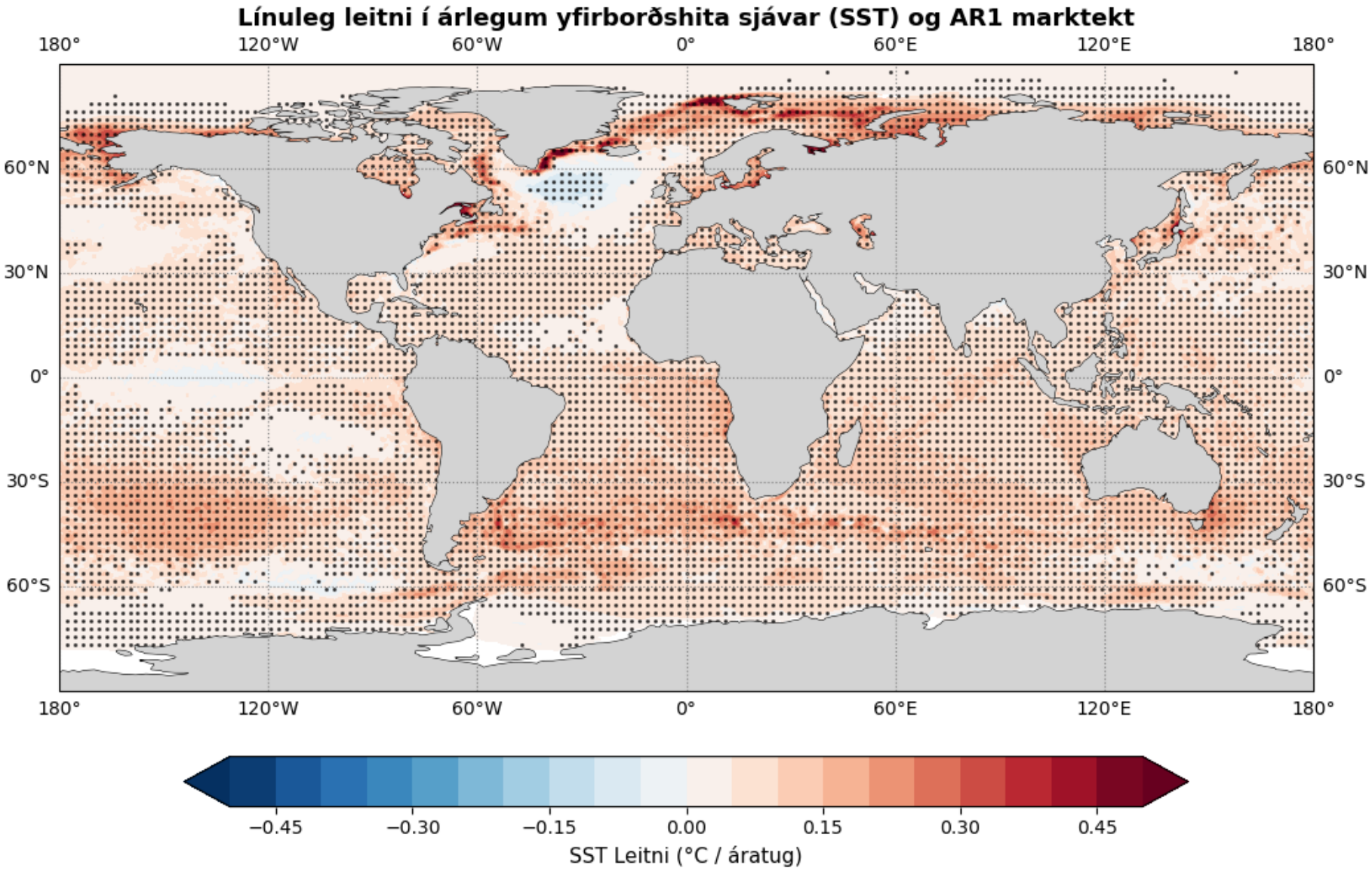
- voru vangaveltur hjá höfundum um hvernig ætti að ræða marktækni sjávarhitabreytinga



SST leitni 1955 til 2022. **Gildi með p> 0.1 er metin marktæk og merkt með x**
Angel Ruiz gerði runu af myndum og þessi er ein þeirra

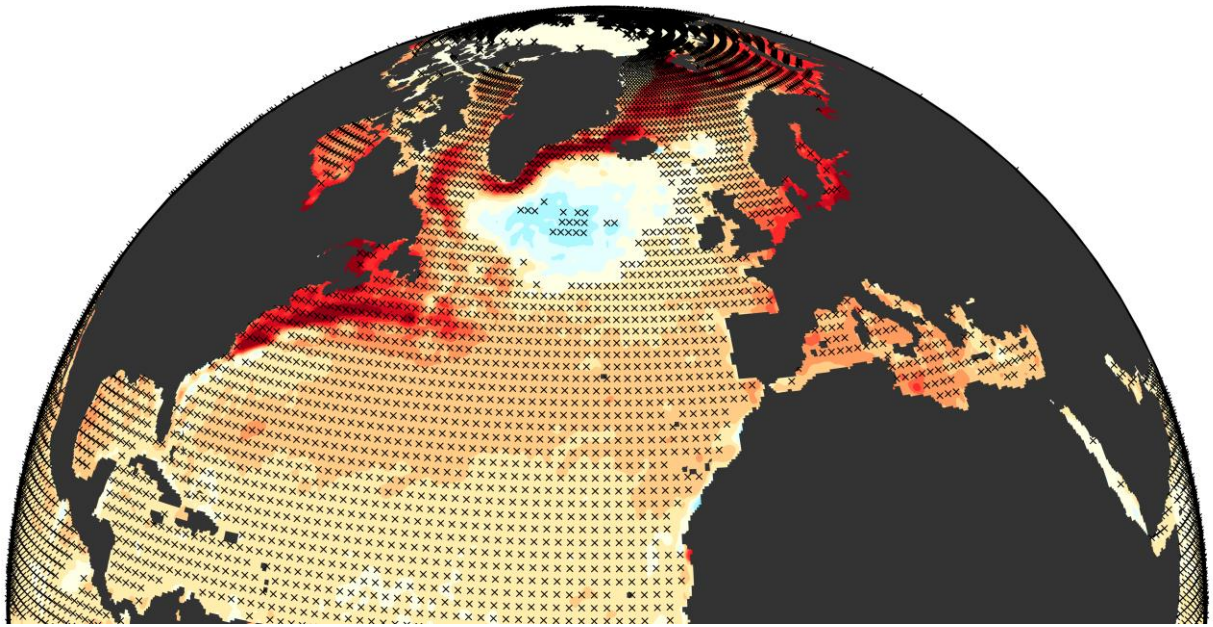
Leitni 1940 til 2025 og AR1 95% marktækni

(marktækt merkt með .)



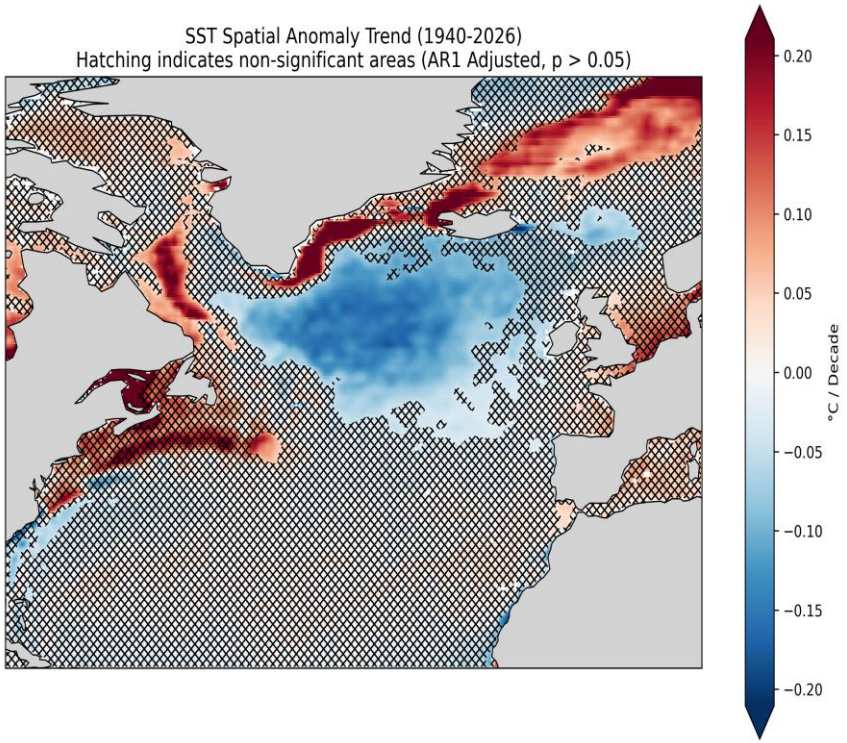
Marktækni hvers?

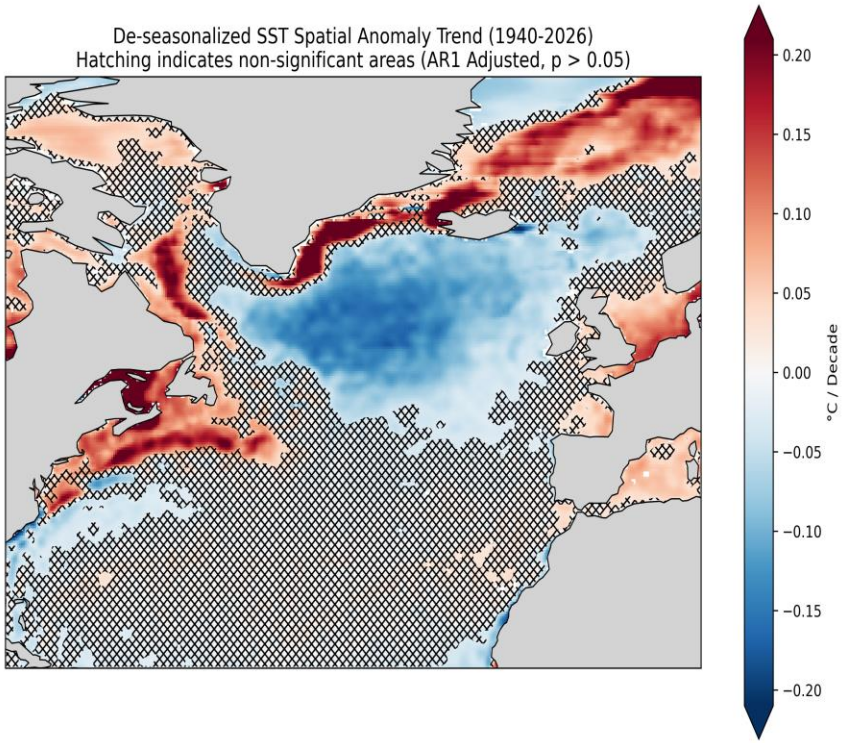
Á að skoða marktækni hitabreytinga ?
Eða marktækni þess hversu þetta svæði er ólíkt öðrum svæðum ?



Eftir að greinin kom út fór ég að skoða þetta aðeins og reiknaði vik sjávarhita (mánaðargagna) frá meðaltali sjávarhita í norður Atlantshafi

Tvær útgáfur:
a) svæðisbundið mánaðarmeðaltal dregið frá SST gögnum: Monthly Spatial Anomaly
b) MSA löguð frekar þannig að ársíðasveiflan (leif) er reiknuð og dregin frá hverjum mánuði (De-seasonalized SST SA Trend)

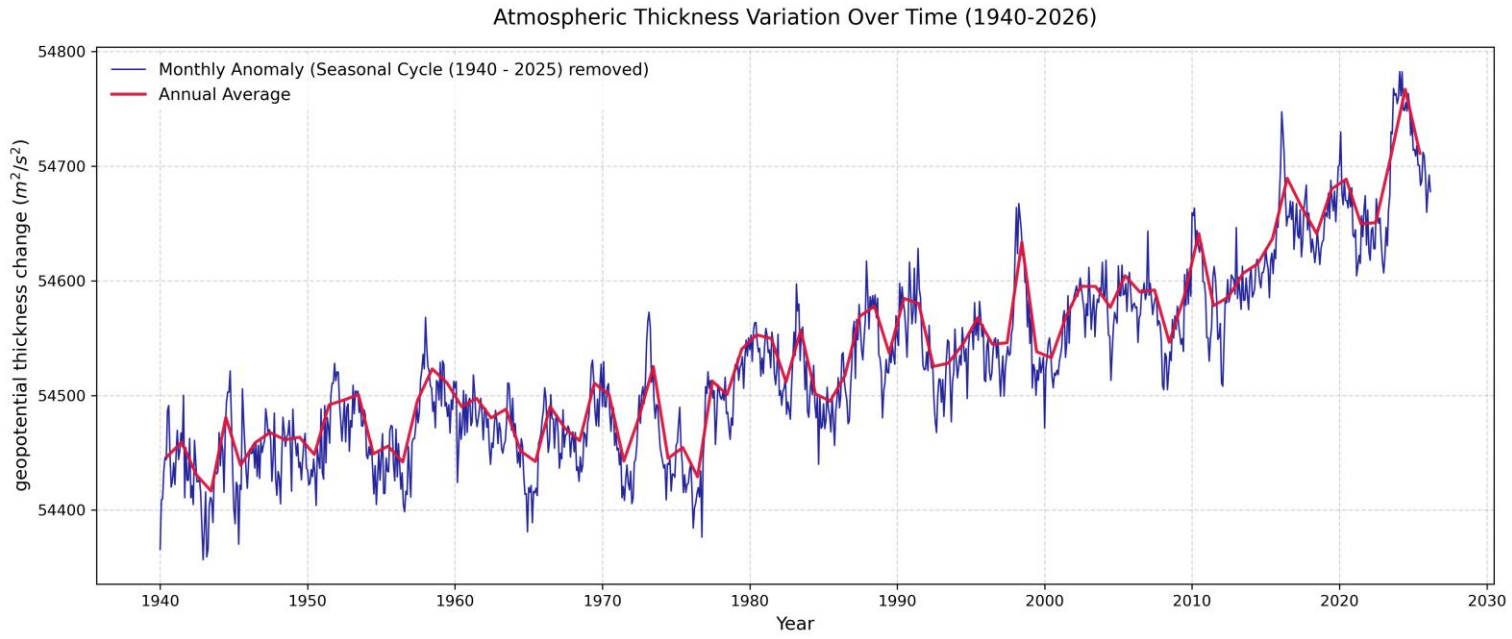


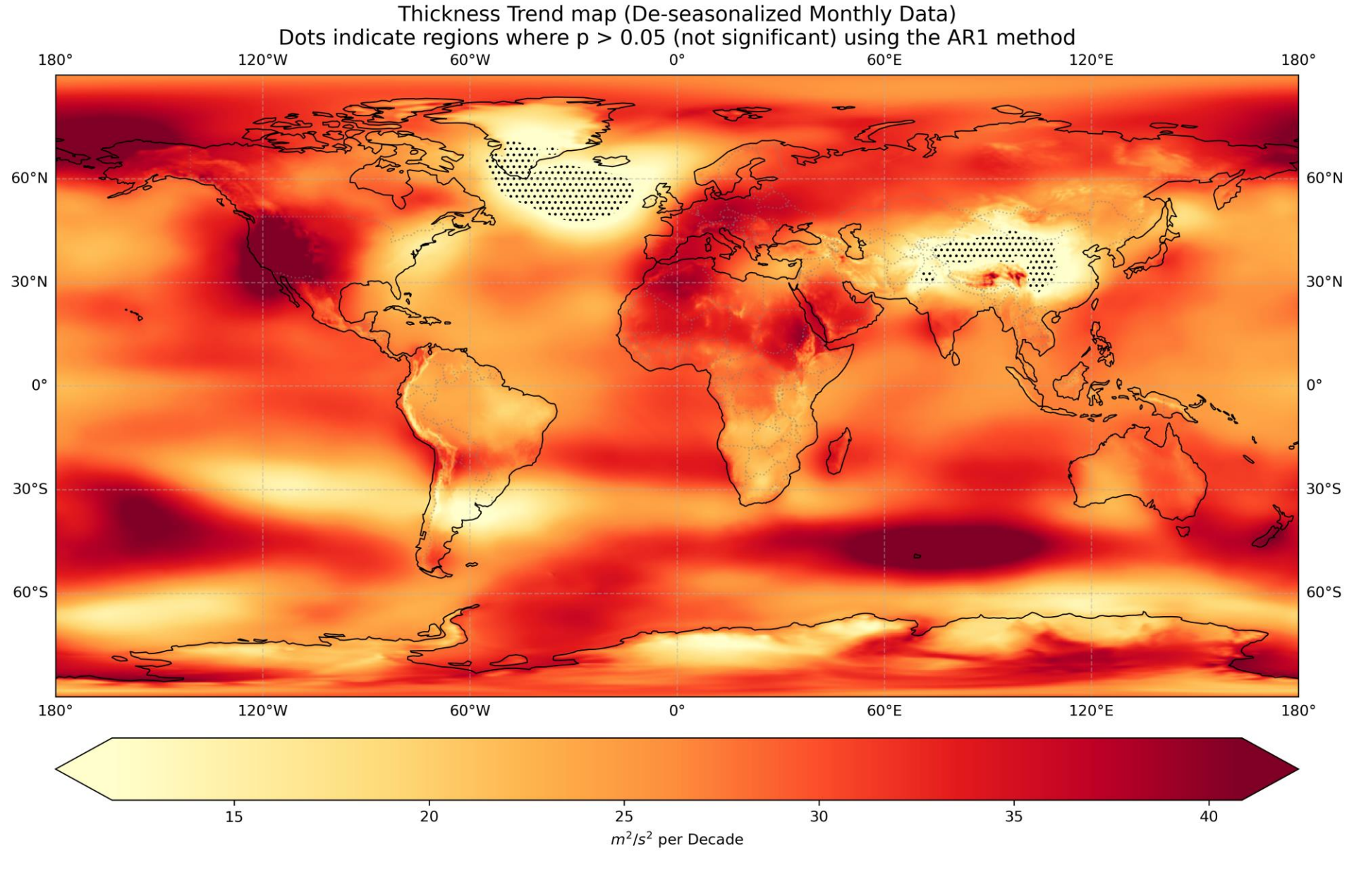


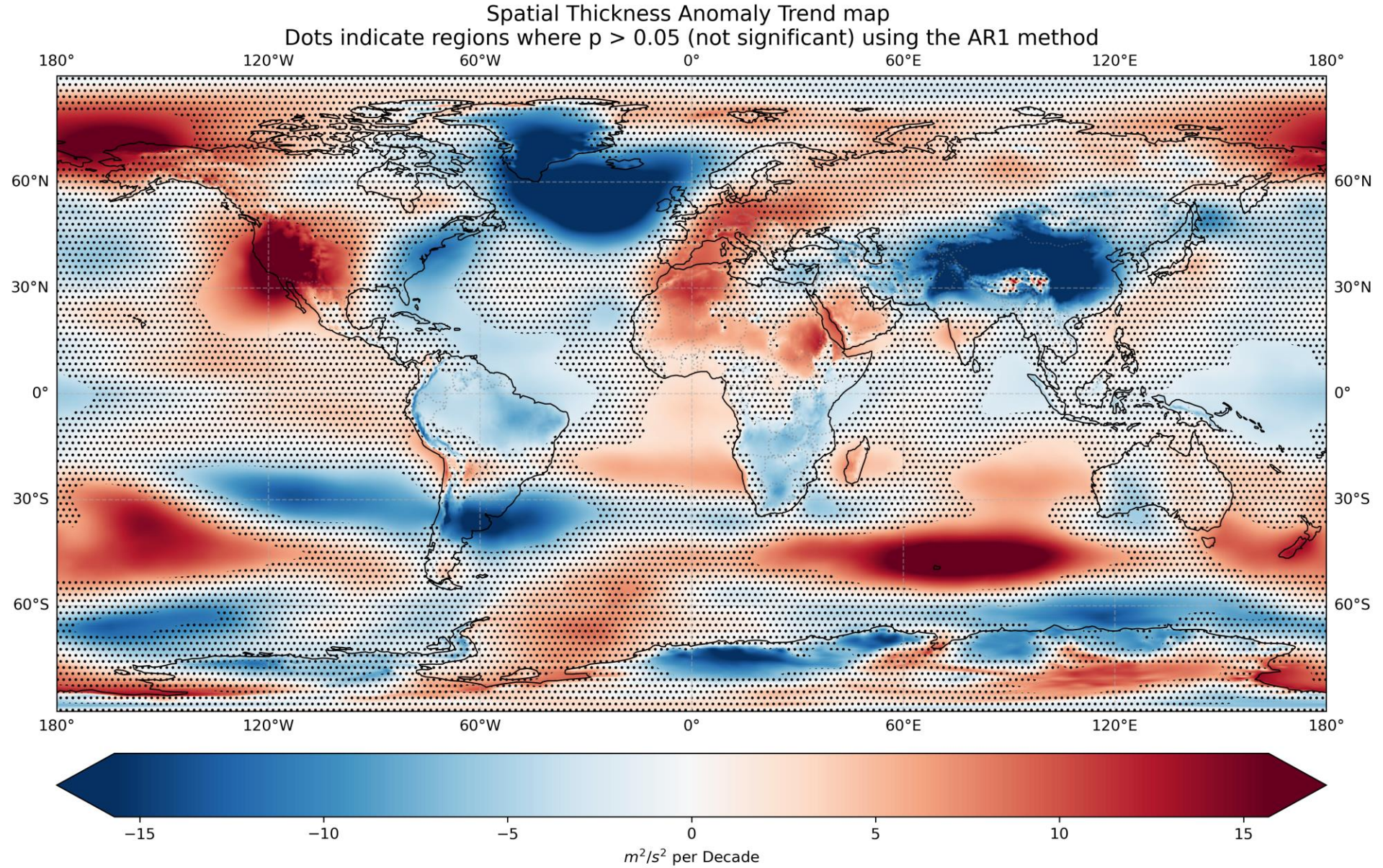
Niðurstaðan er sú að kólnun á bláa blettinum er mjög markæk (og svo er fullt af öðru skemmtiefni þarna). **Hér eru ómarktæk svæði merkt x**

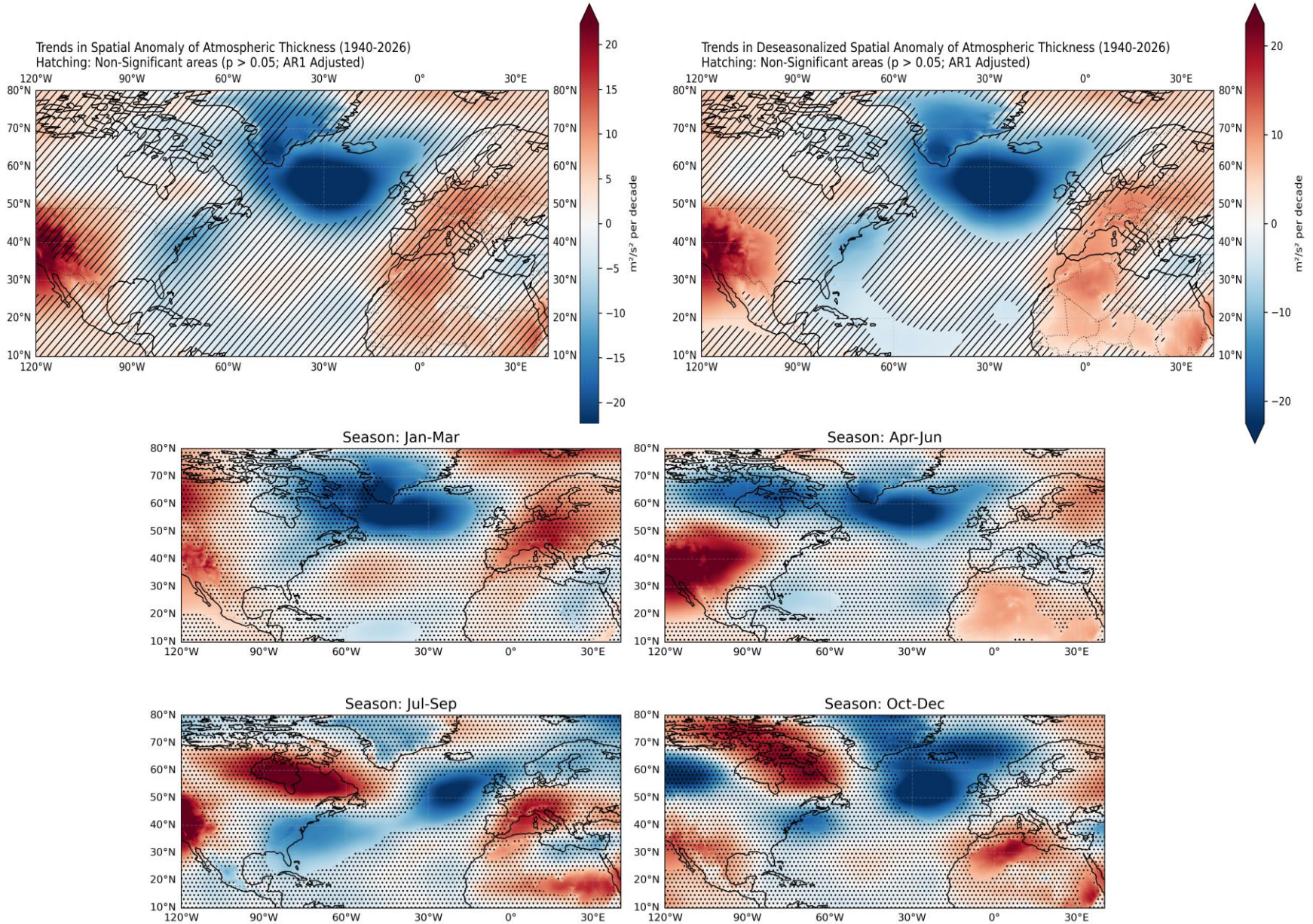
Vangaveltur 3:
Hefur þetta haft áhrif á lofthjúpinn?

- Ef eitt svæði kólnar og jaðar þess hlýnar myndum við búast við þykktarbreytingum.
- Skoðum þróun 500hPa mættishæðar
  - Hefur aukist í takt við hlýnun jarðar




Thickness Trend map (De-seasonalized Monthly Data)
Dots indicate regions where p > 0.05 (not significant) using the AR1 method
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
30°N
0°
30°S
60°S
15
20
25
30
35
40
m^2/s^2 per Decade


Spatial Thickness Anomaly Trend map
Dots indicate regions where p > 0.05 (not significant) using the AR1 method
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
30°N
0°
30°S
60°S
−15
−10
−5
0
5
10
15
m^2/s^2 per Decade

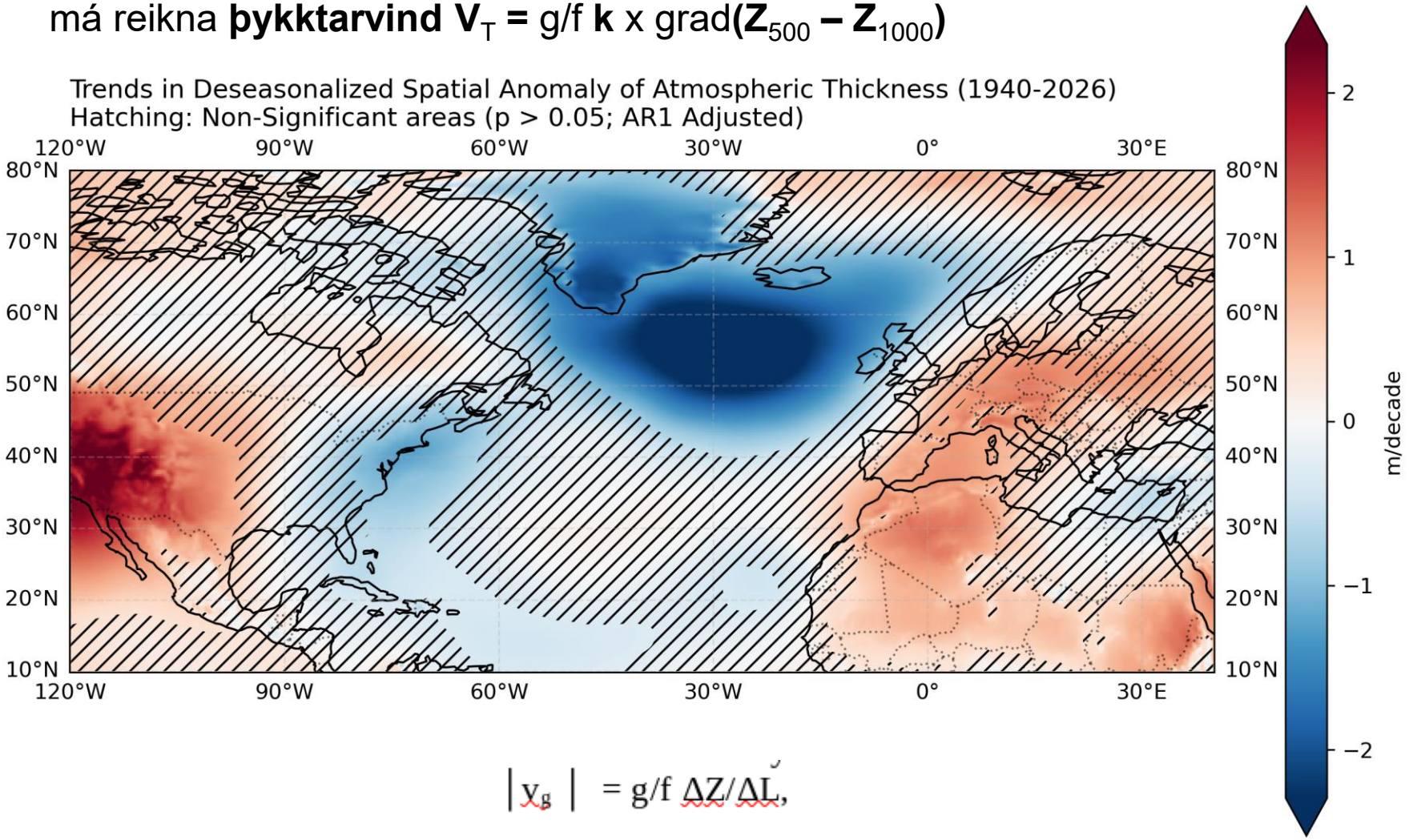

Trends in Spatial Anomaly of Atmospheric Thickness (1940-2026)
Hatching: Non-Significant areas (p > 0.05; AR1 Adjusted)
Trends in Deseasonalized Spatial Anomaly of Atmospheric Thickness (1940-2026)
Hatching: Non-Significant areas (p > 0.05; AR1 Adjusted)
m²/s² per decade
Season: Jan-Mar
Season: Apr-Jun
Season: Jul-Sep
Season: Oct-Dec
Trends in De-seasonalized Spatial Anomaly of Atmospheric Thickness (1940-2026) by Season
Hatching: Non-Significant areas (p > 0.05; AR1 Adjusted)
Thickness Trend (m²/s² per decade)

Hefur þetta haft áhrif á lofthjúpinn?

- Þykktarbreytingar í fylgja svipuðu mynstri og sjávarhiti (SST).
- Á meðan þykkt eykst nær um nánast allsstaðar vegna hlýnunar, er engin marktæk aukning yfir bláa blettinum (NAWH).
- Fjalllendi krefst varúðar: Túlka þarf 1000 hPa sviðið með varúð yfir hálendi (Klettafjöllum, Himalaja, Andes og Grænlandi).
- Aukið vestan við bláa blettinn til Evrópu: Meiri þykktarstigull yfir kuldablettinum gæti útskýrt aukna þykkt og hlýnun yfir Vestur-Evrópu.
- Getum skoðað þetta með því að athuga þykktarvind (thermal wind)

Þykktarvindur, mættishæð og ΔZ

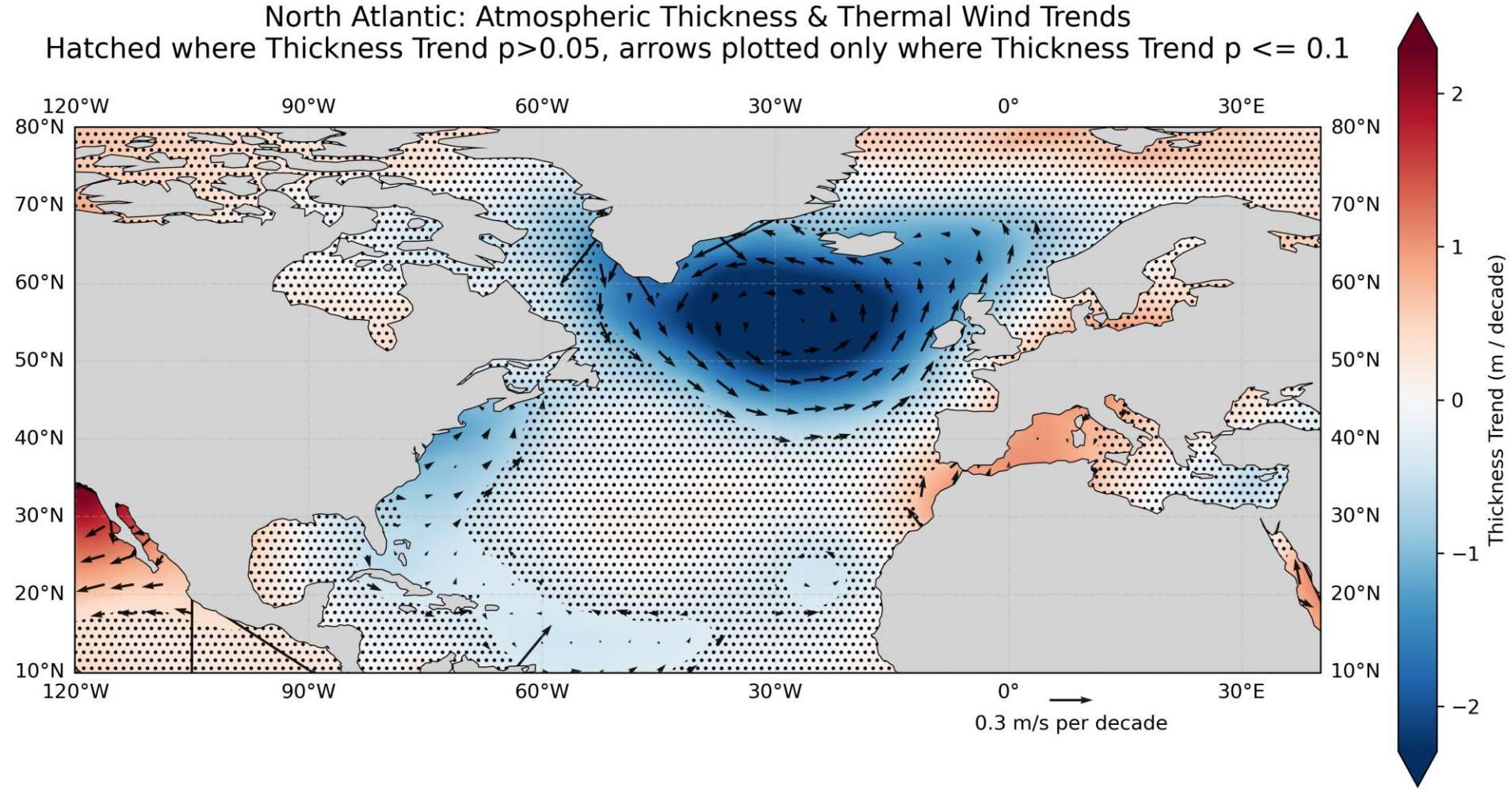
ΔZ er skylt mættishæð Φ þ.a. ΔZ = Φ/g og út frá ΔZ
má reikna **þykktarvind V_T = g/f k x grad($Z_{500} - Z_{1000}$)**



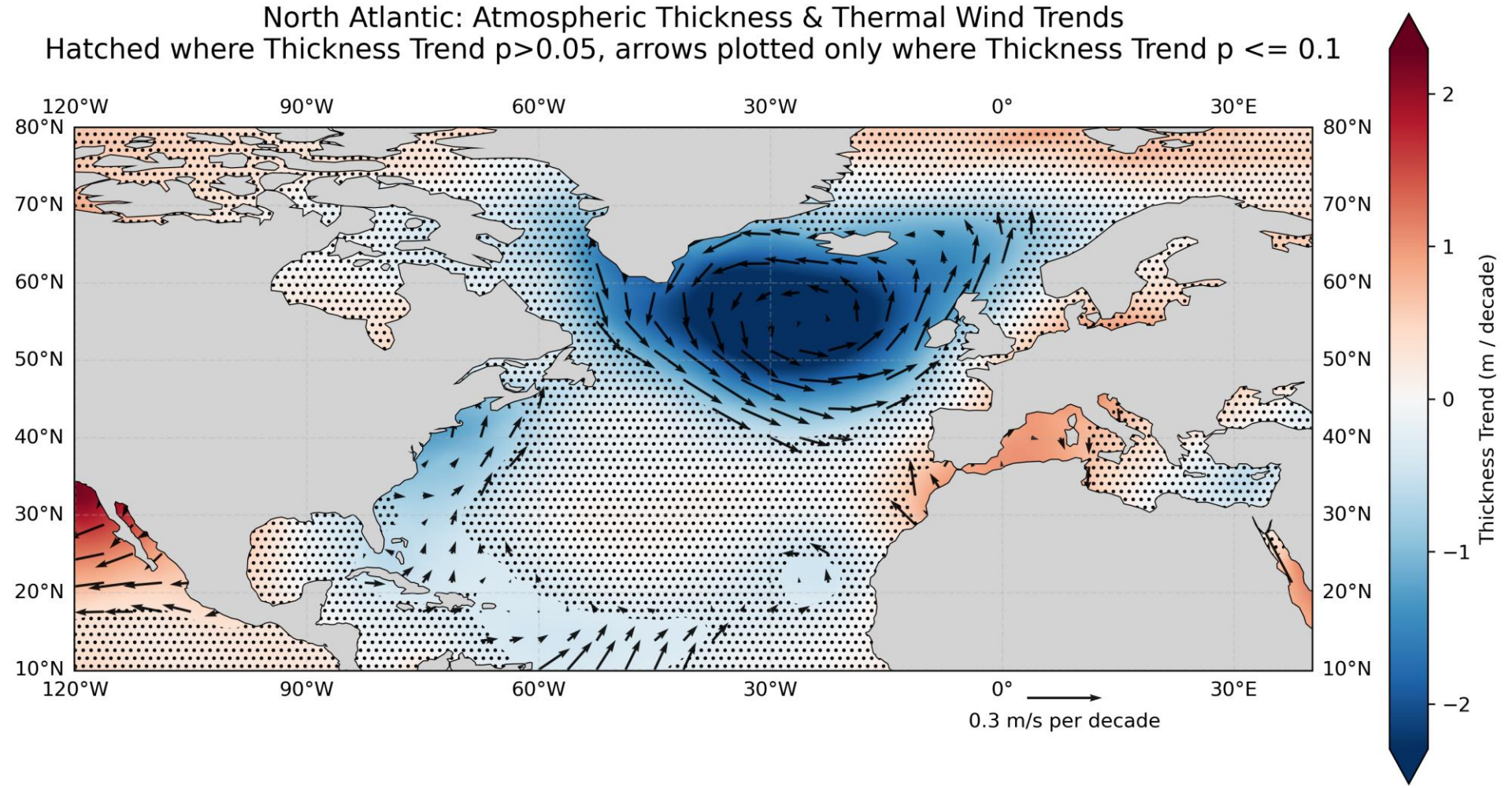
$$|v_g| = g/f\ \Delta Z/\Delta L,$$

Notum g≈10 m/s^2 ; f≈10^{-4} s^{-1} & ΔZ/ΔL = $2/10^6$ svo vindhraðaleitnin er um 0.2 m/s per áratug

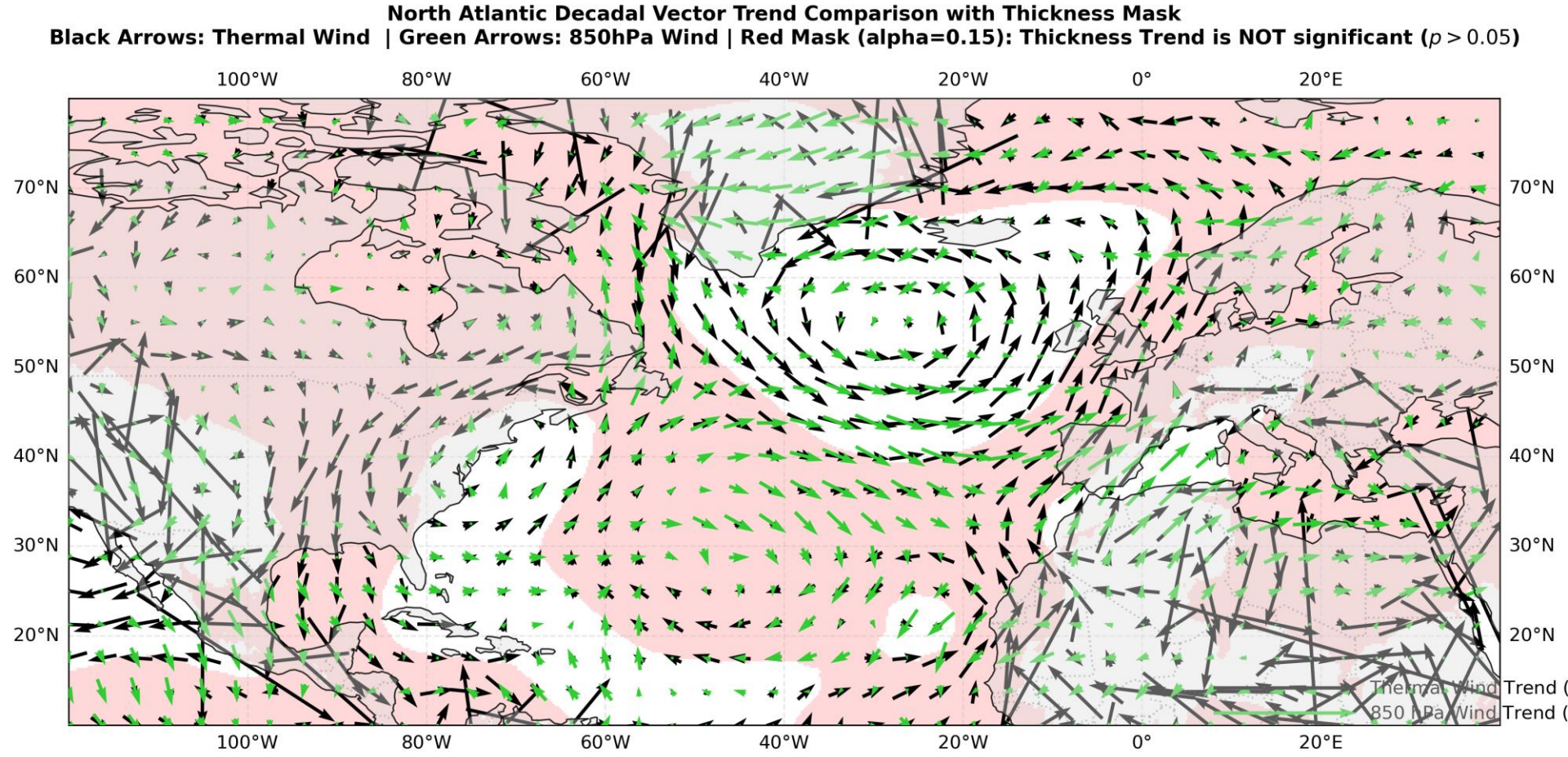
Þykktarvindur reiknaður frá ΔZ



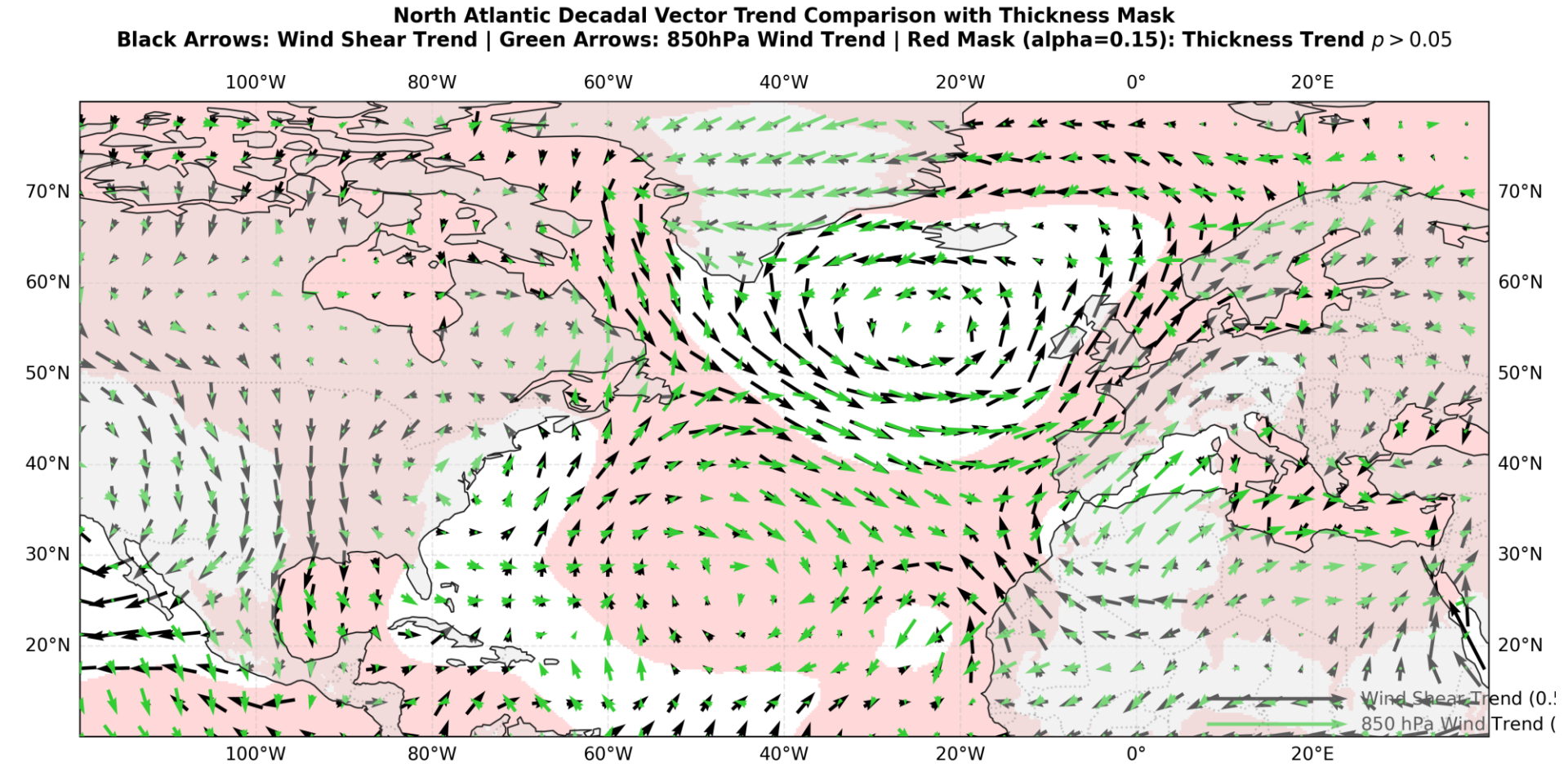
Þykktarvindur reiknaður beint frá vindhraða í 1000 hPa og 500 hPa flötum í ERA5



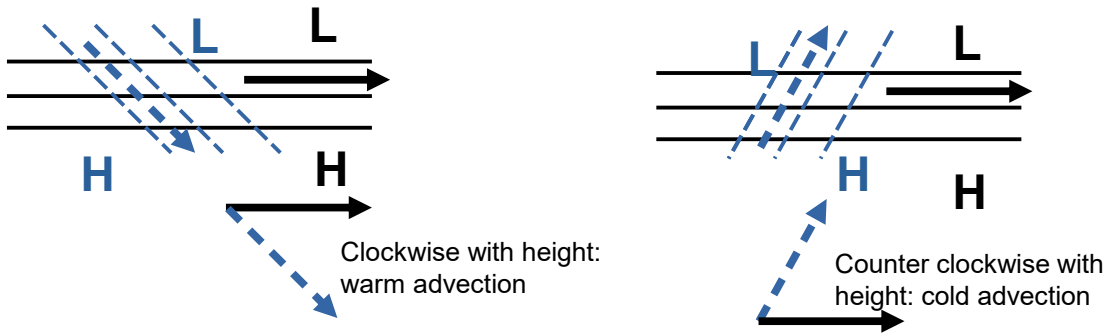
Leitni þykktarvinds og 850 hPa vinds eru yfirleitt samstefna. Sá síðari er oftar minni. Hér er þykktarvindur reiknaður beint frá mættishæð

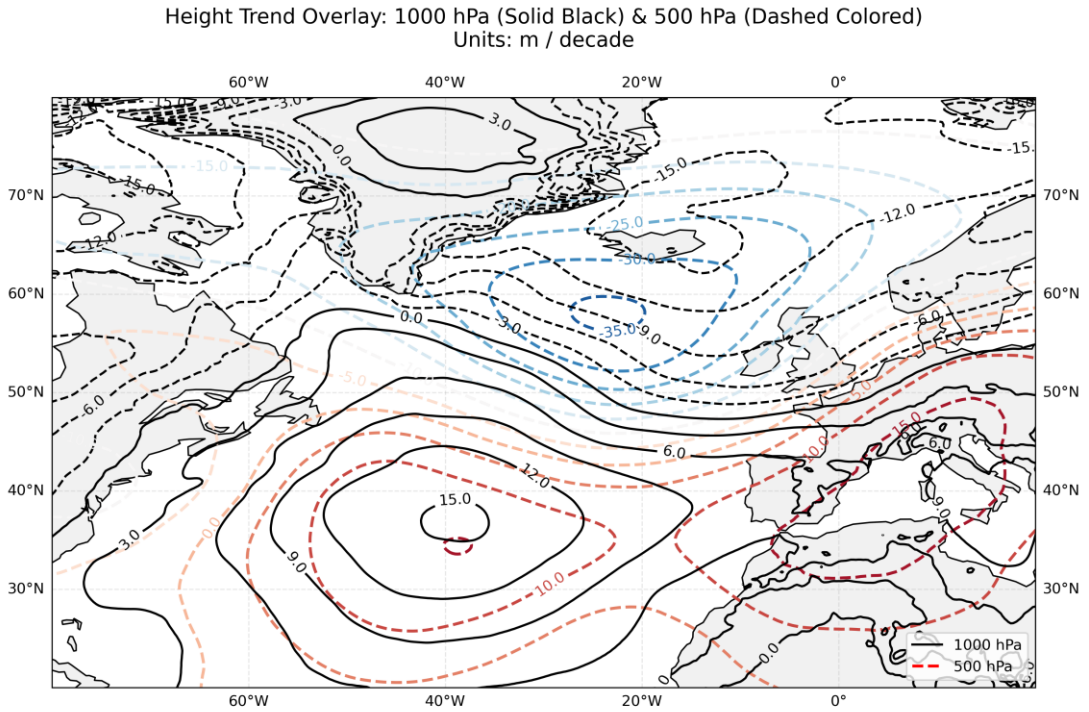


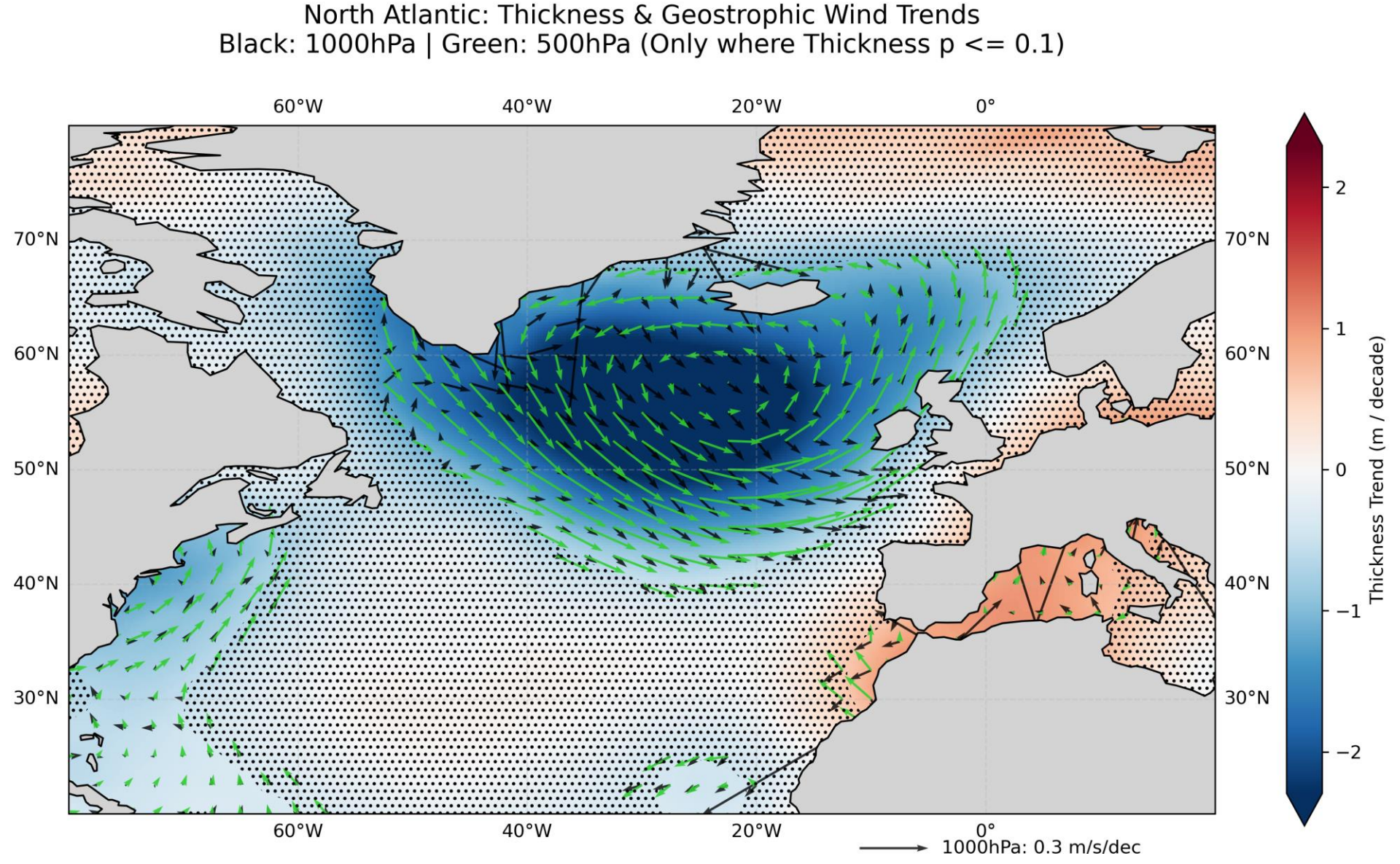
Leitni þykktarvinds og 850 hPa vinds eru yfirleitt samstefna.
Hér er þykktarvindur reiknaður beint frá ERA5 vindum



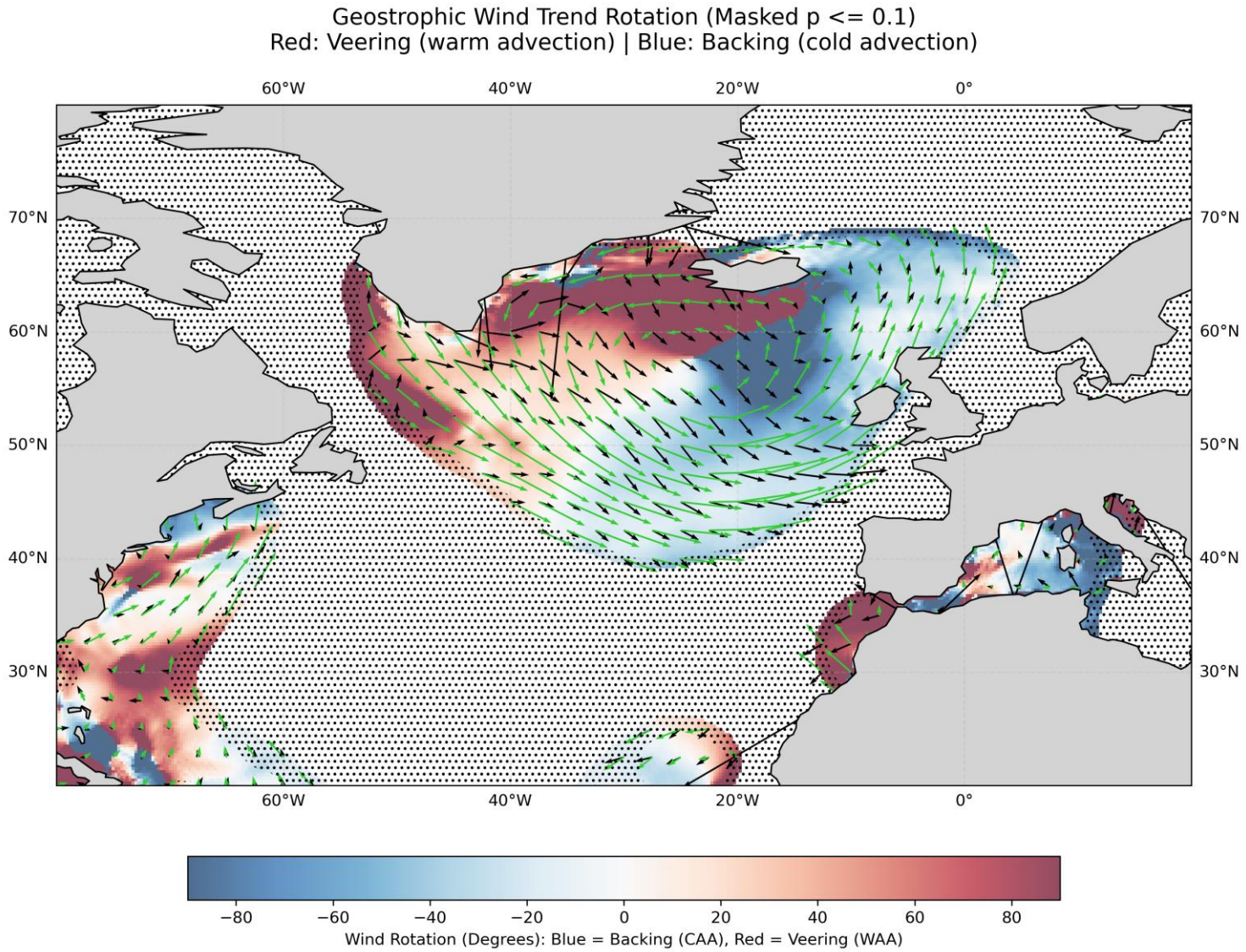
Afleiðingar 1: Heitt og kalt aðstreymi



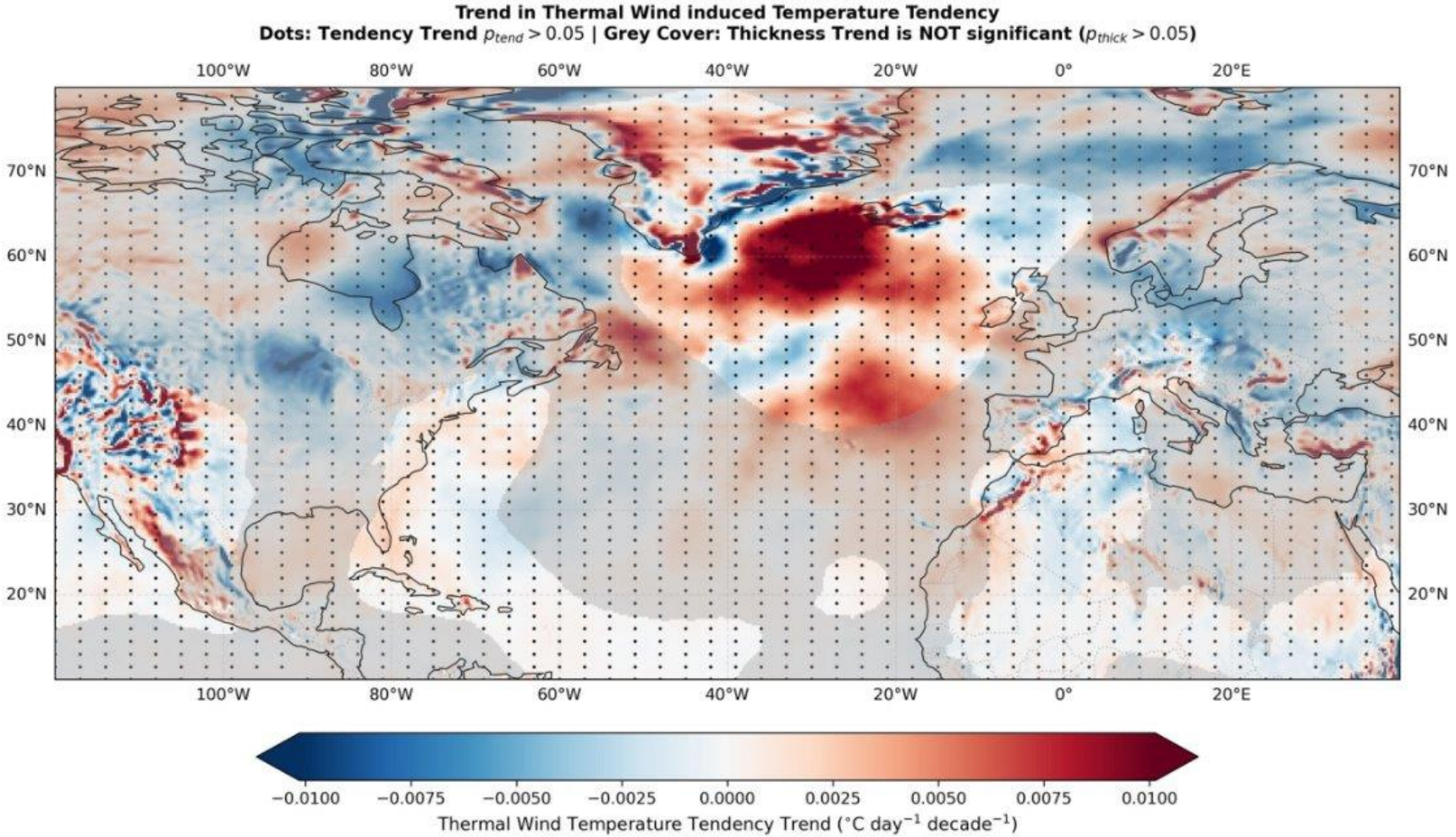



North Atlantic: Thickness & Geostrophic Wind Trends
Black: 1000hPa | Green: 500hPa (Only where Thickness p <= 0.1)
60°W
40°W
20°W
0°
70°N
60°N
50°N
40°N
30°N
1000hPa: 0.3 m/s/dec
Thickness Trend (m / decade)
2
1
0
−1
−2

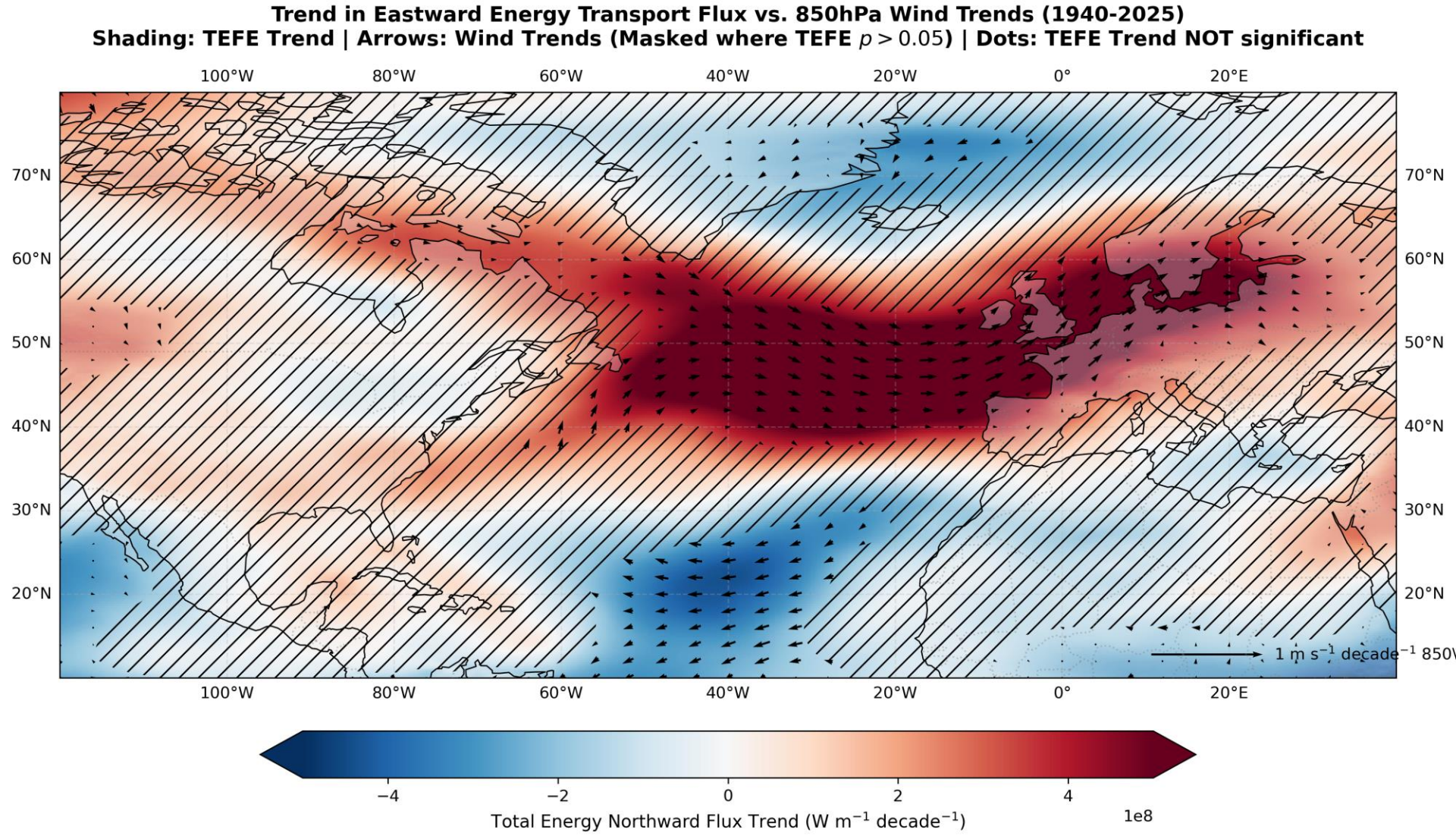
Afleiðingar 1: Heitt og kalt aðstreymi

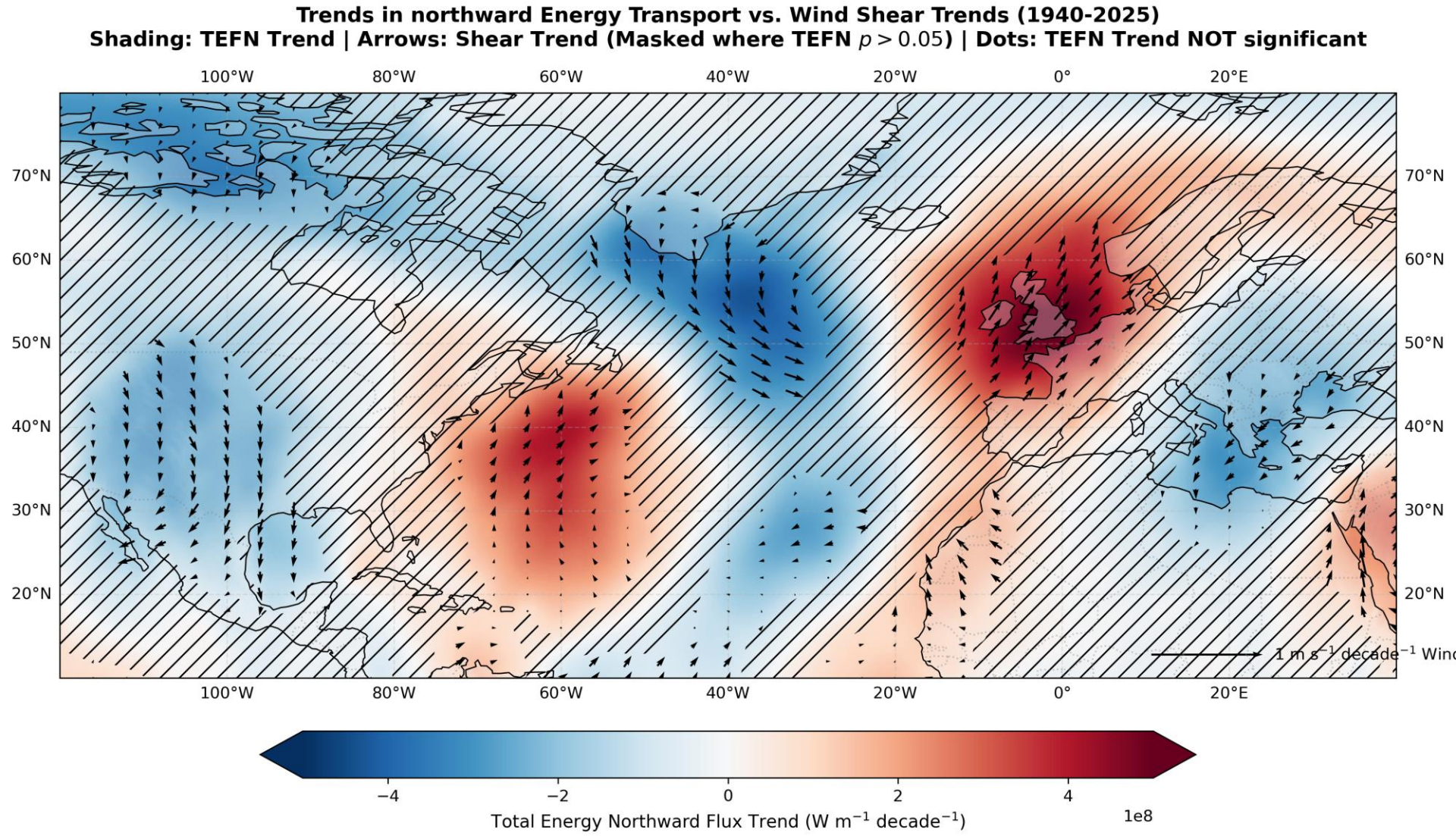


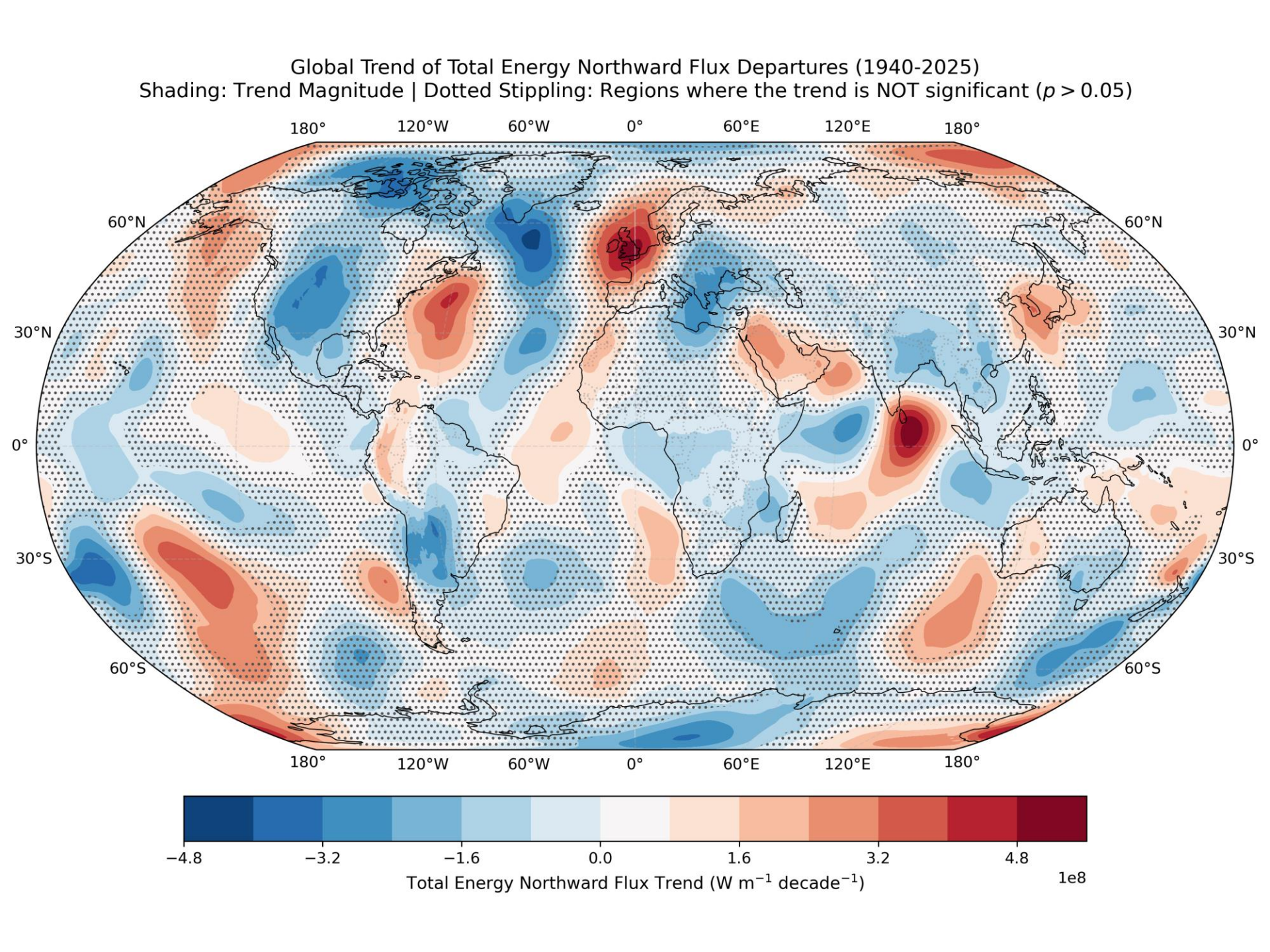
Afleiðingar 1: Reikningar á leitni hitahneigðar vegna þykktarvinds sýna "merki" en lítið markækt!

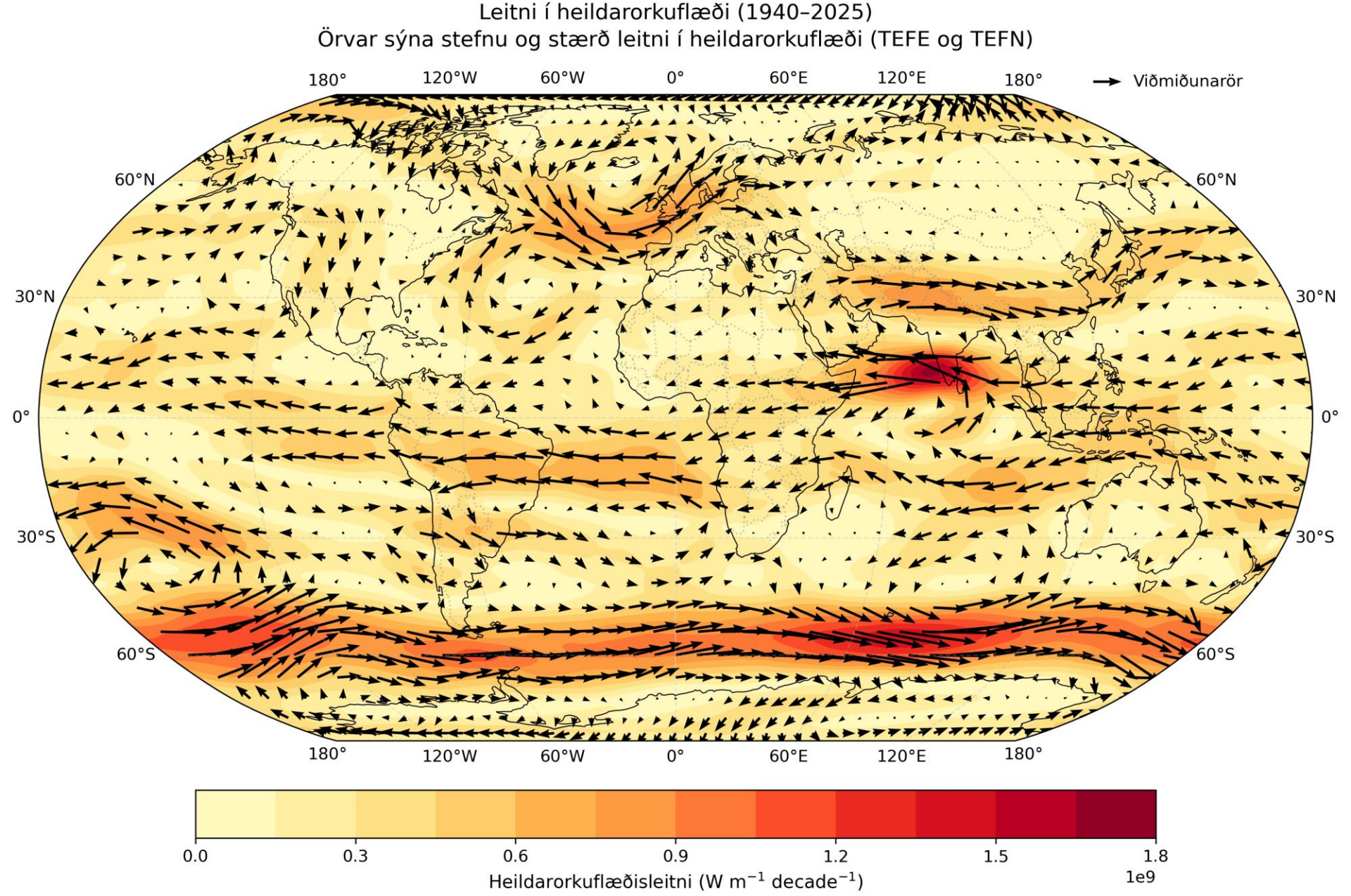


Afleiðingar 2: Varmaflæði yfir Atlantshafi

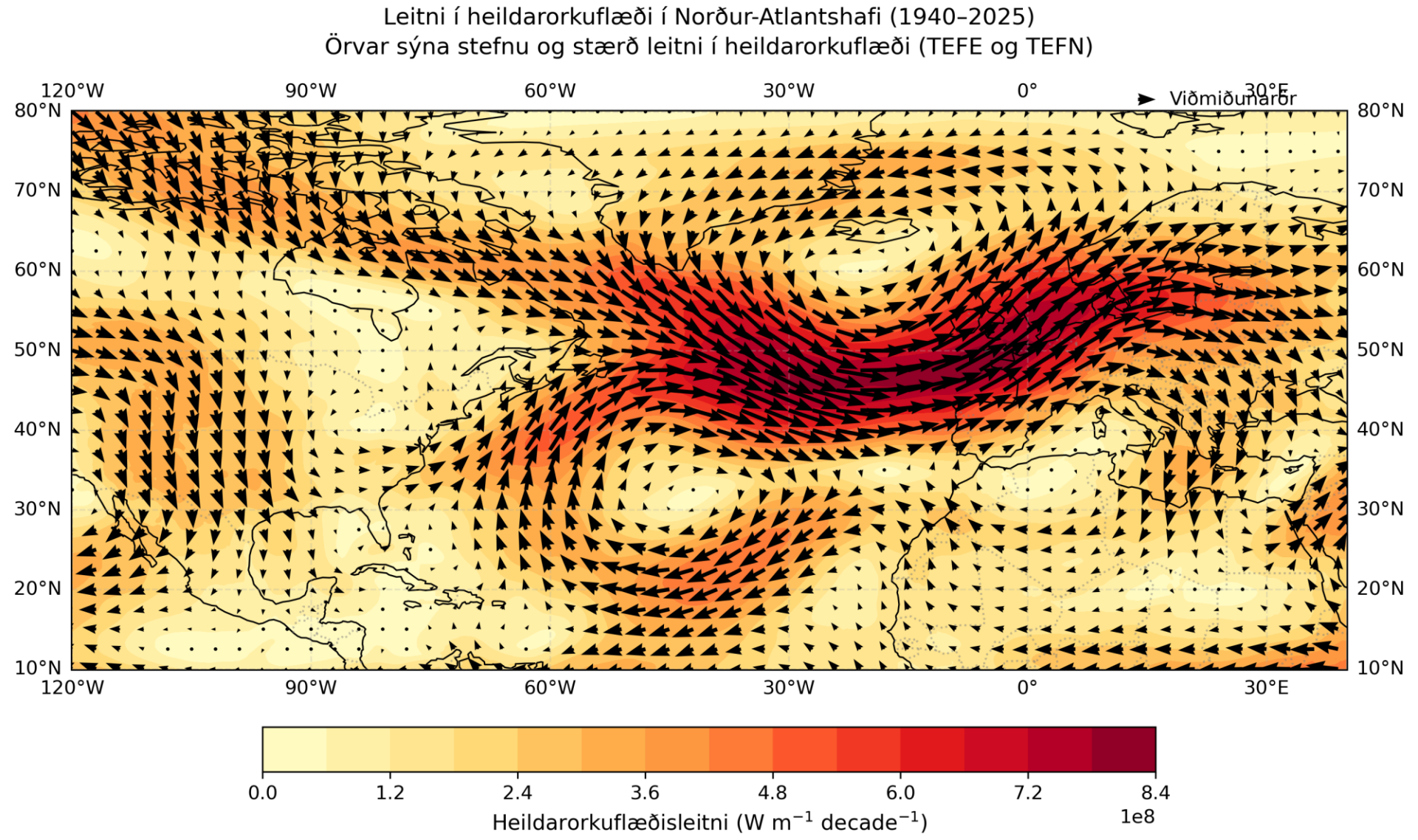



Trends in northward Energy Transport vs. Wind Shear Trends (1940-2025)
Shading: TEFN Trend | Arrows: Shear Trend (Masked where TEFN $p > 0.05$) | Dots: TEFN Trend NOT significant
100°W
80°W
60°W
40°W
20°W
0°
20°E
70°N
60°N
50°N
40°N
30°N
20°N
1 m s^{-1} decade^{-1} Wind
−4
−2
0
2
4
1e8
Total Energy Northward Flux Trend (W m^{-1} decade^{-1})


Global Trend of Total Energy Northward Flux Departures (1940-2025)
Shading: Trend Magnitude | Dotted Stippling: Regions where the trend is NOT significant ($p > 0.05$)
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
30°N
0°
30°S
60°S
−4.8
−3.2
−1.6
0.0
1.6
3.2
4.8
1e8
Total Energy Northward Flux Trend (W m^{-1} decade^{-1})


Leitni í heildarorkuflæði (1940–2025)
Örvar sýna stefnu og stærð leitni í heildarorkuflæði (TEFE og TEFN)
Viðmiðunarör
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
30°N
0°
30°S
60°S
0.0
0.3
0.6
0.9
1.2
1.5
1.8
1e9
Heildarorkuflæðisleitni (W m^{-1} decade^{-1})

Afleiðingar 2: Varmaflæði yfir Atlantshafi



Samantekt

- Marktæk NAWH => Minni þykkt => cyclonísk hringrás => Kalt aðstreymi vestur af NAWH og hlýtt aðstreymi austan við + hvassari vestlægir vindar sem hafa áhrif á orkuflutninga í lofthjúpi.
- Í prinsippiu gæti þetta leitt til aukinnar hlýnunar yfir Evrópu.

  - Það er hinsvegar suð í gögnunum og meiri vinnu þarf til að skoða þetta.

Significance of the NAWH and the Atmospheric Response

Halldór Björnsson, IMO

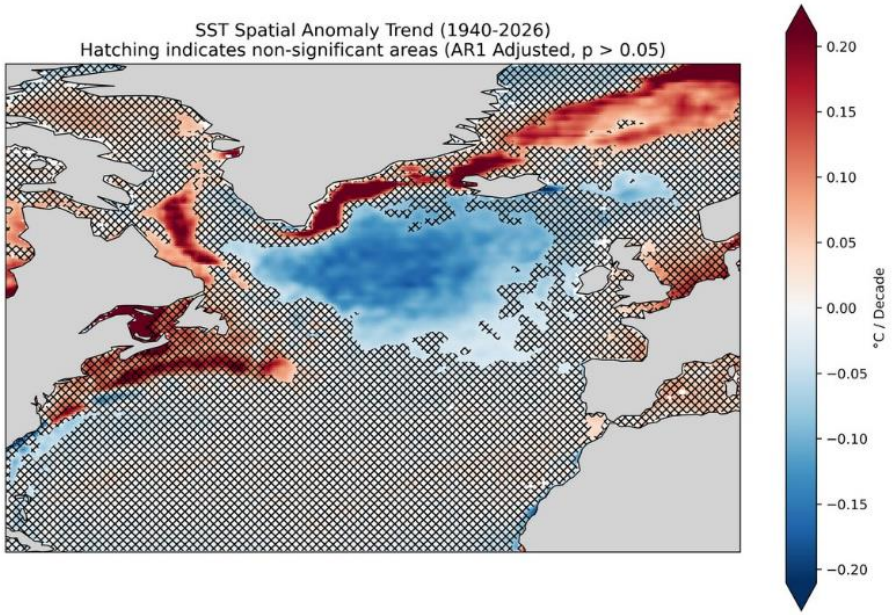
Angel Ruiz Angulo, UNI

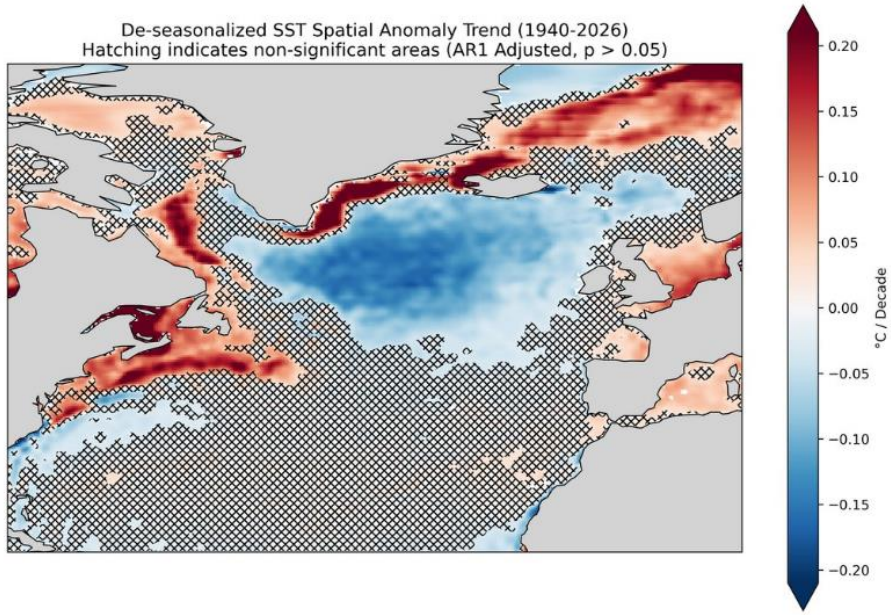
The significance of the NAWH

- Standard test on the significance of the SST trends are essentially asking if the trends are different from zero.
- However, this misses the point that this region has not warmed when the rest of the basin did.
- So a more appropriate dataset is one with spatial anomalies where a time series of basin averages has been subtracted from the monthly data.
- A further refinement is by removing the seasonal cycle at each gridpoint (de-seasonalizing).
  - This will not affect trends but allows for better constraints on significance levels

How different is the NAWH ?

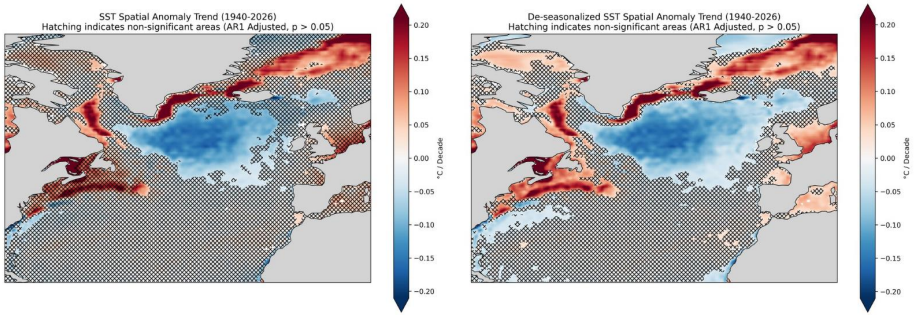
Trends (1940 to 2025) of SSTs





Areas where the SST trends are not significant are hatched

How different is the NAWH ?

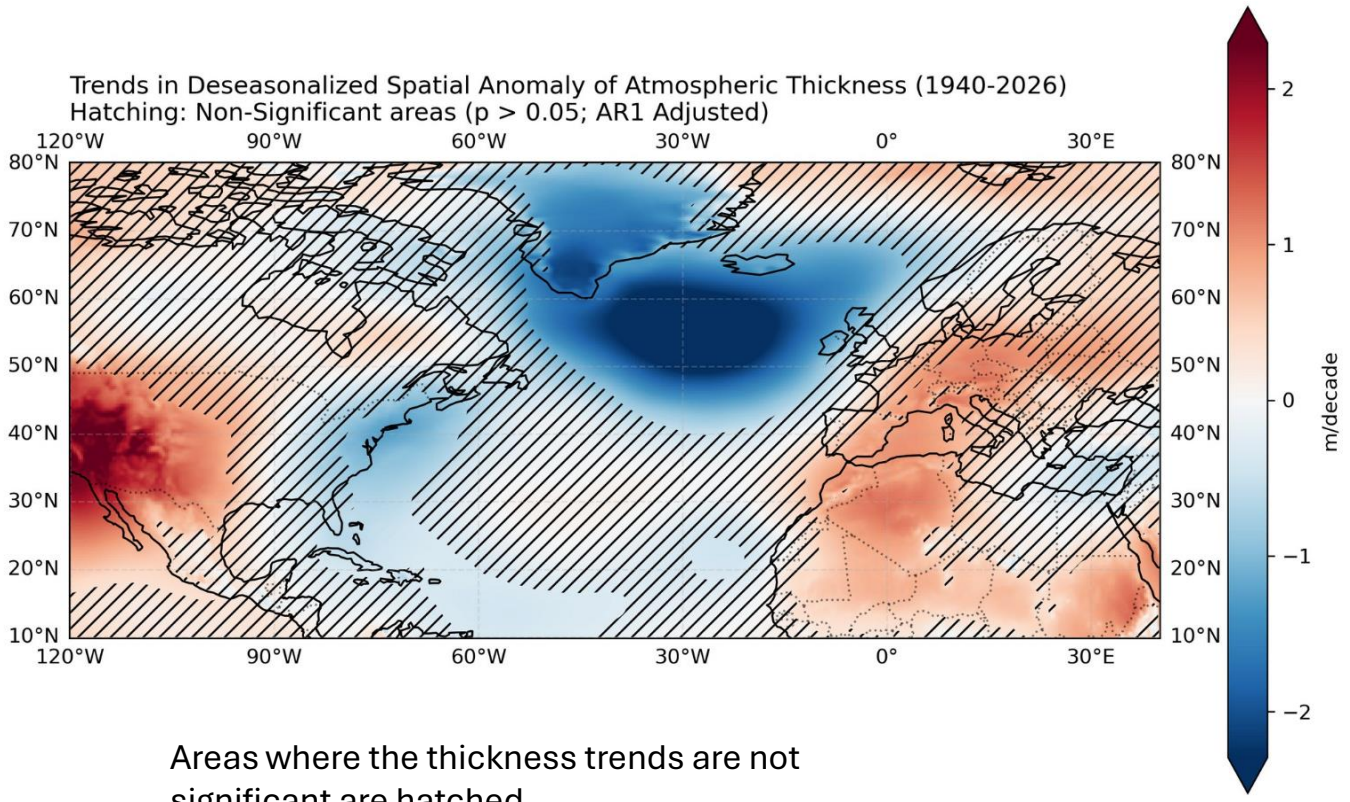


- Notice that this plot shows regions were the SST evolution differs from the basin average.
- Areas that warm along with basin average trends are grayed out, as those do not show significant differences (~zero trend)
- Significance is calculated using AR1 autocorrelation to shrink the sample size.
- Note significant warming in sea ice regions, off the Eastern Seaboard and European coastal seas.
- Note a very significant NAWH.
  - Significance area is bigger with de-seasonalized data.

Does the NAWH have a significant atmospheric response?

- Calculate the 1000 hPa to 500 hPa thickness for each month in the 1940 to 2026 ERA5 dataset
  - Use geopotential meters as unit
- Calculate spatial anomalies
- Remove the seasonal cycle
- Calculate the trend and map the results. Shade areas where the spatial trends are not different from zero
  - Again, we are asking if the patterns are different from the background warming trends.

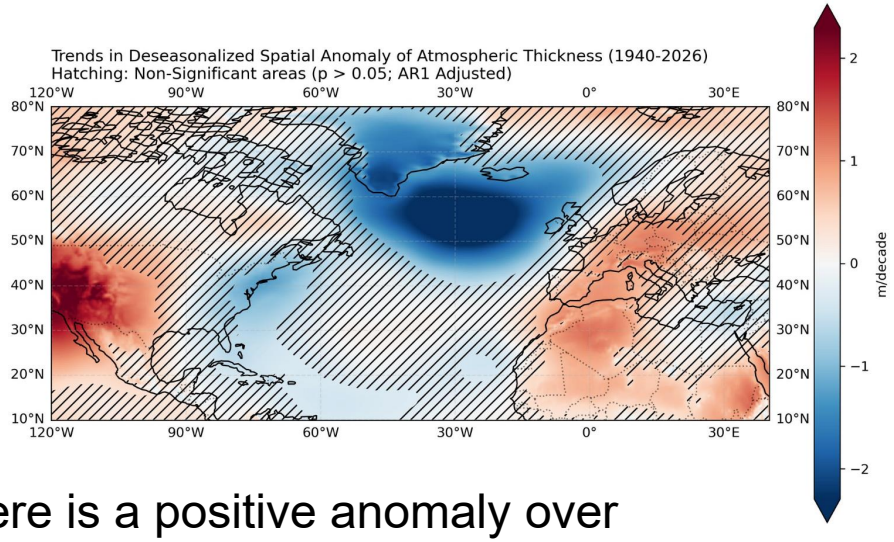
Thickness hole as a response to NAWH



Areas where the thickness trends are not significant are hatched

Thickness hole as a response to NAWH

- Two things stand out
  - First, there is a clear cold-core thickness response to reduced heatflux from the ocean
  - This should lead to a cyclonic circulation around the thickness hole
    - Geostrophic response & associated thermal wind shear

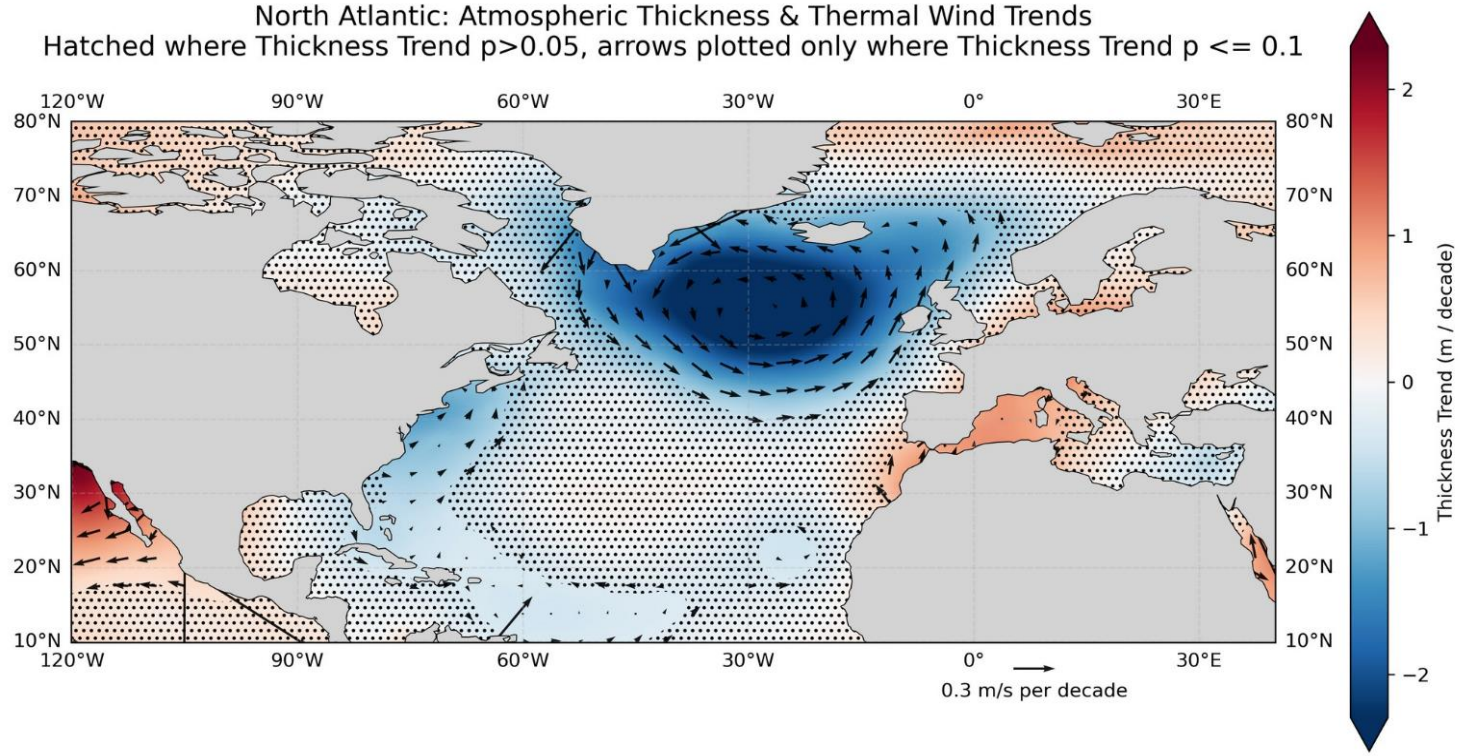


  - Second, it is noteworthy that there is a positive anomaly over Europe, partly downstream from the assumed cyclonic circulation

Atmospheric response to the thickness anomaly

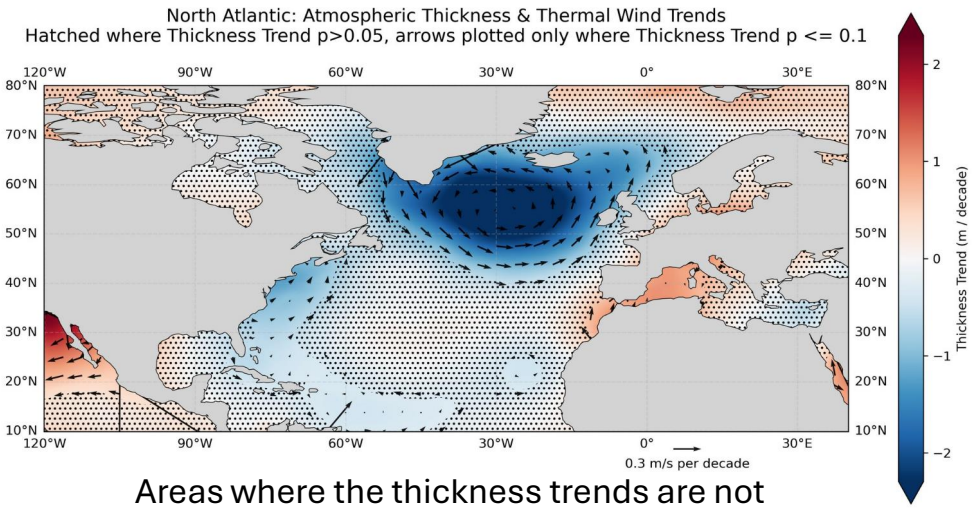
- Given that the atmosphere is in geostrophic balance over this time period a thermal wind type circulation should evolve
  - Use ERA5 pressure fields (500 hPa and 1000 hPa) and calculate the de-seasonalized spatial anomalies.
  - Calculate geostrophic winds for each month for both levels. Take the difference to get the windshear.
  - Calculate the trend
  - Overlay the wind vectors on a plot of the thickness anomaly

Thermal wind and thickness anomaly trends



Thermal wind and thickness anomaly trends

- Cyclonic circulation anomaly around the thickness hole
- The arrows are only shown for oceanic areas where the thickness change is significant
- The chain of influences here is:
  - Ocean surface heat flux drop --> Atmospheric cooling and reduced thickness --> Cyclonic circulation anomaly
- Based on this circulation it is expected to see warm advection towards Europe in the southern part of the NAWH



Areas where the thickness trends are not significant are shaded

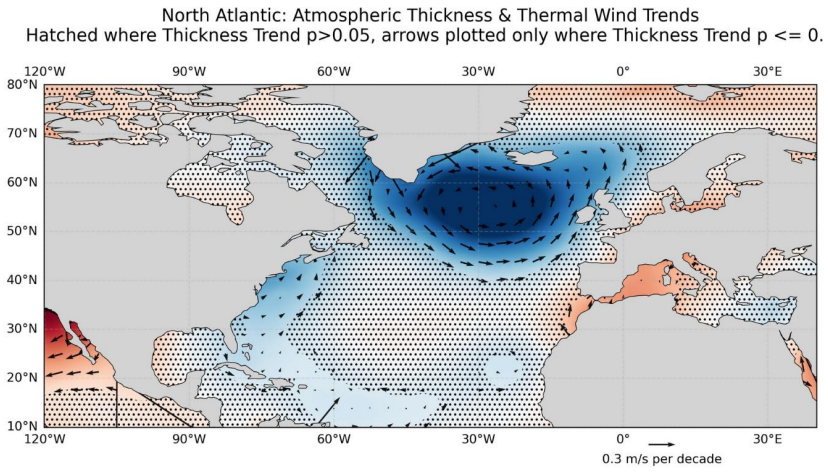
Analyzed winds

- How well do the calculated thermal wind trends match trends calculated from analyzed ERA5 winds?
  - Download ERA5 winds at 1000 hPa and 500 hPa levels and calculate deseasonalized anomalies.
  - Calculate the wind shear and compare with results for thermal wind

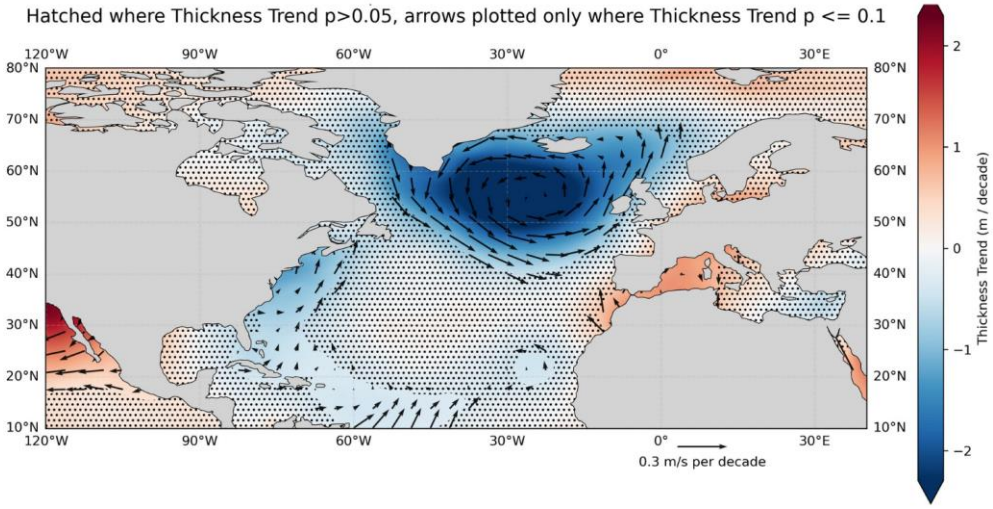
- (This is a test of the methodology for calculating the thermal winds, as well as the assumption of geostrophy)

Thermal wind and windshear from analyzed winds

Thermal wind



ERA5 windshear

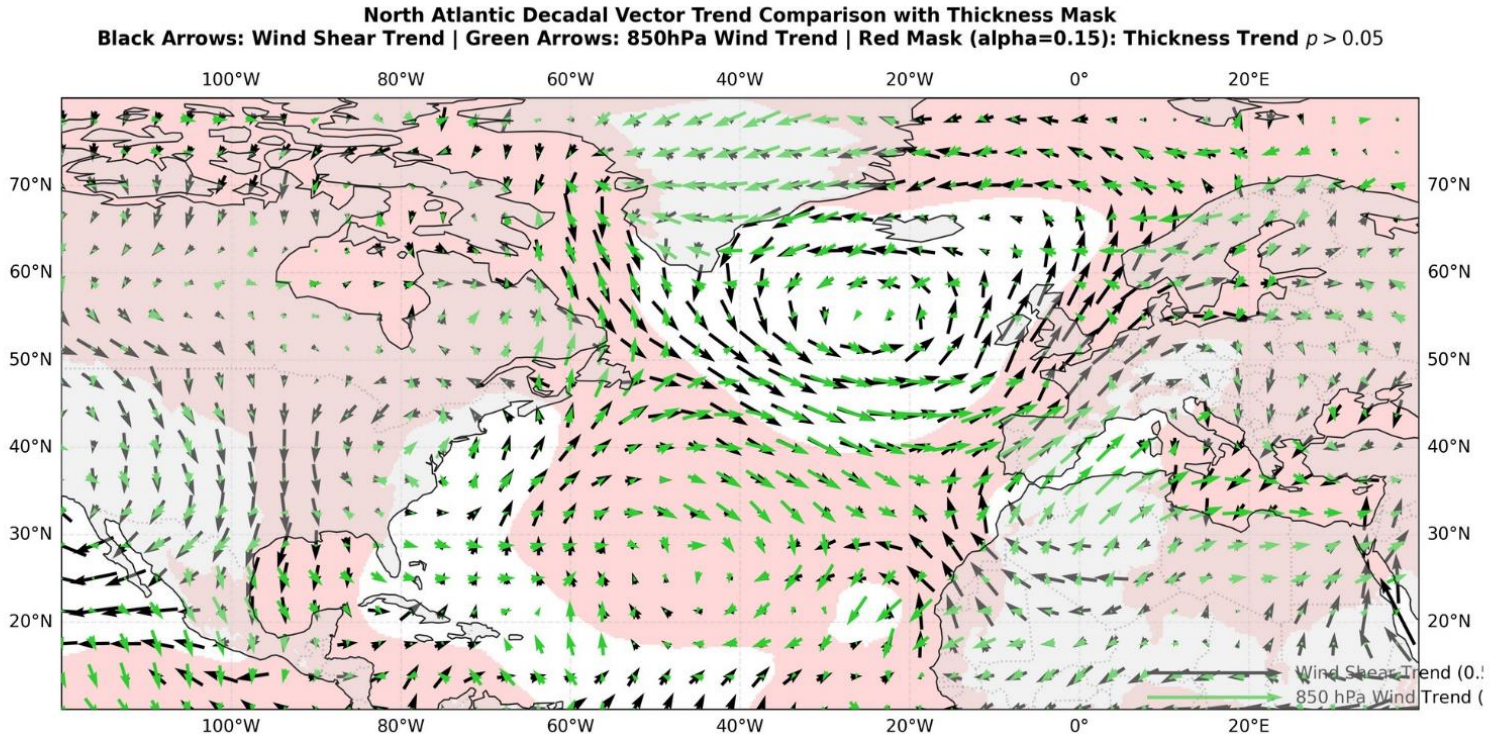


In general the comparison is very good especially over the ocean. Areas where the thickness trends are not significant are shaded

Comparison with 850 hPa level winds

- The previous slides have shown that the thermal wind response can also be seen in windshear calculations from analyzed winds.
- A clear pattern showing a cyclonic circulation windshear anomaly trend around the NAWH region.
- However, a windshear anomaly does not have to be unidirectional with wind anomalies.
- To test this winds at 850 hPa level were compared against the wind shear trends previously calculated
  - As before, the 850 hPa wind vectors were de-seasonalized and spatial anomalies calculated prior to trend calculations.

Comparison of windshear (black) with 850 hPa level winds (green)

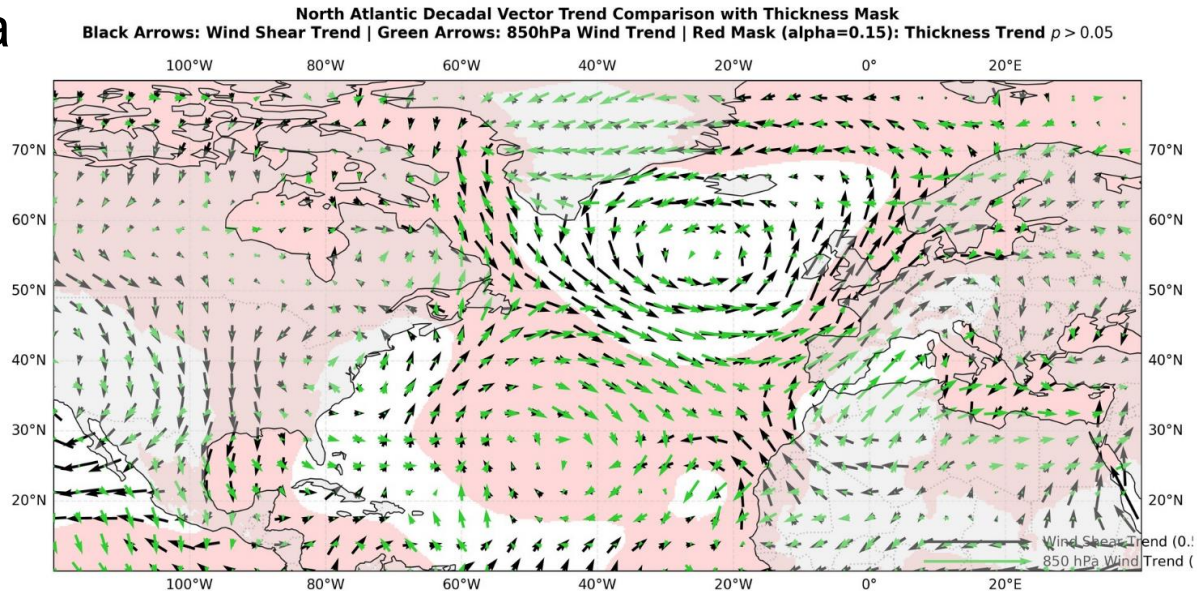


Pink shading shows where the thickness trends are not significant are shaded

Comparison with 850 hPa level winds

- Both the trends in windshear and the trends in 850 hPa winds show a clear cyclonic circulation anomaly

- However, the 850 wind direction differs in the Labrador sea region and the winds towards the European continent are more zonally oriented



Summary of the preceeding slides

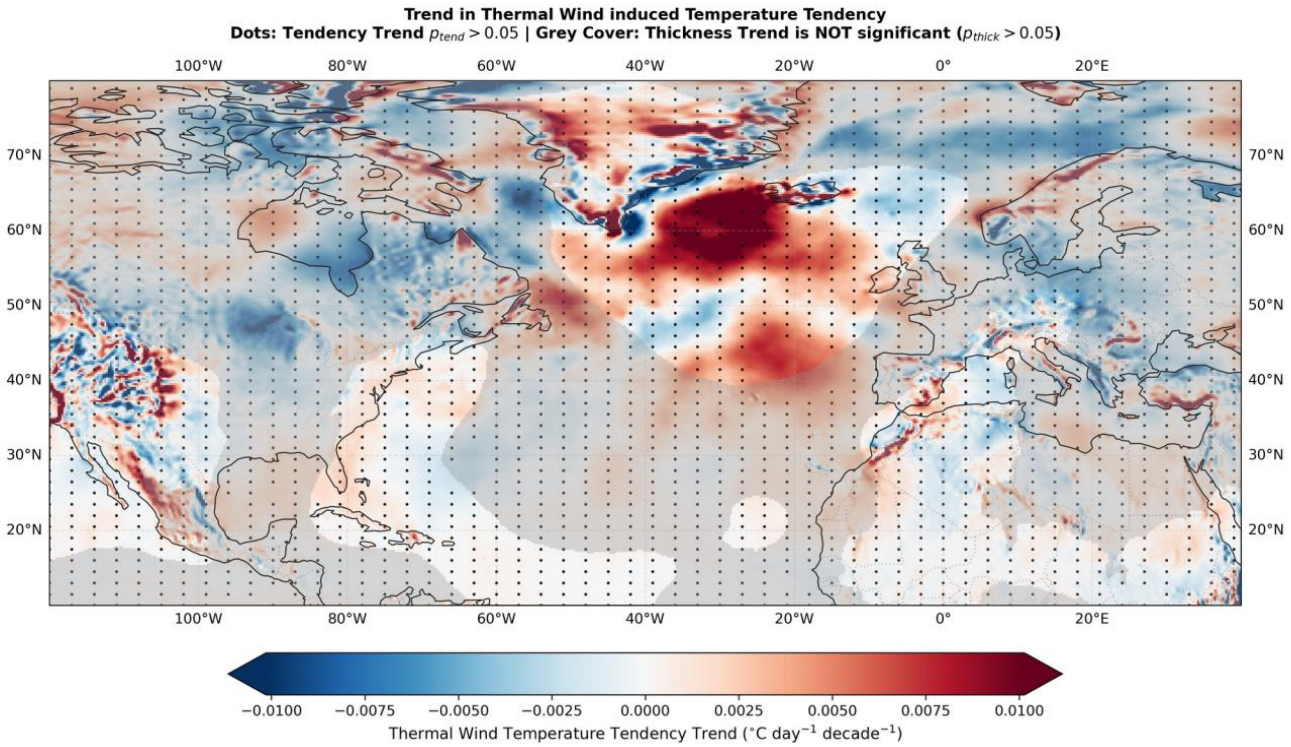
- Significant NAWH => Reduced atmospheric thickness => cyclonic circulation anomaly through thermal wind and also cyclonic circulation in analyzed winds at 850 hPa.
- What are the consequences?
  - Can we expect that the advection anomalies lead to regions of reduced warming or of greater warming ?
  - Lets look at two different physical processes that may be affected
    - The temperature tendency associated with the thermal wind
    - Transports of total energy

Temperature tendency associated with thermal wind advection

- The temperature tendency (say ΔT/day) can be estimated from the 1000 hPa and 500 hPa winds that are used to calculate the thermal wind
  - If the wind turns clockwise with height (veering) that indicates warm advection and $T_t > 0$
  - If the wind turns counterclockwise with height (backing) that indicates warm advection and $T_t < 0$
  - The temperature tendency T_t can be estimated via

$$T_t = f/(R \ln(p_{1000}/p_{500})) (u_{500} v_{1000} - u_{1000} v_{500})$$

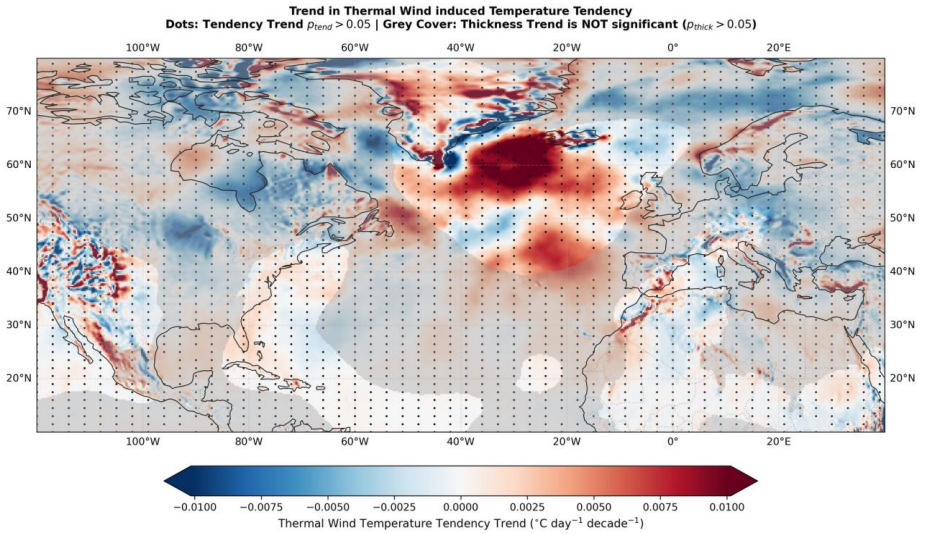
Temperature tendency associated with thermal wind advection



Temperature tendency associated with thermal wind advection

- Results are mostly not significant, except for patches within the significant thickness anomaly (see grey shading)

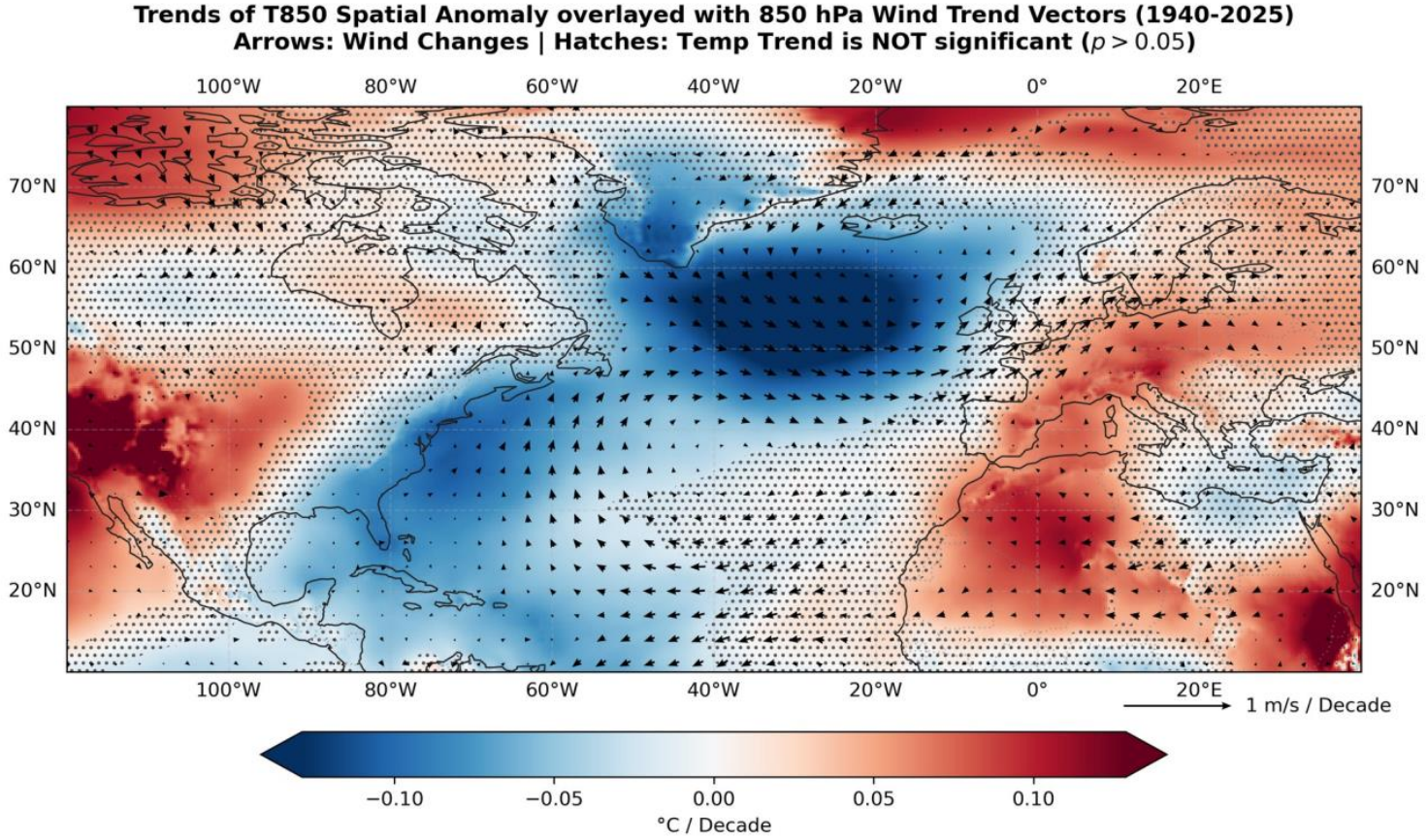
- Possible interpretation is that the thermal wind advection tries to fill in the deepening thickness anomaly, but lack of significance makes interpretations of figure difficult



How about thermal advection by upper level winds? (U, V @850hPa)

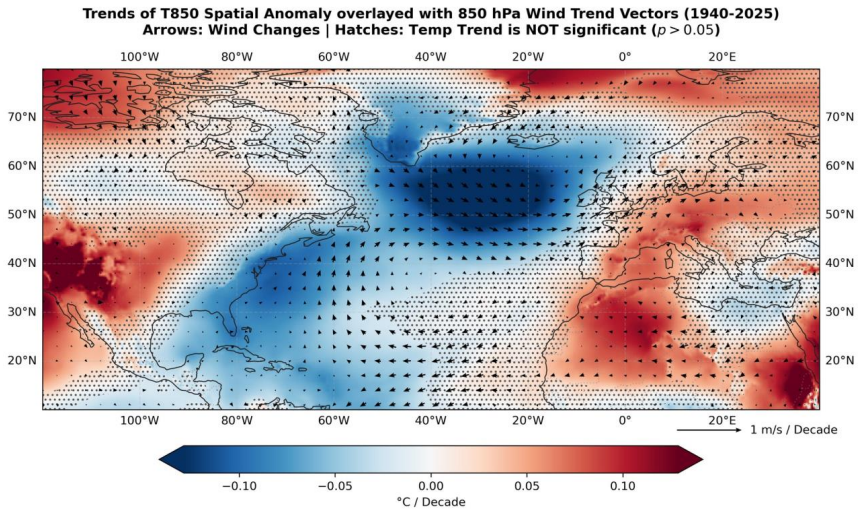
- Advection by thermal wind shear trends may be too esoteric to interpret
- However, we know that the trends in upper level winds (at 850 hPa) are mostly oriented in the same direction as trends in the wind shear so it may be simpler just to look at the trends in upper level winds
- Calculate the de-seasonalized spatial anomaly trends of temperature at 850 hPa and winds and plot together

Temperature advection by upper level winds

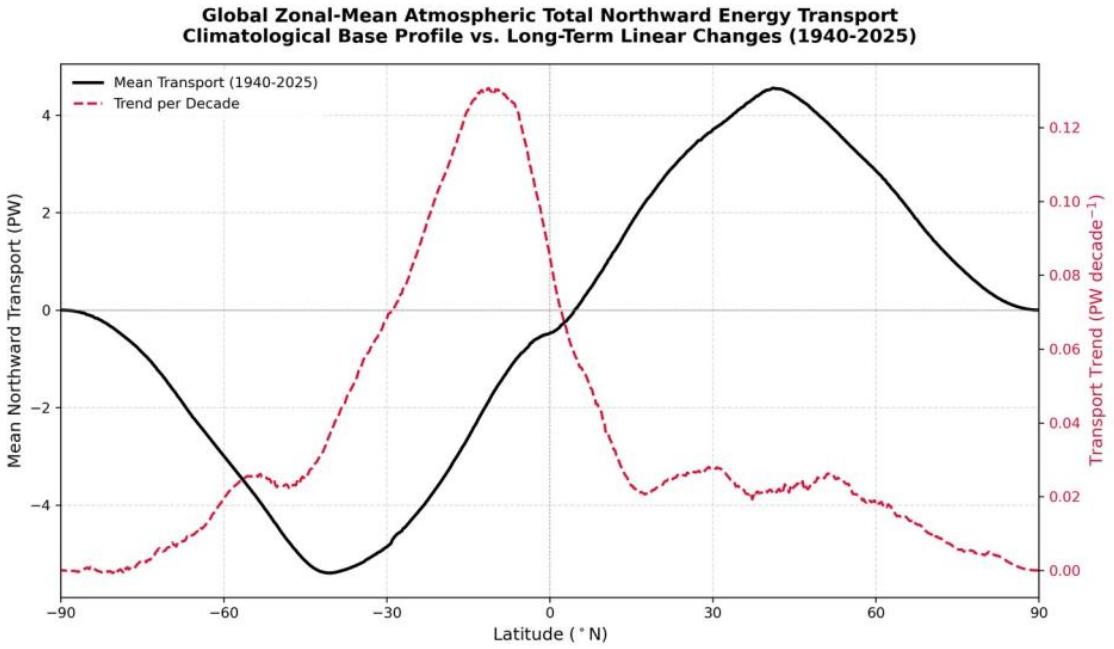


Temperature advection by upper level winds

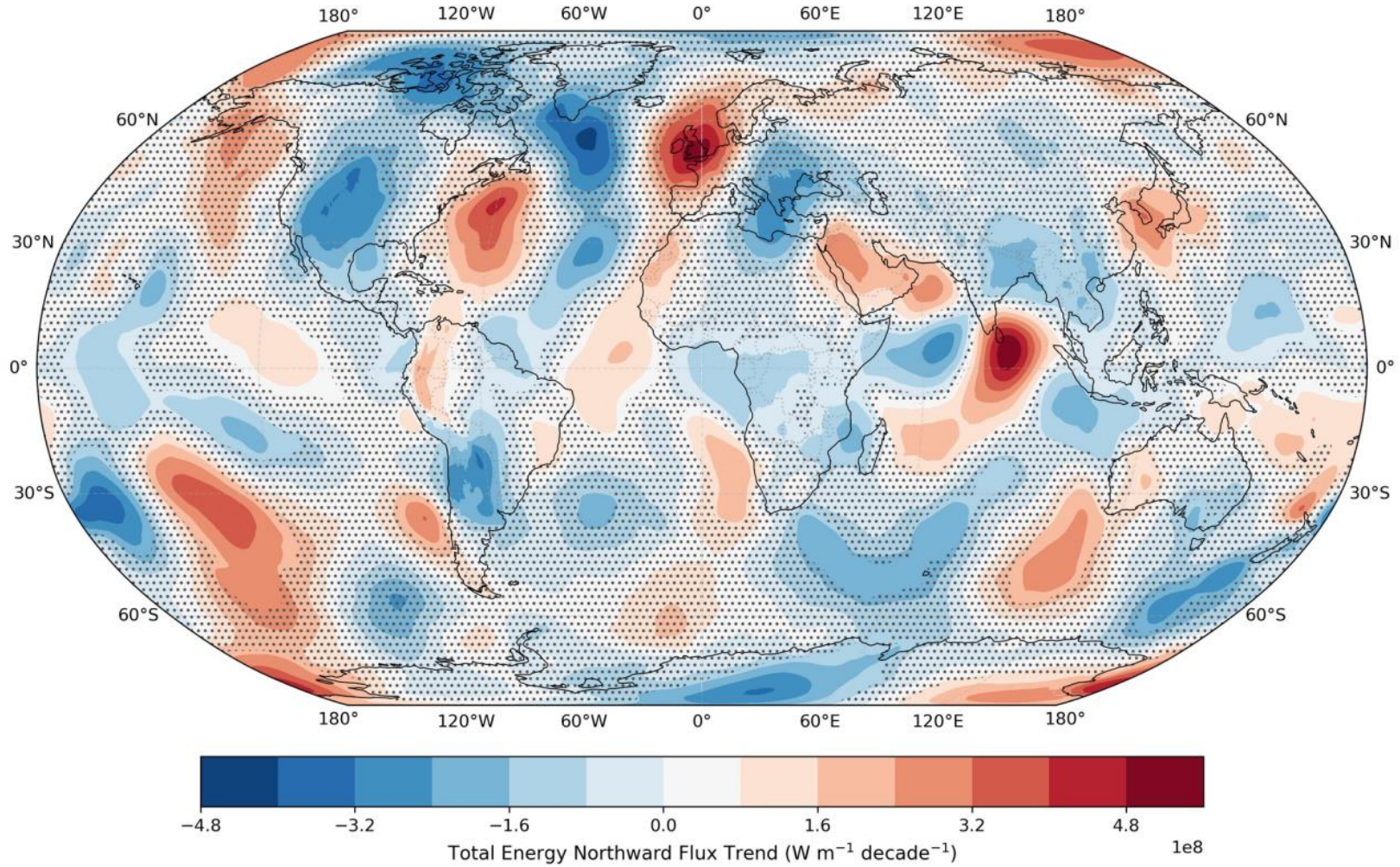
- Associated with the thickness anomaly is significant cooling over the NAWH
- The cyclonic circulation brings warm SW winds to Europe
- These trends in the circulation should enhance heat transport to Europe



Trends in Northward Energy Transports

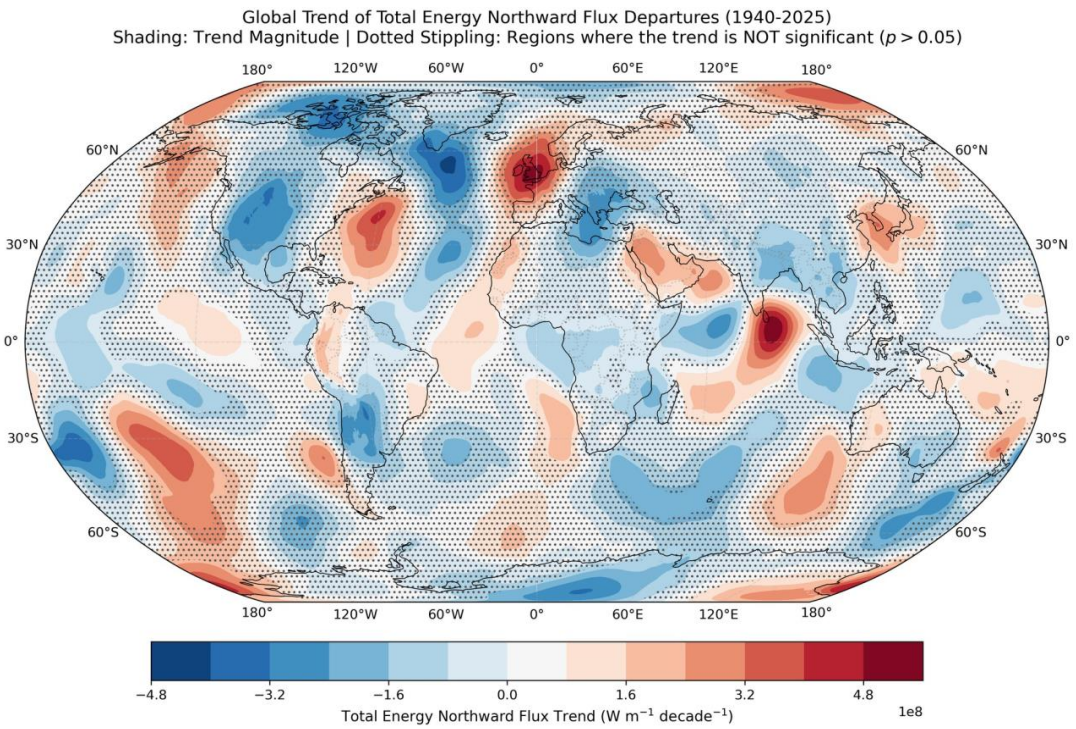


- The zonally averaged total northward energy transport is a well known curve (e.g Trenberth Caron 2001)
- The trends in the zonally averaged transport are very small, indicating that spatial anomalies in energy transports must balance

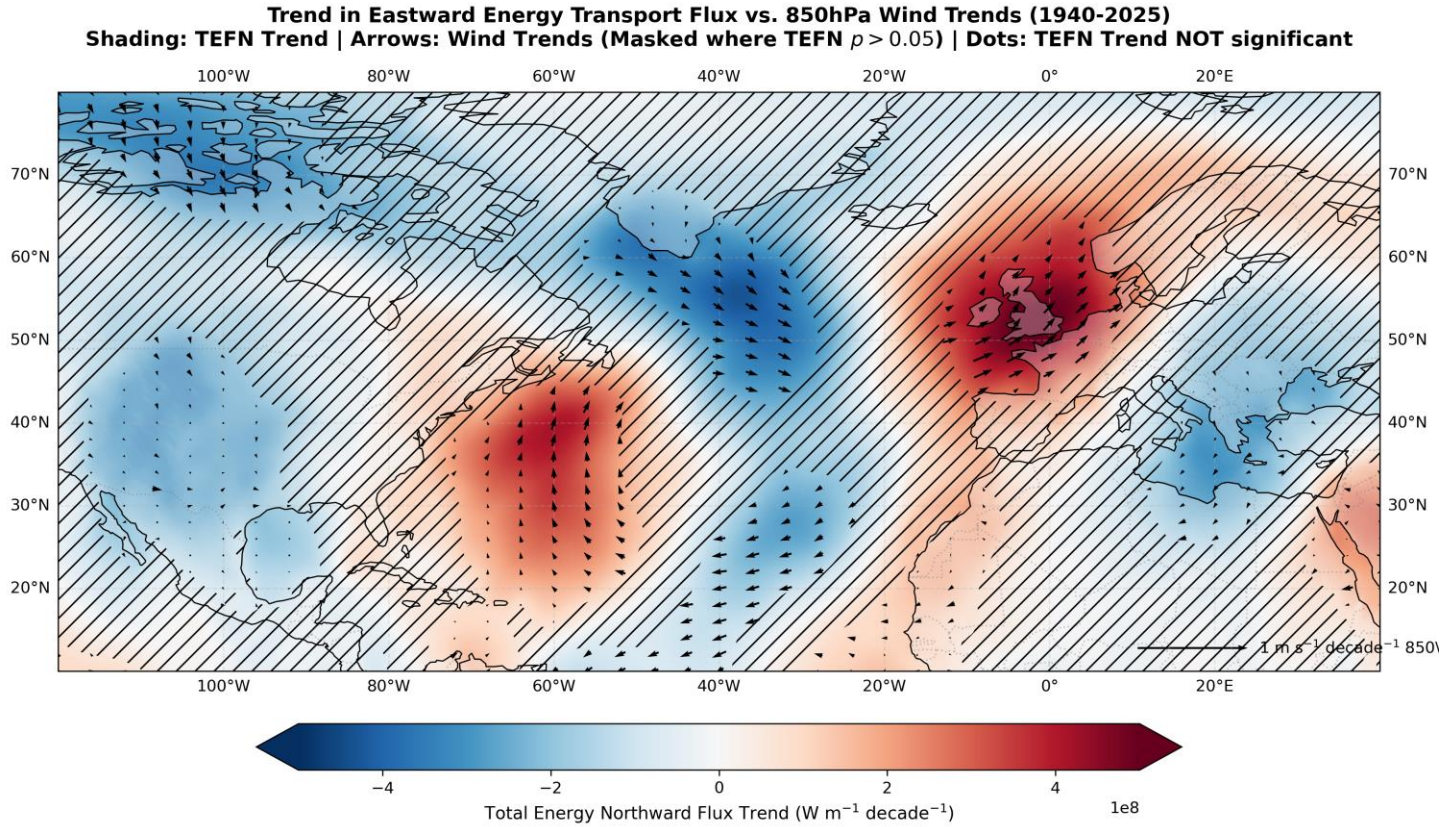

Global Trend of Total Energy Northward Flux Departures (1940-2025)
Shading: Trend Magnitude | Dotted Stippling: Regions where the trend is NOT significant ($p > 0.05$)
180°
120°W
60°W
0°
60°E
120°E
180°
60°N
30°N
0°
30°S
60°S
−4.8
−3.2
−1.6
0.0
1.6
3.2
4.8
1e8
Total Energy Northward Flux Trend (W m^{-1} decade^{-1})

Spatial trends in Northward Energy Transports

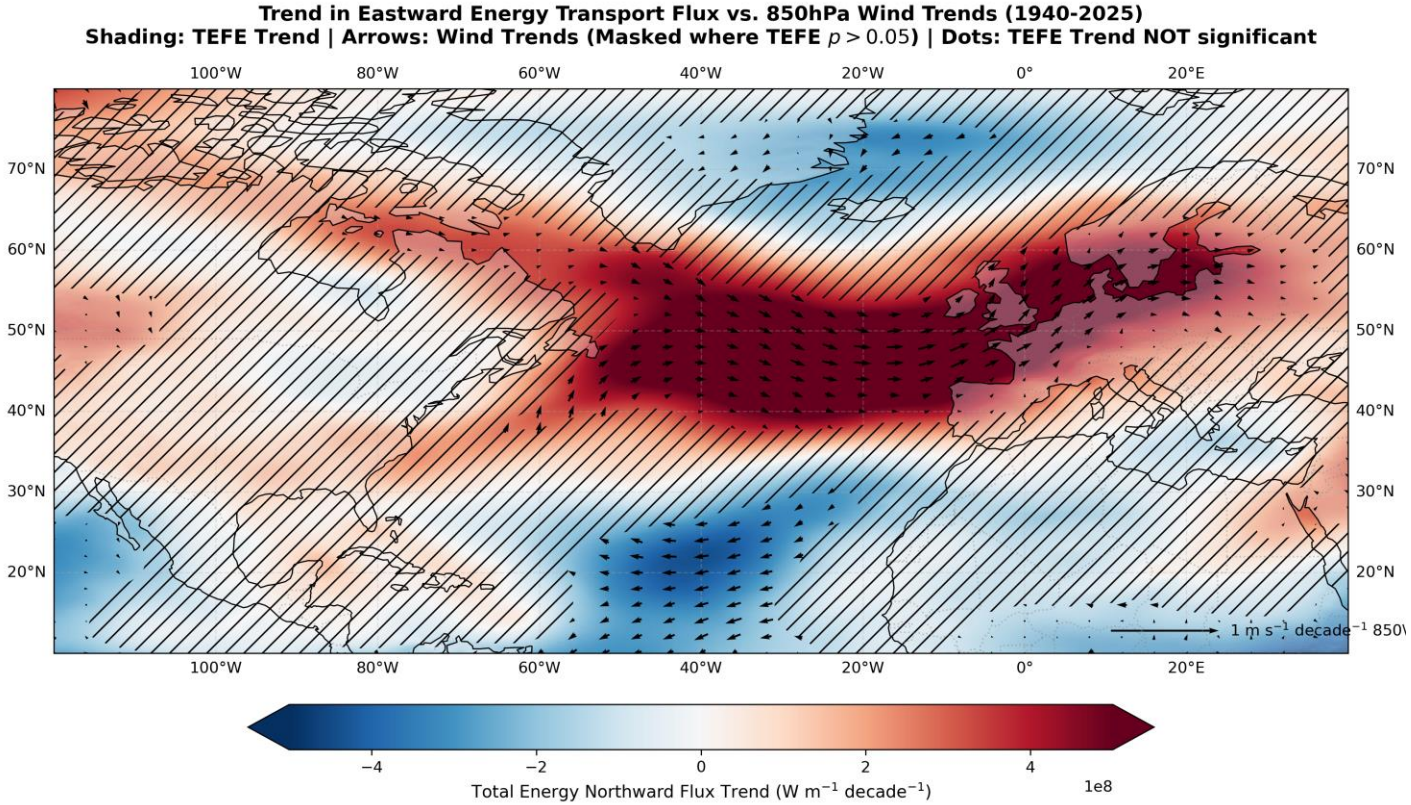
- Alternating positive and negative anomalies
- Given their size they could be associated temperature anomalies of opposite sign
- The cyclonic circulation anomaly resulting from NAWH could also impact these negative/positive transport anomalies



Spatial trends in Northward Energy Transports and upper level wind anomalies

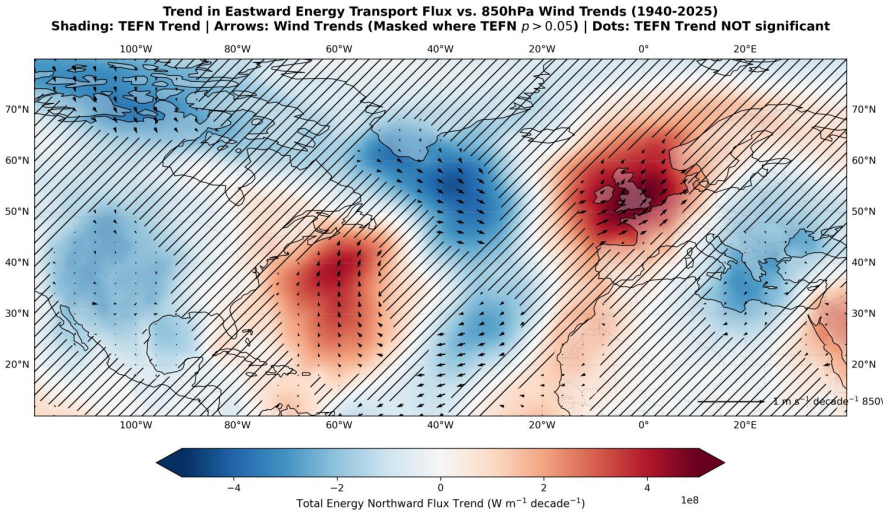


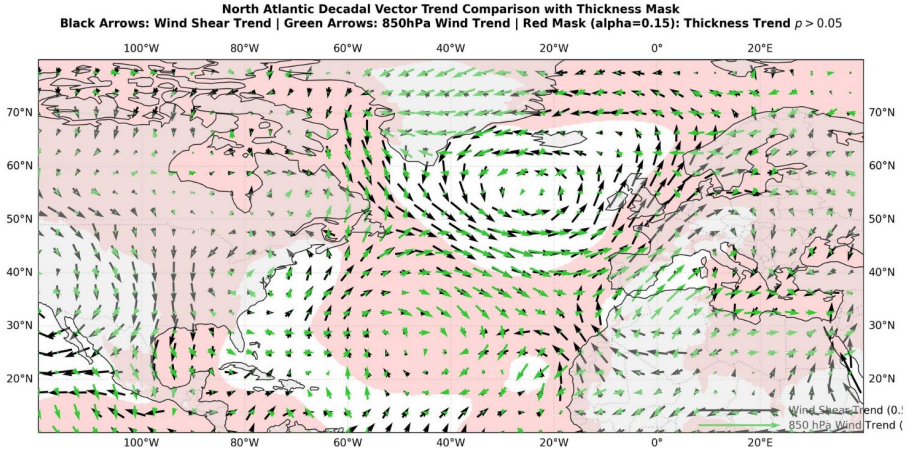
Spatial trends in Eastward Energy Transports and upper level wind anomalies

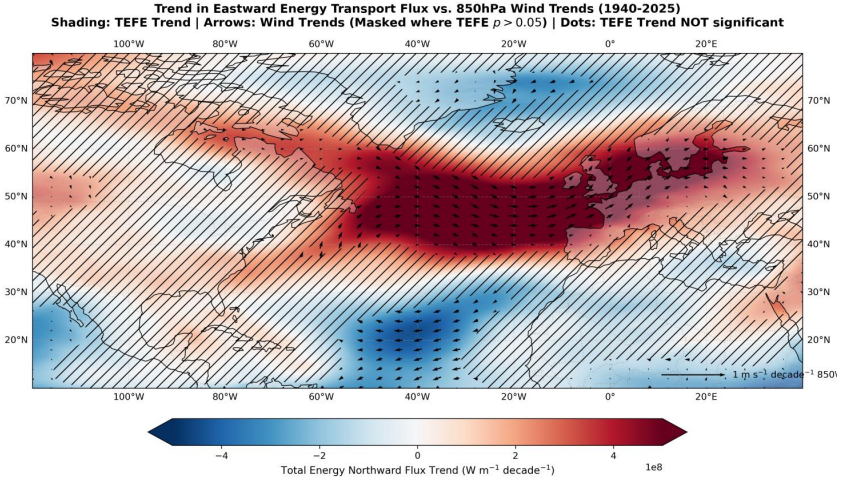


The northward energy transport anomalies seem asociated with cold and warm advection by upper level winds

The eastward energy tranport anomaly is associated with a trend for enhanced westerlies in the southern part of the NAWH







Conclusions

- Significant NAWH => Reduced atmospheric thickness => cyclonic circulation => Cold advection on the west side of the NAWH and warm advection on the east side + enhanced westerly zonal winds affecting energy transports
- The energy transports could in principle lead to enhanced warming over Europe.
  - It is not easy to see this in divergence data, - but that data is noisy
  - Analysis of different seasons with more powerful significance tests might reveal more.