Provinces of Air-Sea Interaction

In the North Atlantic Ocean

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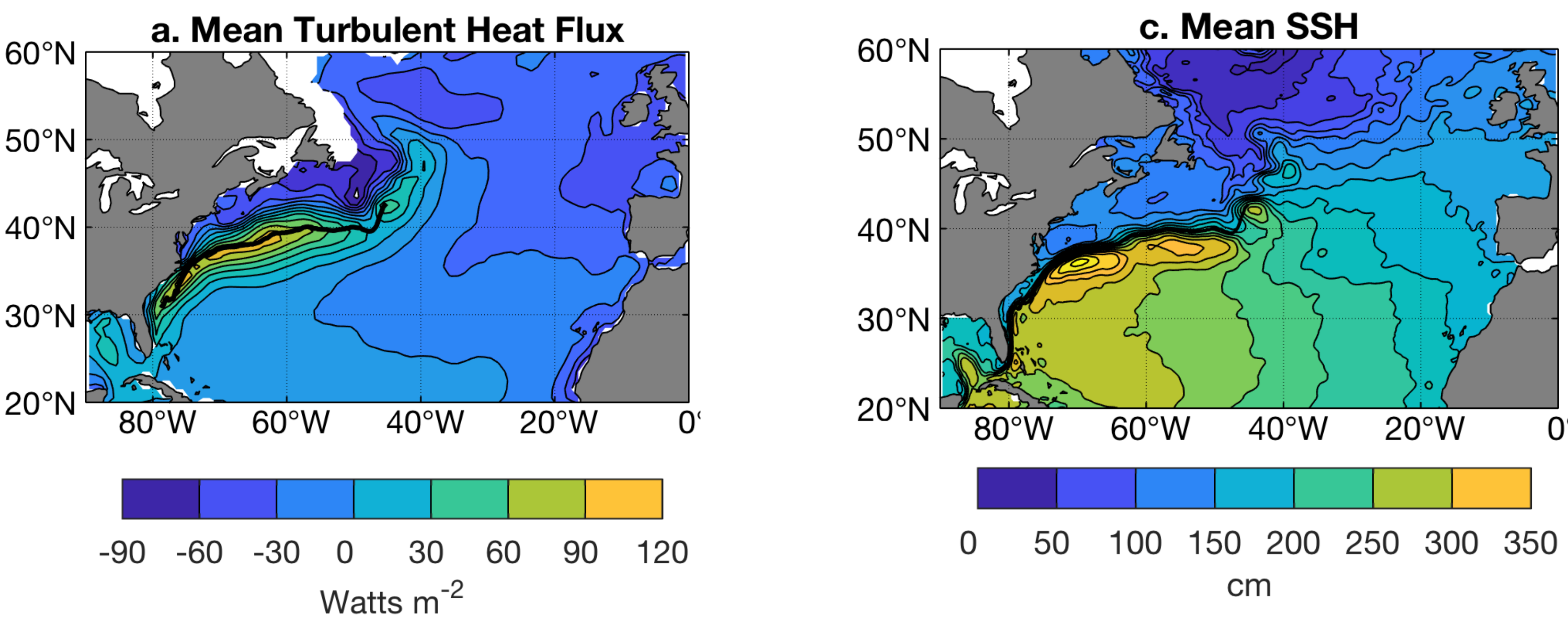
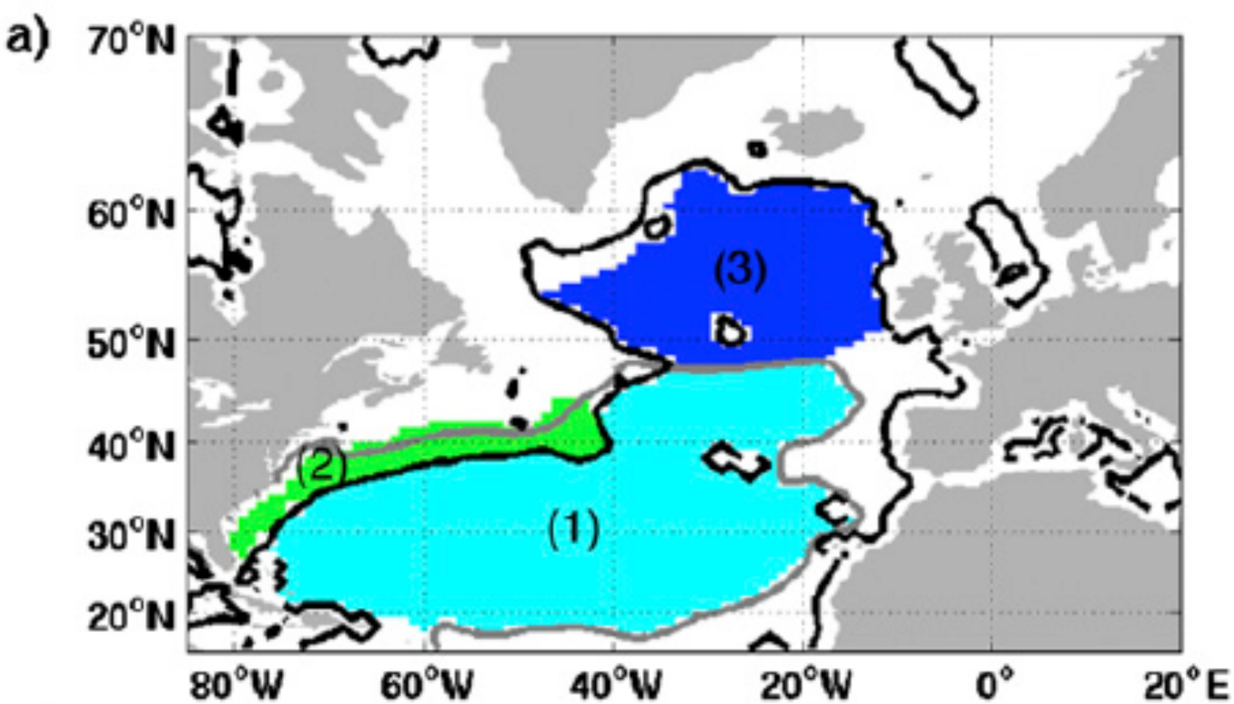
In the mean: Turbulent flux of heat (latent+sensible. Q_{turb}) driven by ocean heat transport convergence

Positie out of the ocean



Dominant contributions by region: Monthly timescale, heat budget of the upper ocean integrated to the maximum MLD in ECCO



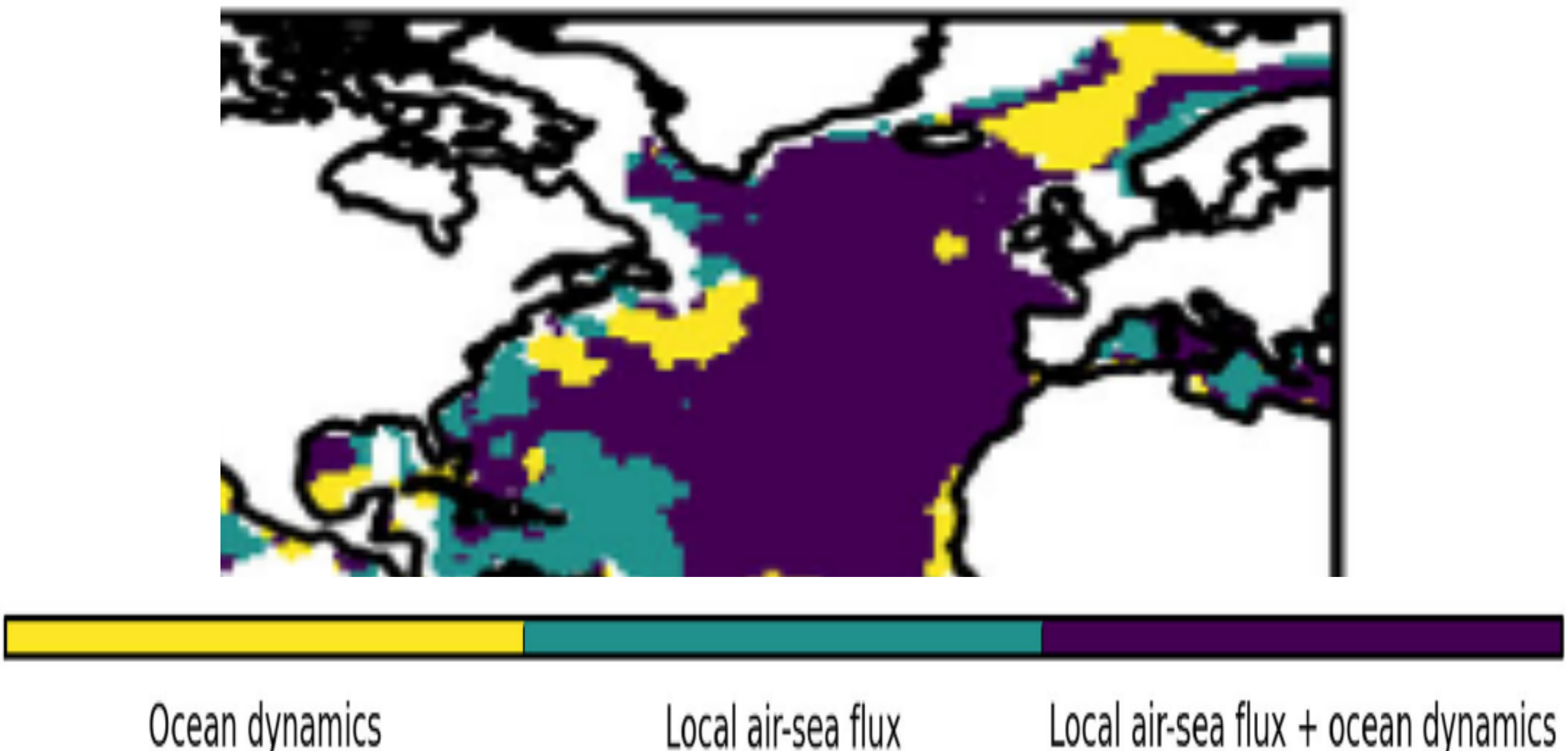
Q_{net} + Ekman

Geostrophic heat transport convergence anomalies and damping by air-sea fluxes

Air-sea fluxes balance bolus fluxes

Buckley et al, 2014

Similar results from observations based upper ocean heat budget on interannual time scales



Roberts et al, 2017

Analysis using surface observations alone to investigate provinces that define the dominant controls of the monthly upper ocean heat budget

Sea level anomaly (SLA) from CMEMS
Sea surface temperature SST from OISST
Turbulent flux of heat Q_{turb} from OAFLUX

Framed with a simple model of air-sea interaction

Stochastic model of air-sea interaction: Frankignoul et al (1998)

Ocean heat content tendency

Q_{turb}

Radiative cooling

$$\rho C_p H \frac{dT_o}{dt} = -\lambda_q (T_o - T_a) - \lambda_r T_o$$

λ_q Turbulent flux feedback

λ_r Radiative flux feedback

$$\lambda_q >> \lambda_r$$

Modification to include:
"ocean noise"= N_o
ocean heat transport convergence from all processes, vertical and horizontal

$$\rho C_p H \frac{dT_o}{dt} = -\lambda_q (T_o - T_a) - \lambda_r T_o + N_o$$

$$T_a = N_a$$

High Frequency Noise: atmospheric forcing

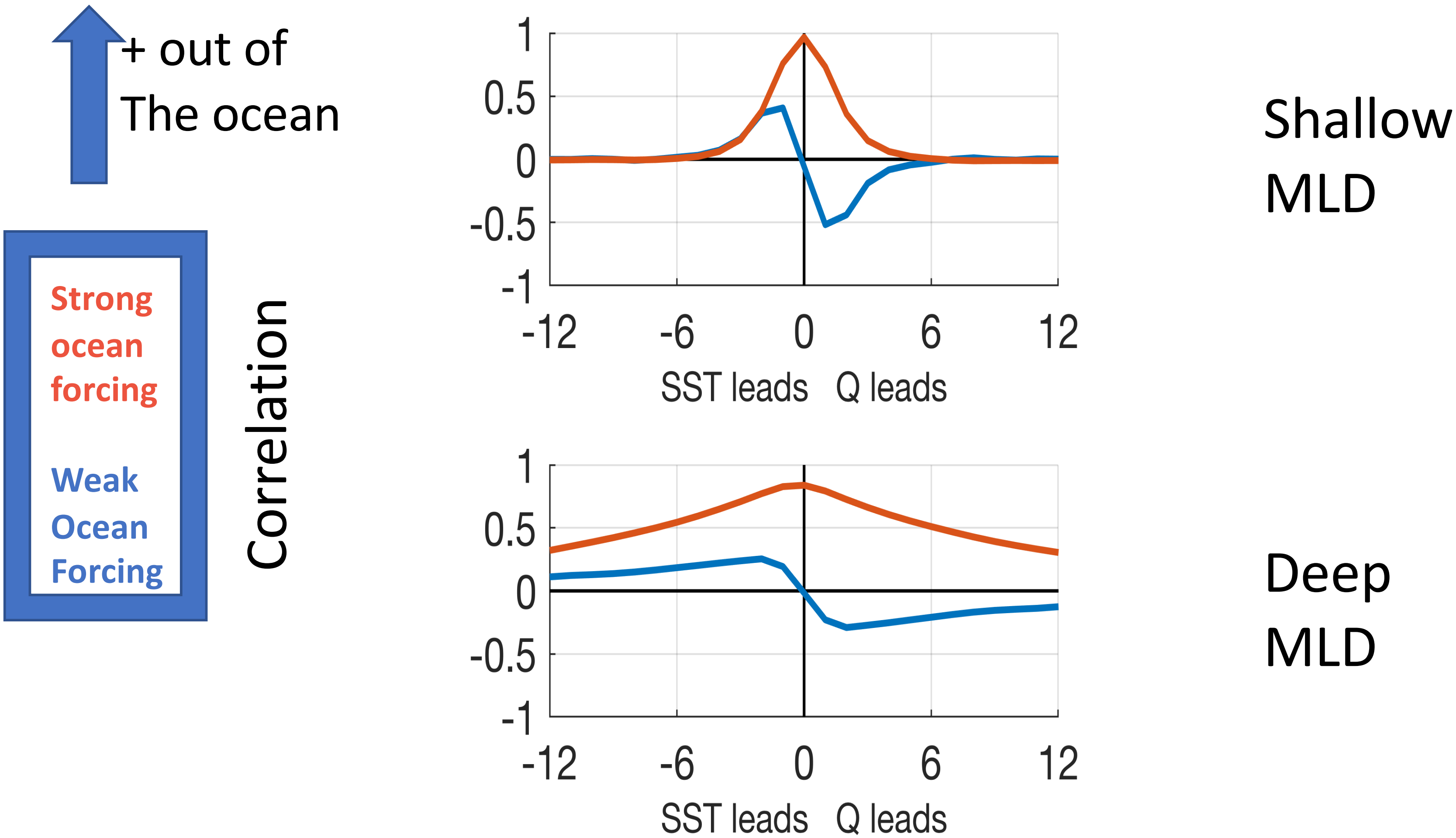
$$N_o$$

Low Frequency Noise coming from ocean heat transport convergence anomalies: ocean forcing

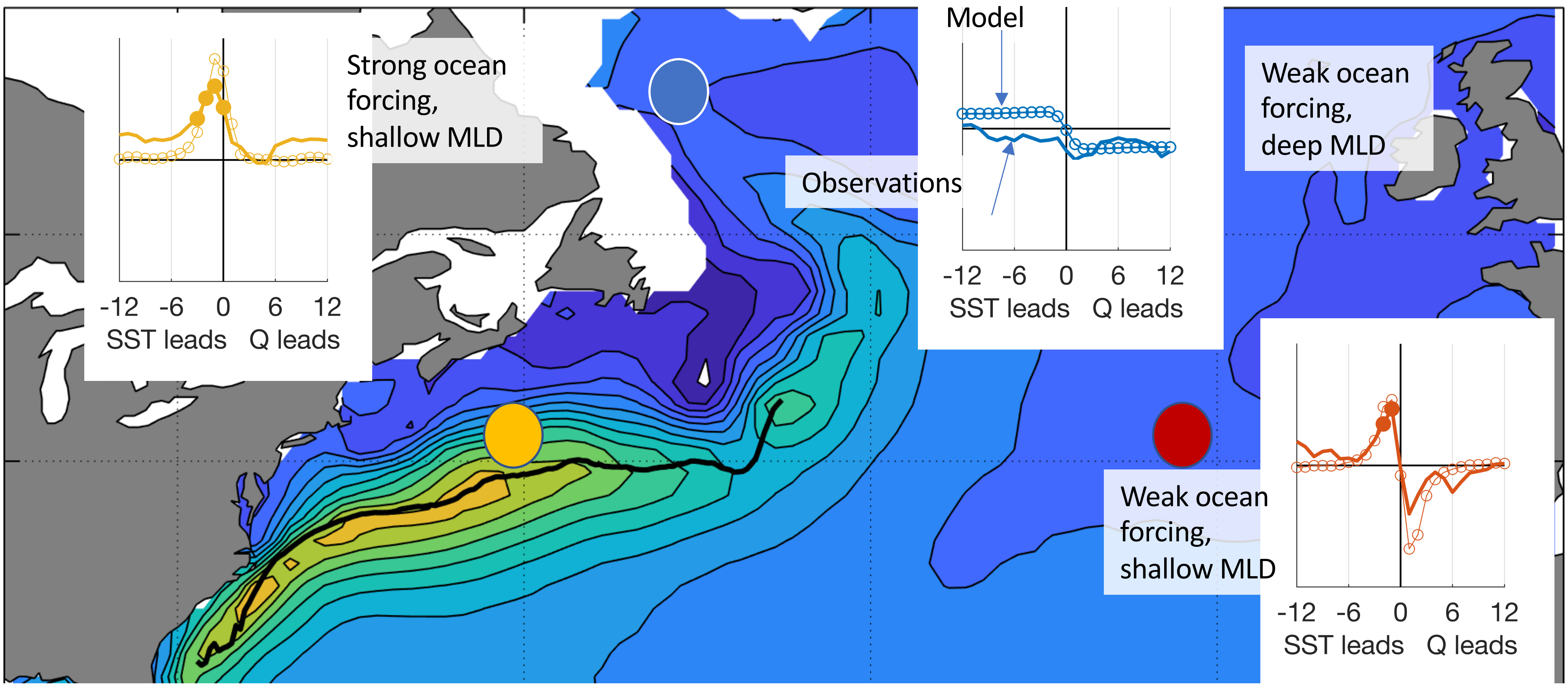
Lagged correlations between Q_{turb} and SST depend on depth of the upper ocean

and

the ratio of the atmospheric to oceanic forcing.



Air-sea interaction processes depends on location: lagged correlations of SST and Q_{turb} are consistent with solutions of the simple model



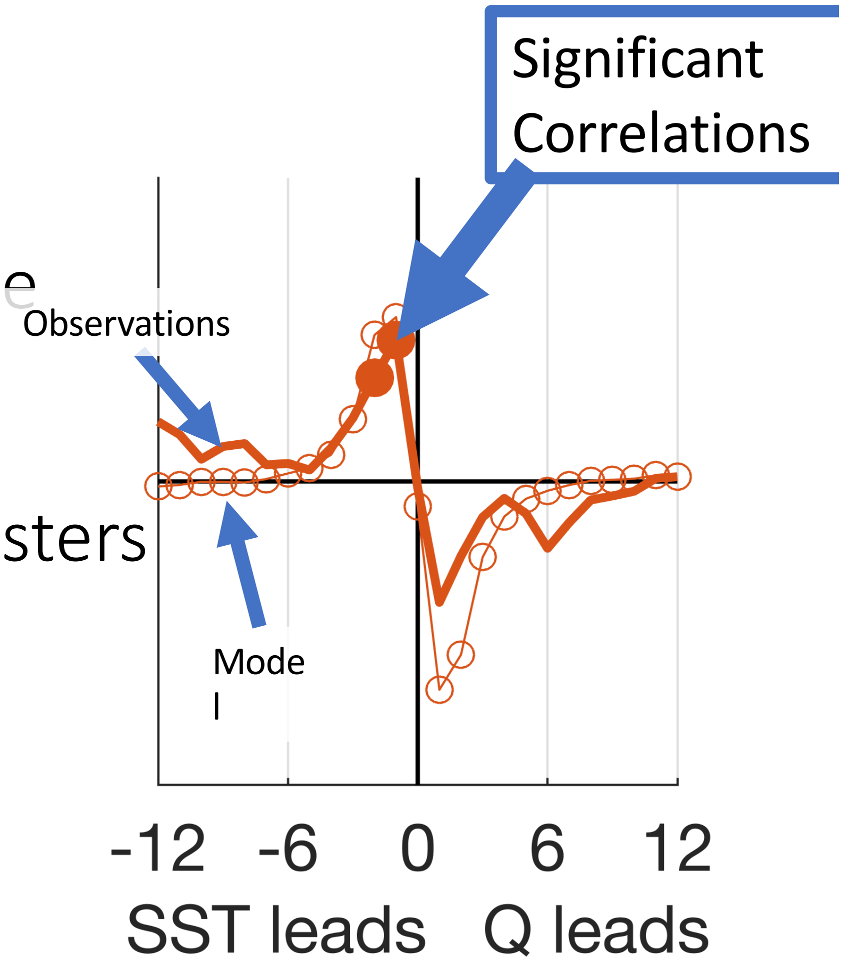
All fields smoothed to 100km full width at half max

Characterization of provinces via clustering

Apply k-means clustering of lagged correlations patterns of SST and Q_{turb}
Minimizes the Euclidian Distance of the lagged-correlations within clusters

3 clusters: various test indicate 2-3 clusters

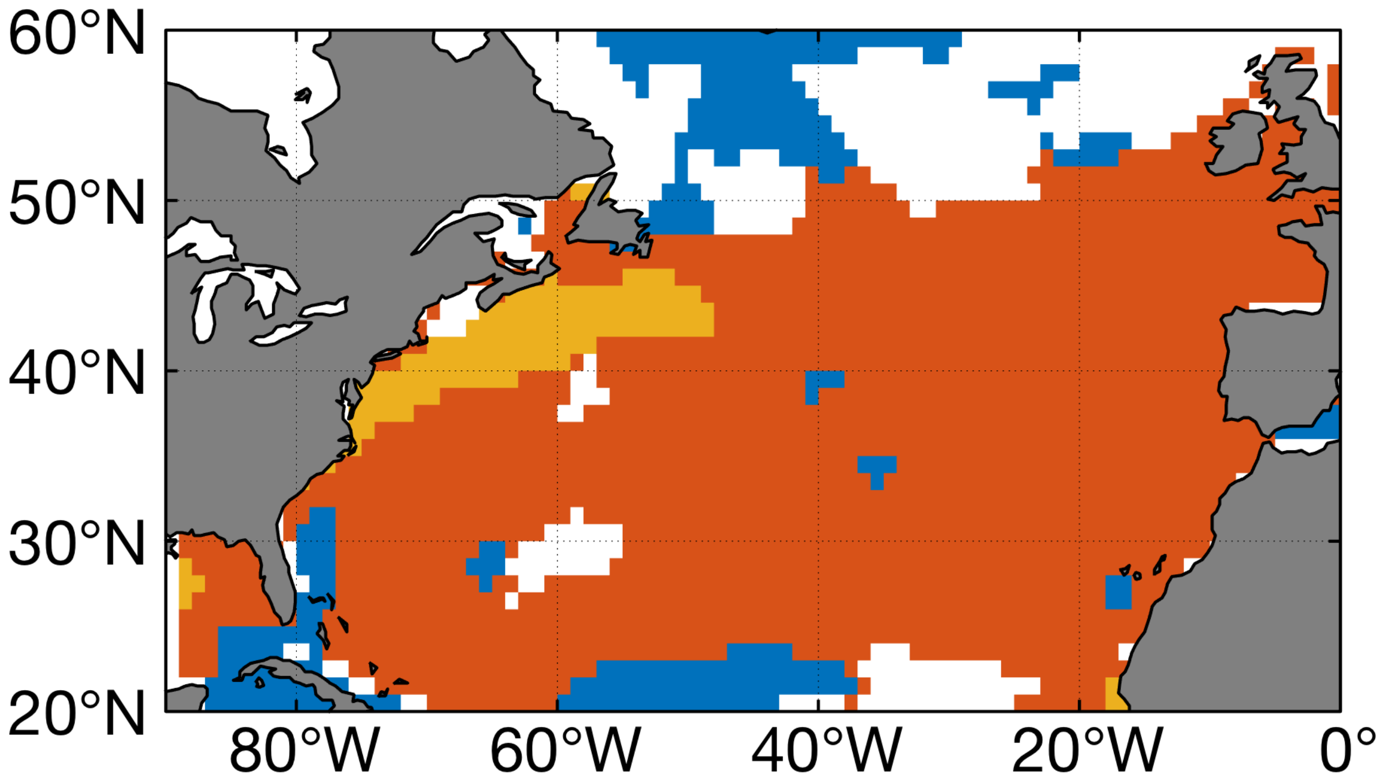
Only use locations with at least one significant lagged correlation



Clustering with k-means groups together similar lagged correlations patterns:

Similar lagged correlations are linked spatially

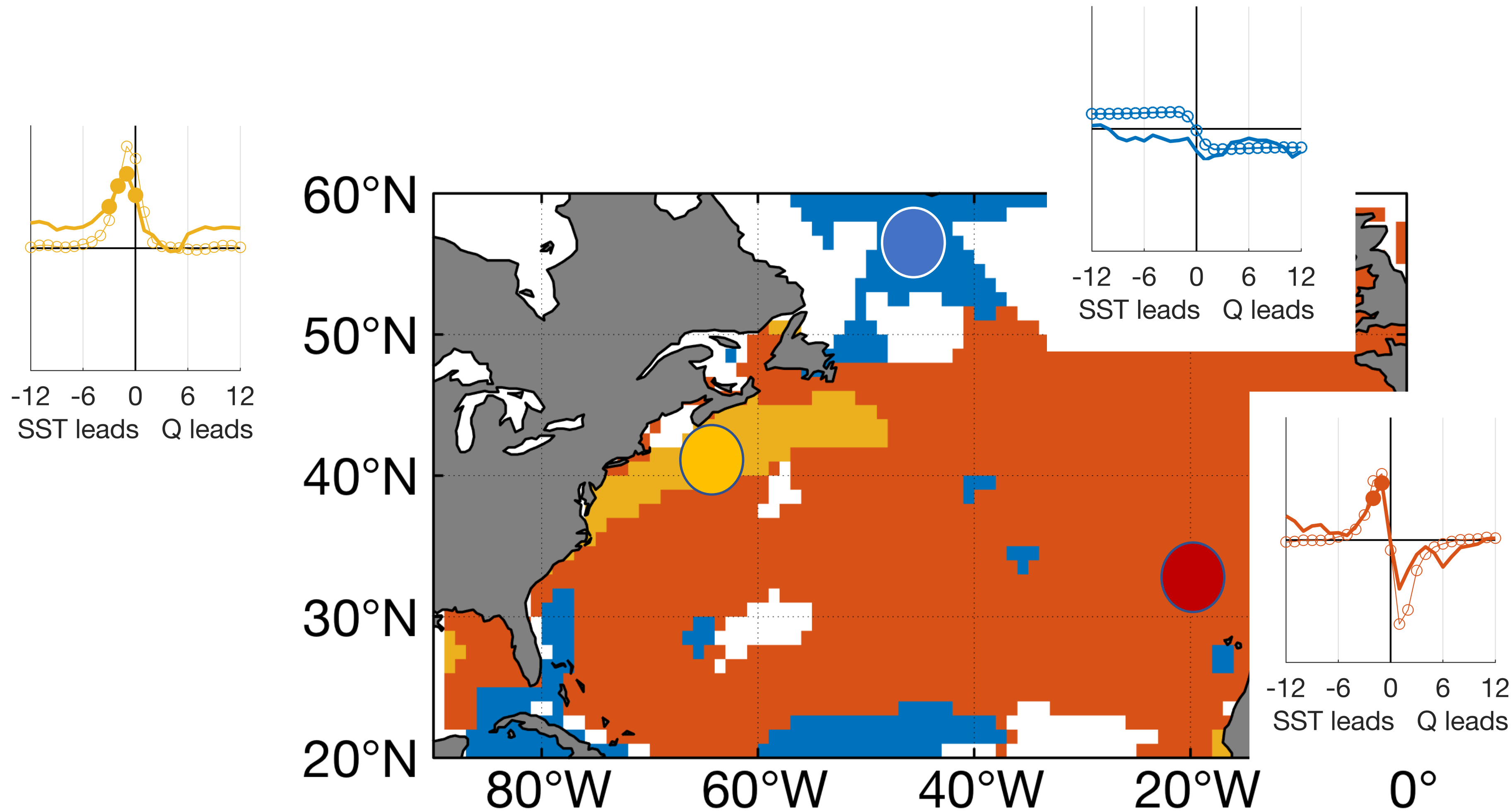
No spatial information is provided in the analysis



Blank areas have NO significant lagged correlations

Spatially coherent

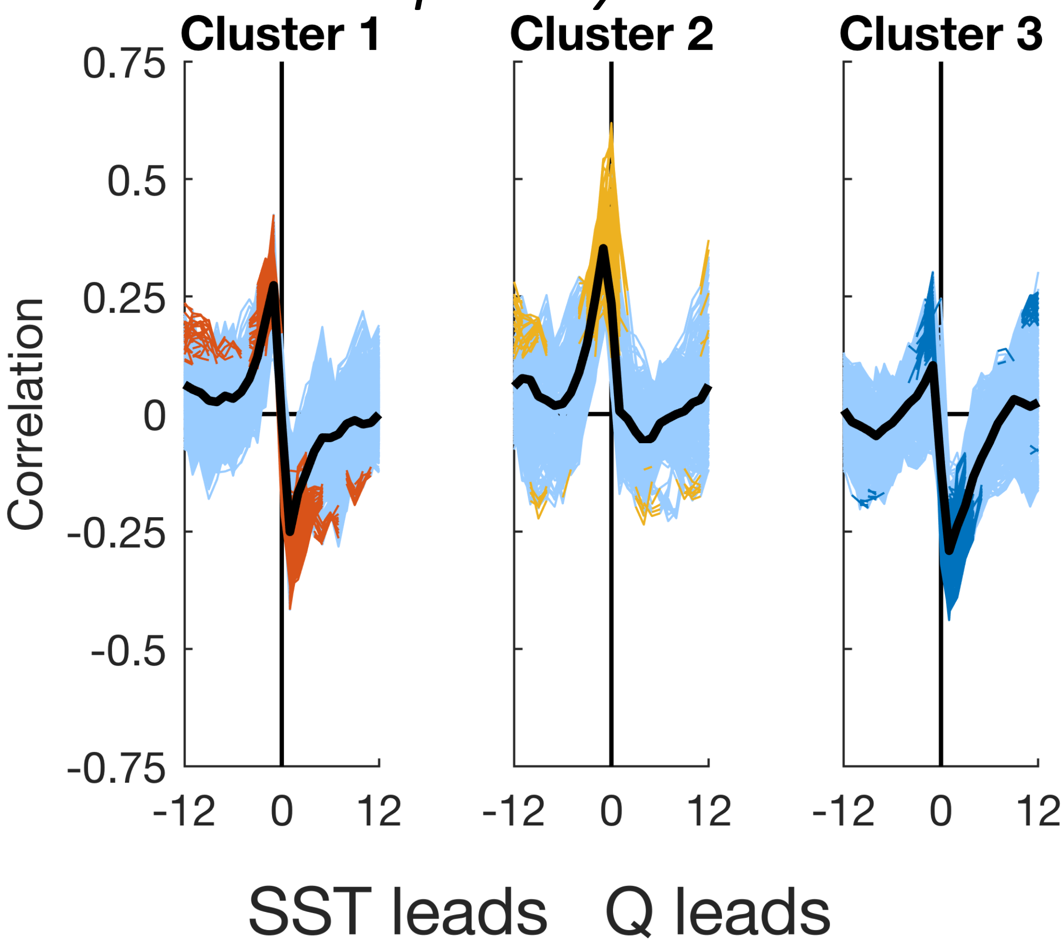
Clustering with k-means groups spatially similar lagged correlations patterns

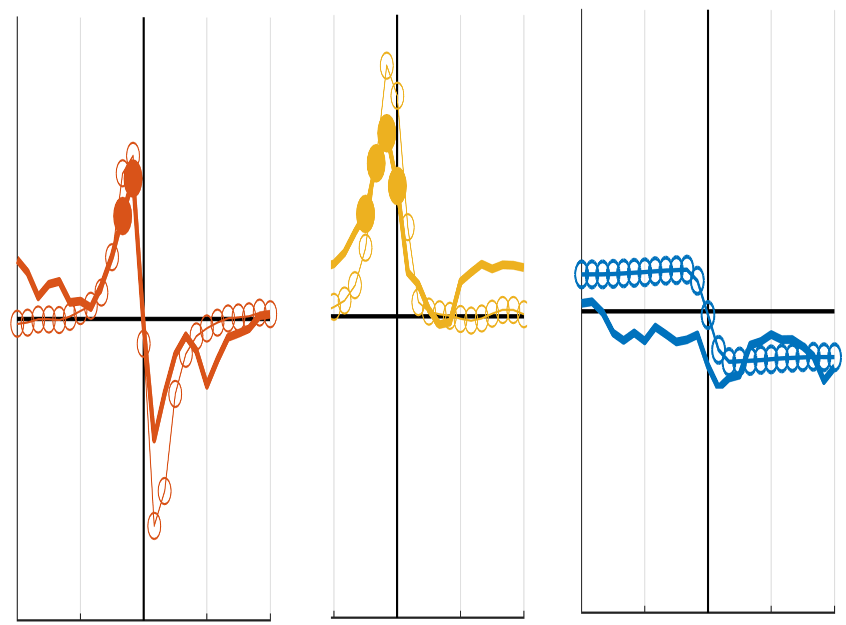


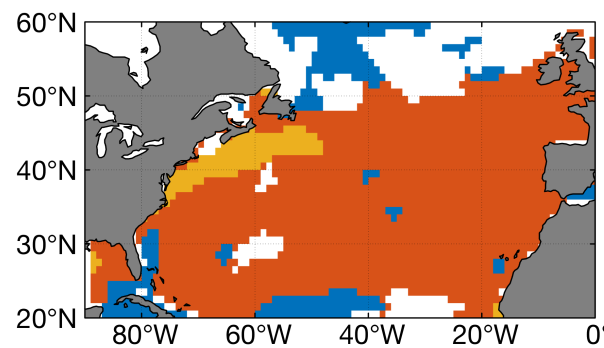
Cluster analysis

K-means sorts by the symmetry properties of the lagged correlations

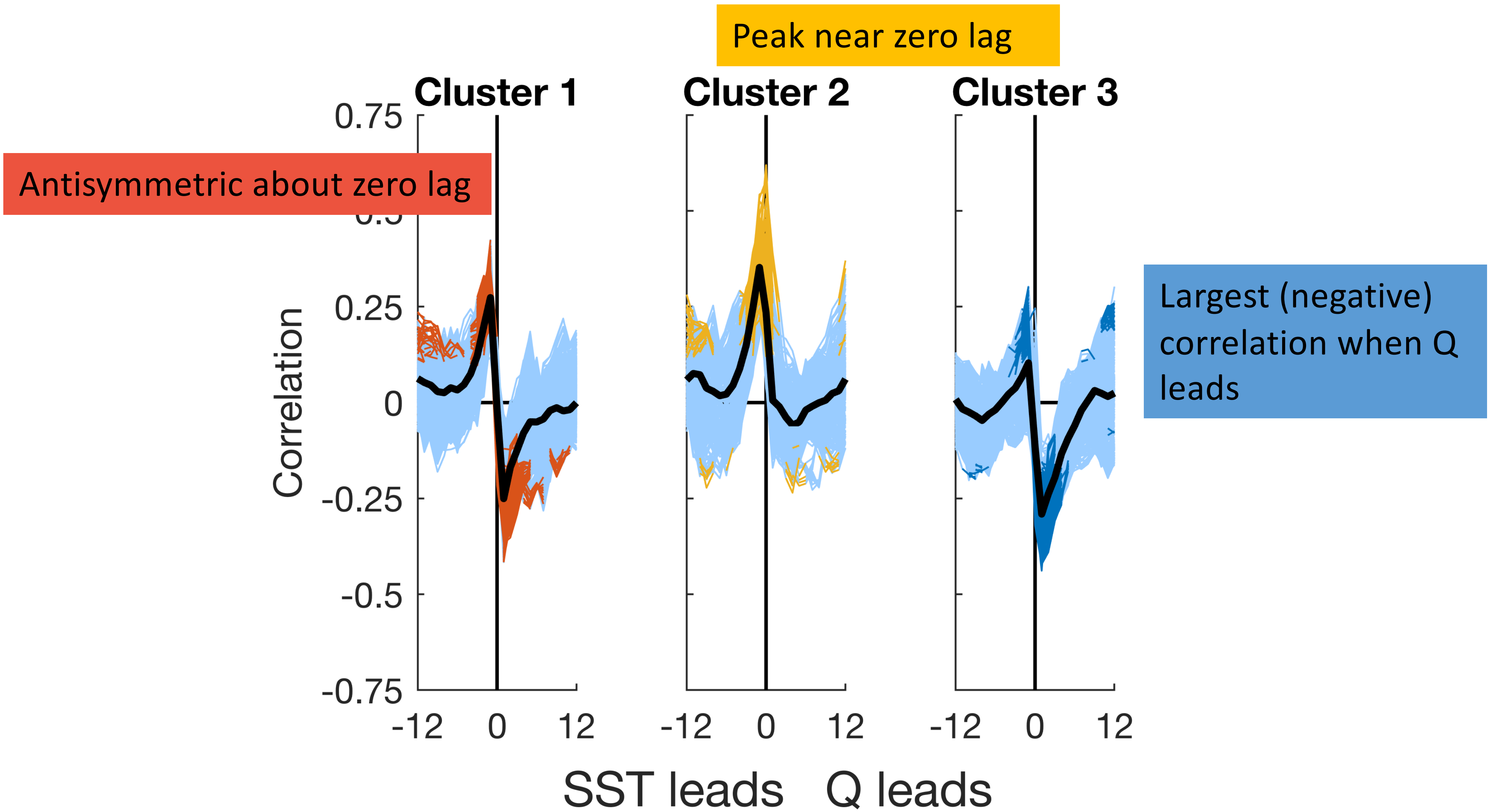
Results are spatially coherent!



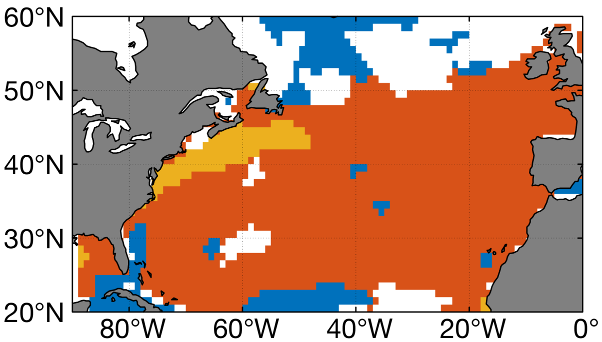


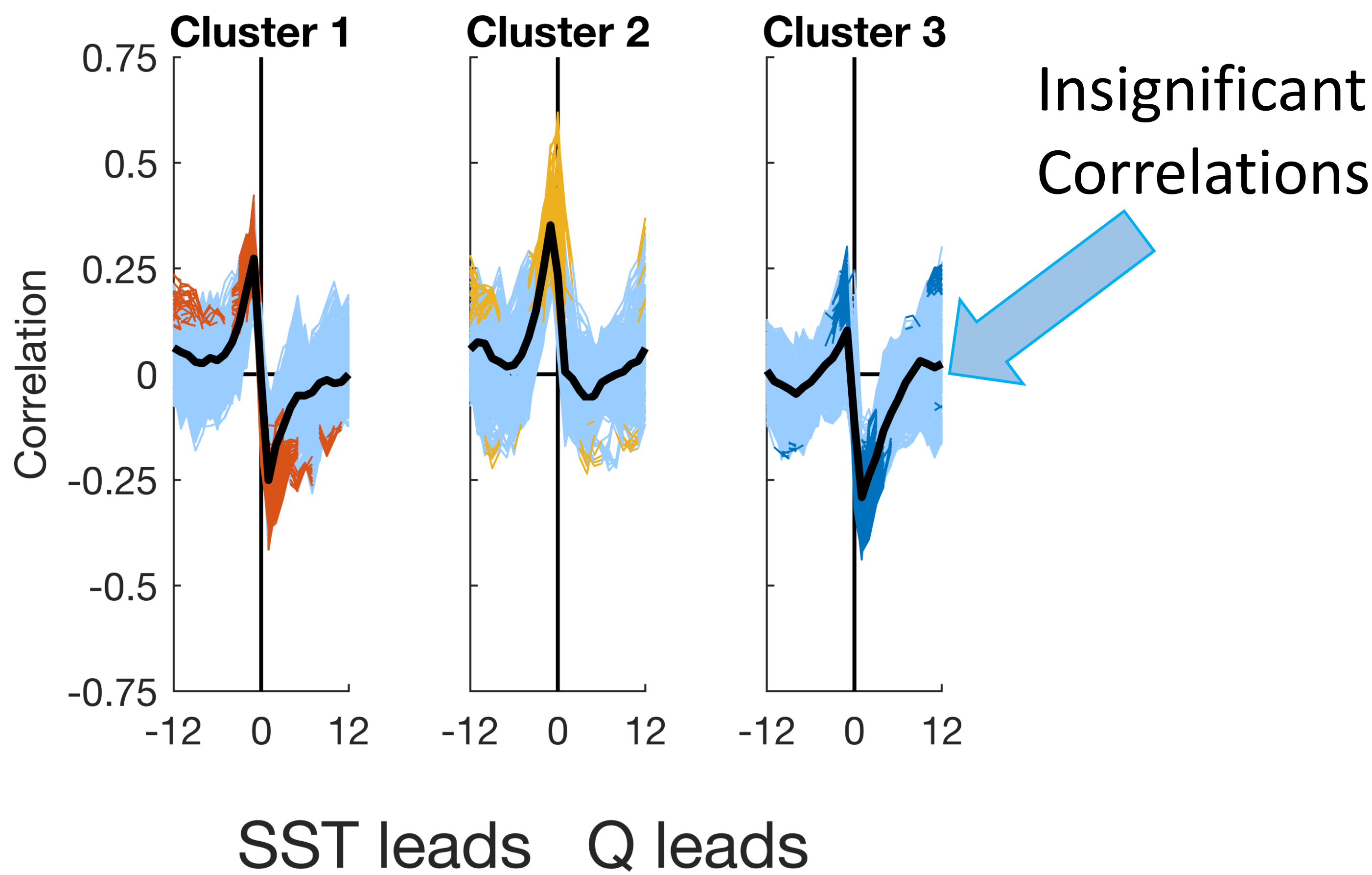


Clusters distinguished by symmetry properties of the lagged correlations

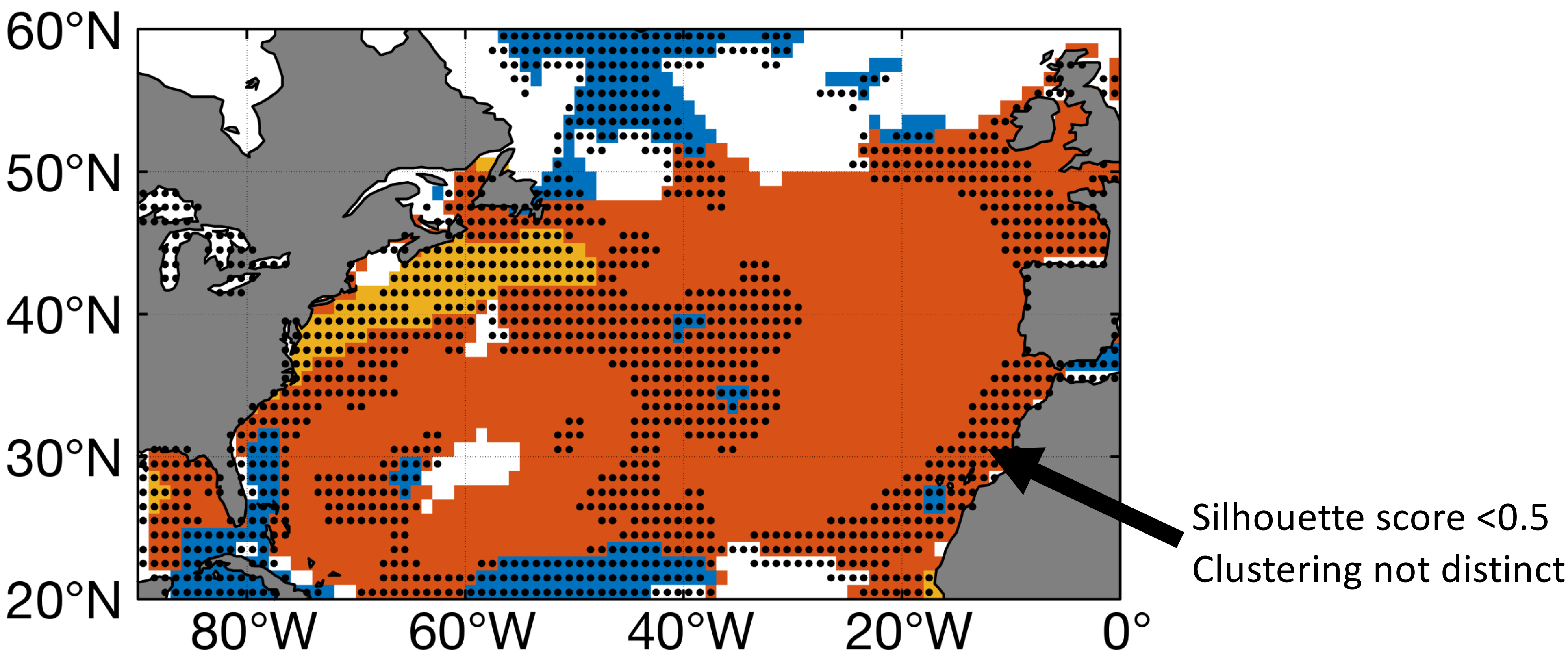


However, lagged correlations in each cluster suggest some overlap between clusters



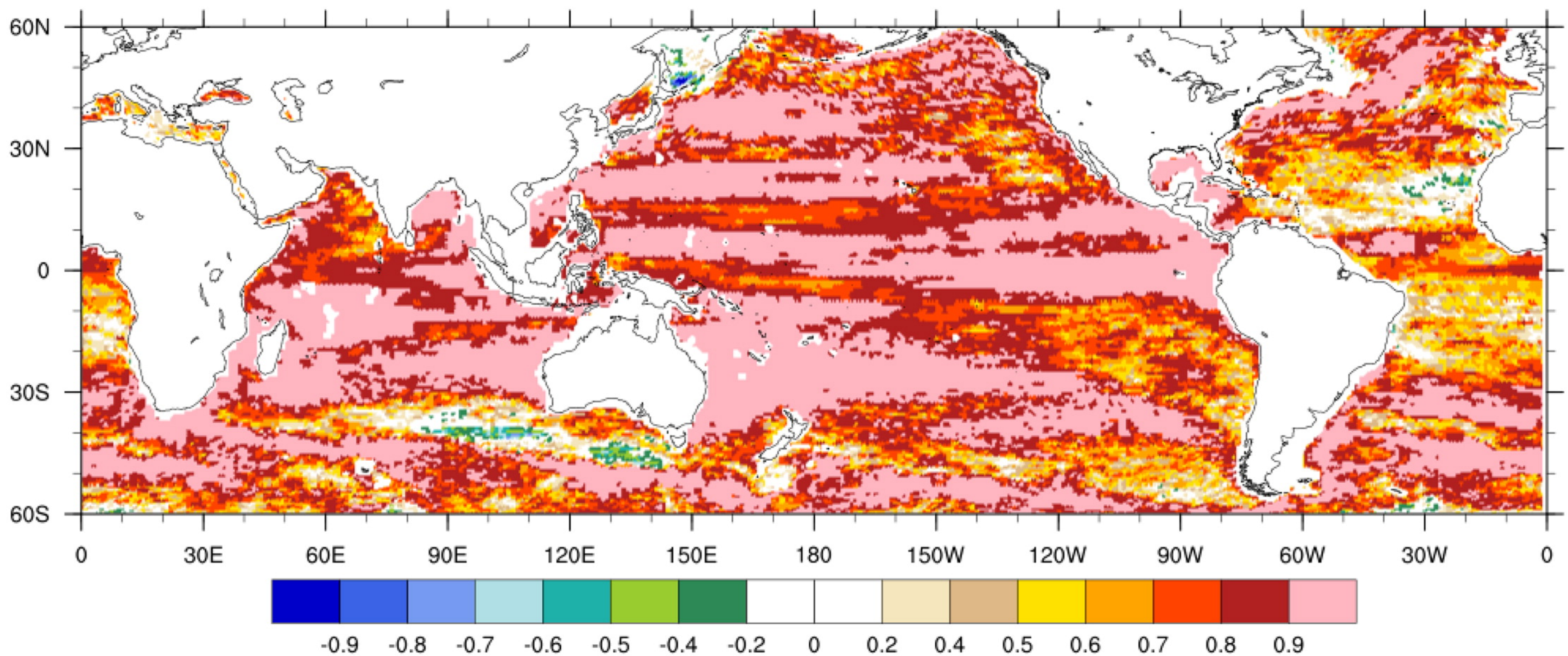


Silhouette score for each location indicates areas with robust distinction between clusters.



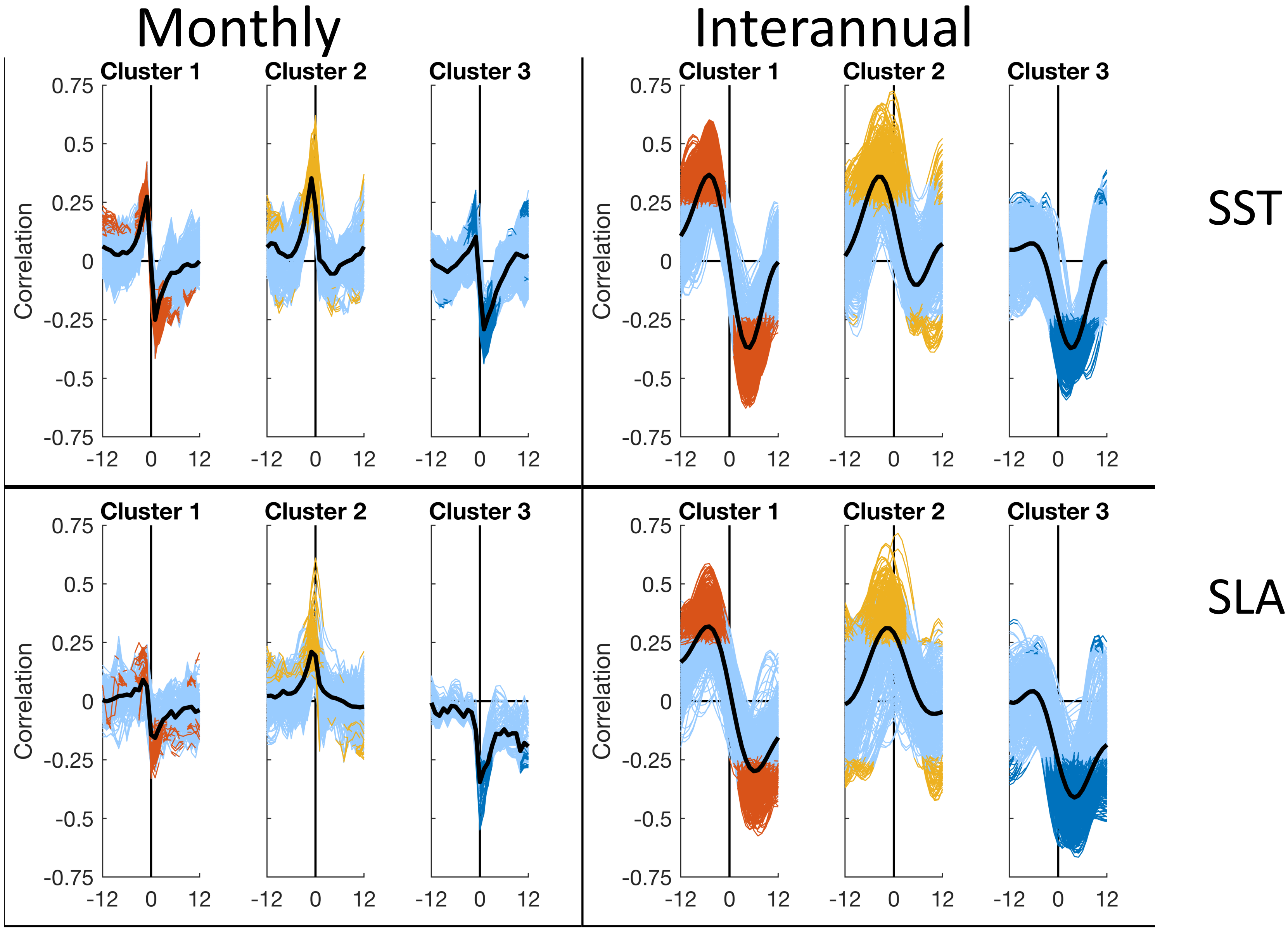
What can we learn by applying the analysis to SLA?

Use the same approach for the upper ocean using SLA as proxy for upper ocean heat content

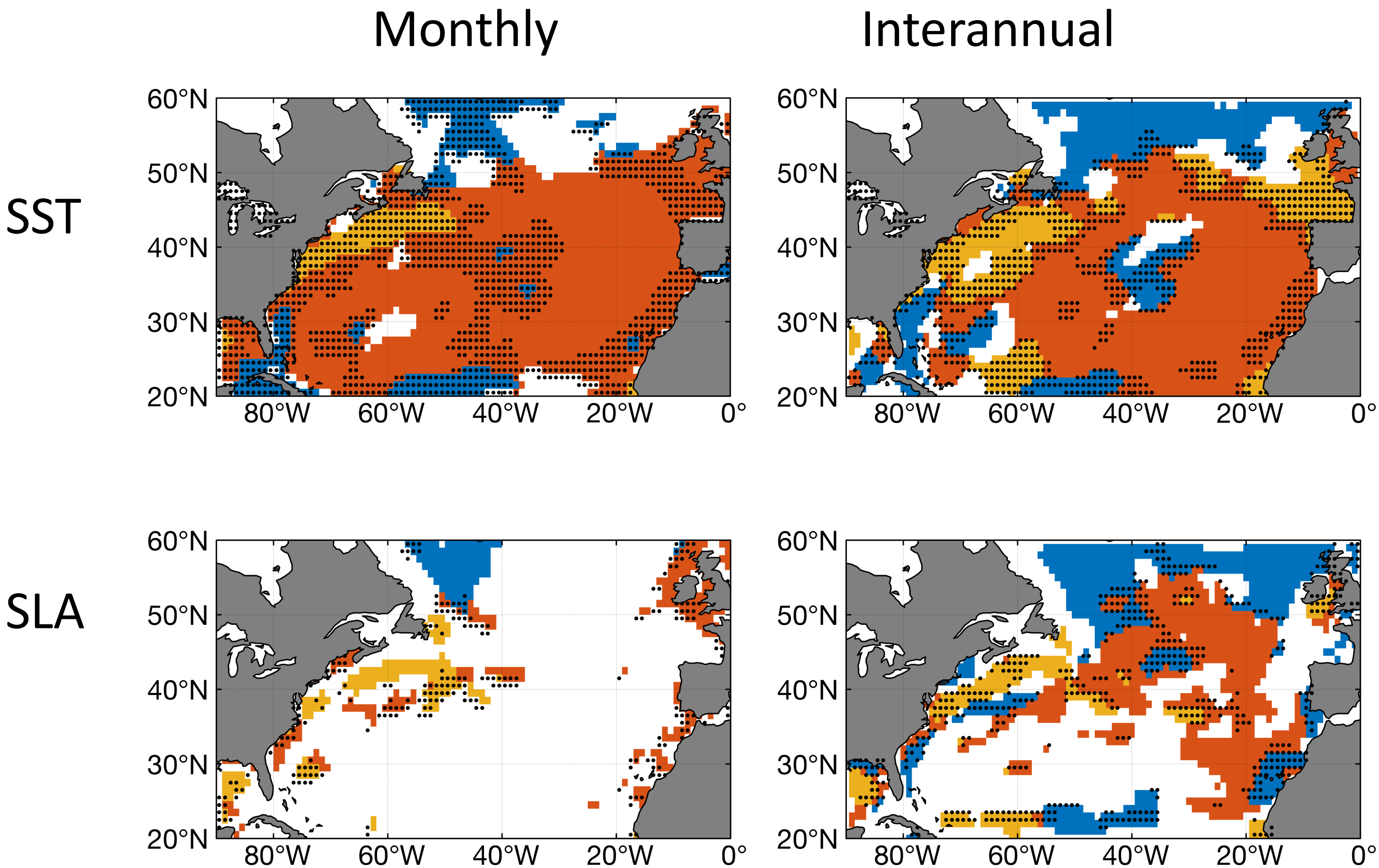


Upper 400m heat content correlation with SLA in high resolution coupled model (Small et al, 2020): Highly correlated in the Gulf Stream/North Atlantic Current and the Gulf of Mexico

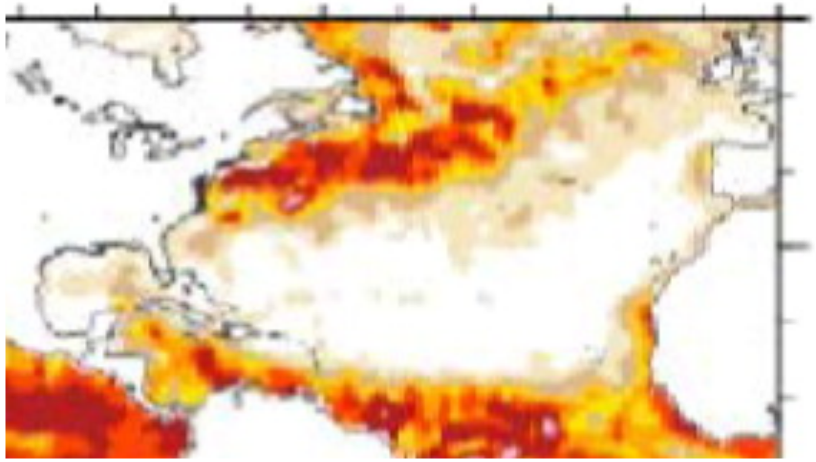
Similar results for SST/SLA, proxy for upper ocean heat content



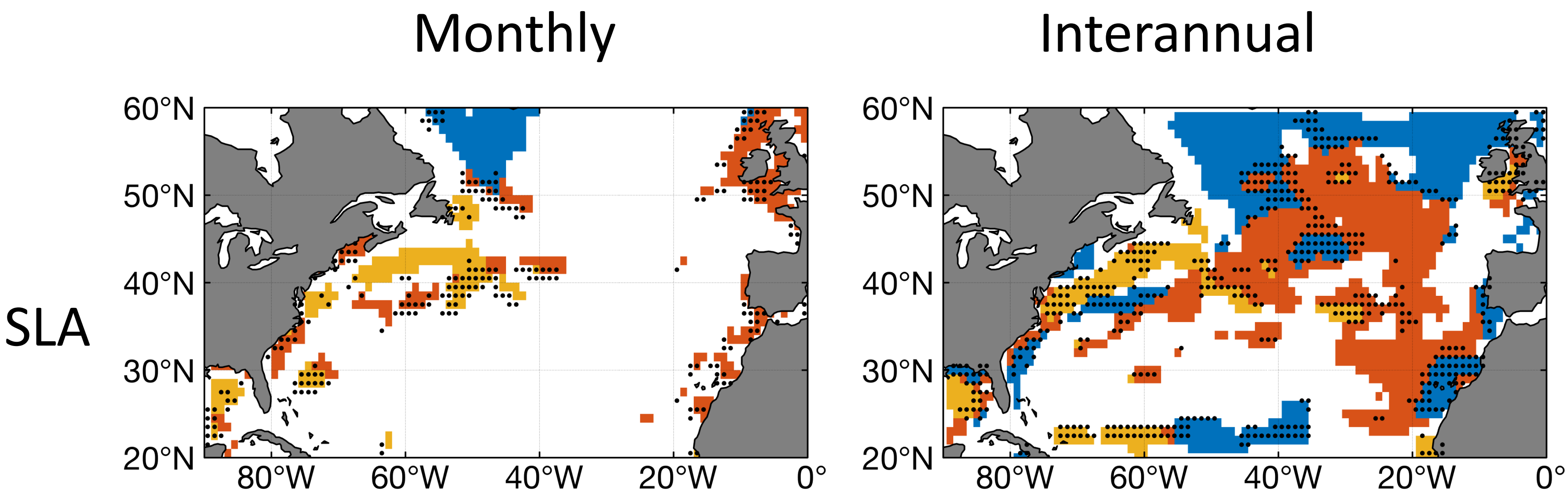
Clusters of SLA provides a more detailed delineating of the provinces of air-sea interaction



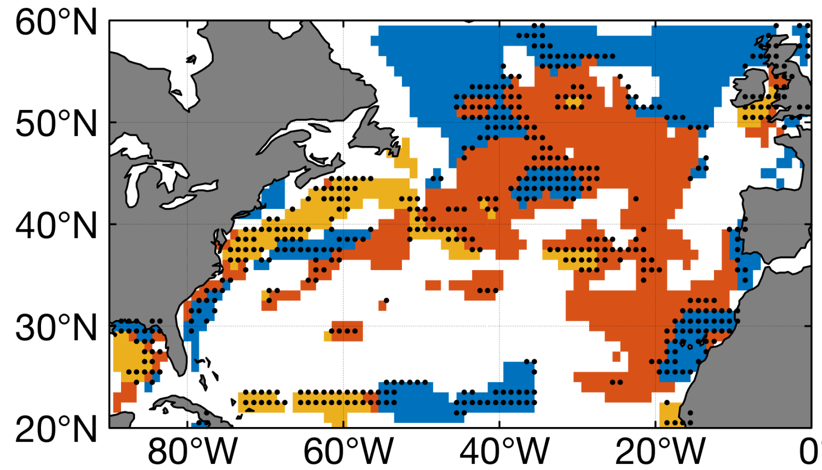
Clusters of lagged correlations between SLA and Q_{turb} consistent with regression in high resolution climate model of rate of change of heat content with Q



Results from high-resolution coupled climate model Small et al, 2020



Conclusions



- K-means clustering defines provinces of differing processes controlling upper ocean heat budget from surface observations alone:
- Three distinct regimes
  - Gulf Stream: Ocean heat transport convergence drives air-sea interaction, shallow MLD, strong ocean forcing
  - Interior subtropical gyre: Atmosphere forces then damps SST anomalies, shallow MLD, weak ocean forcing
  - Subpolar gyre: atmosphere forces a deep ocean, SST anomaly not damped locally, deep MLD, weak ocean forcing
- Results for SLA similar to what is found from heat budget analysis (ECCO, observations, Coupled high resolution model)
- *Heat content anomalies below seasonal thermocline reflected by SSH are not directly interacting with the atmosphere in the summer*