North Atlantic decadal variability in a coupled global model and relevance to observations

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Background

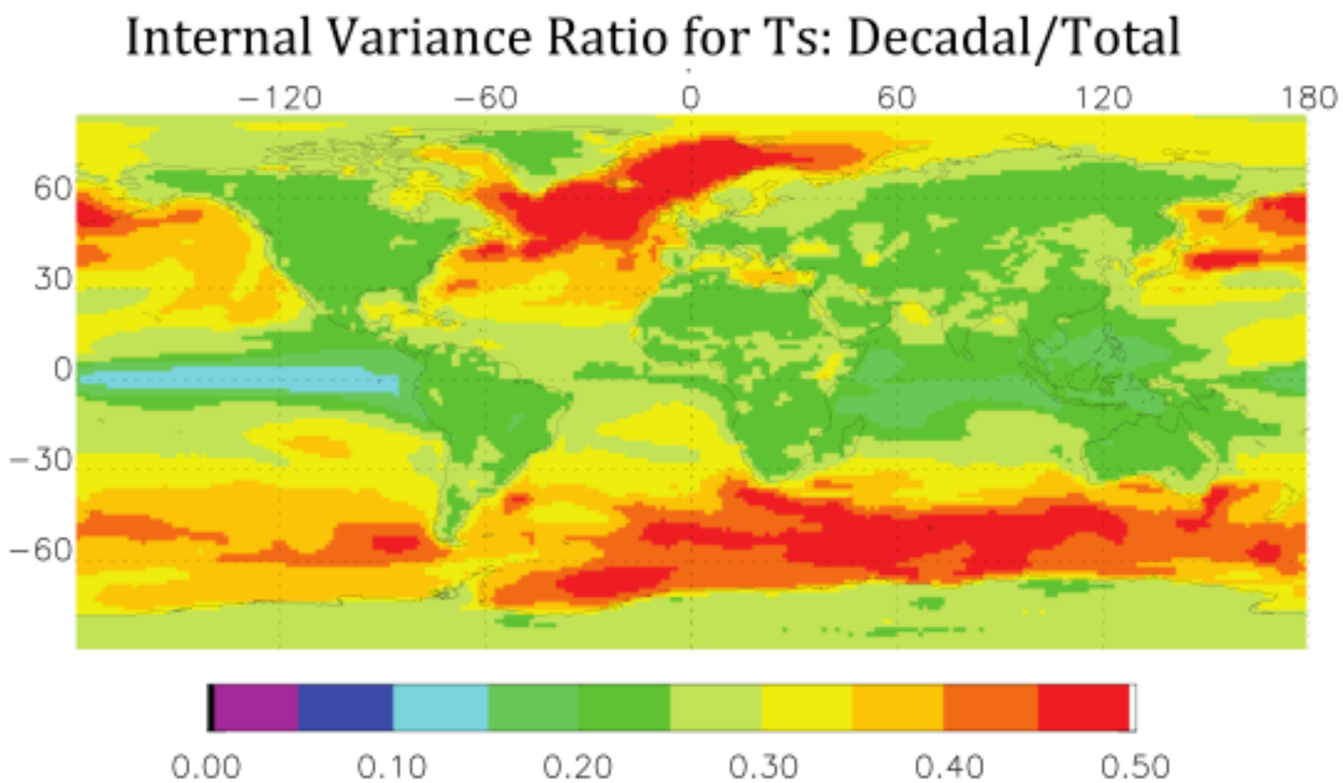
- Several investigators have described decadal variations in the North Atlantic Ocean-atmosphere system that are expressed in quasi-periodic changes of sea level pressure (SLP), sea surface temperatures (SST), upper ocean heat content (UOHC) the position of the Gulf Stream (Deser and Blackmon, 1993; Joyce et al., 2000; Frankignoul et al., 2001; Nigam et al., 2018), etc. These studies also pointed at a time-dependent connections between these different variables.

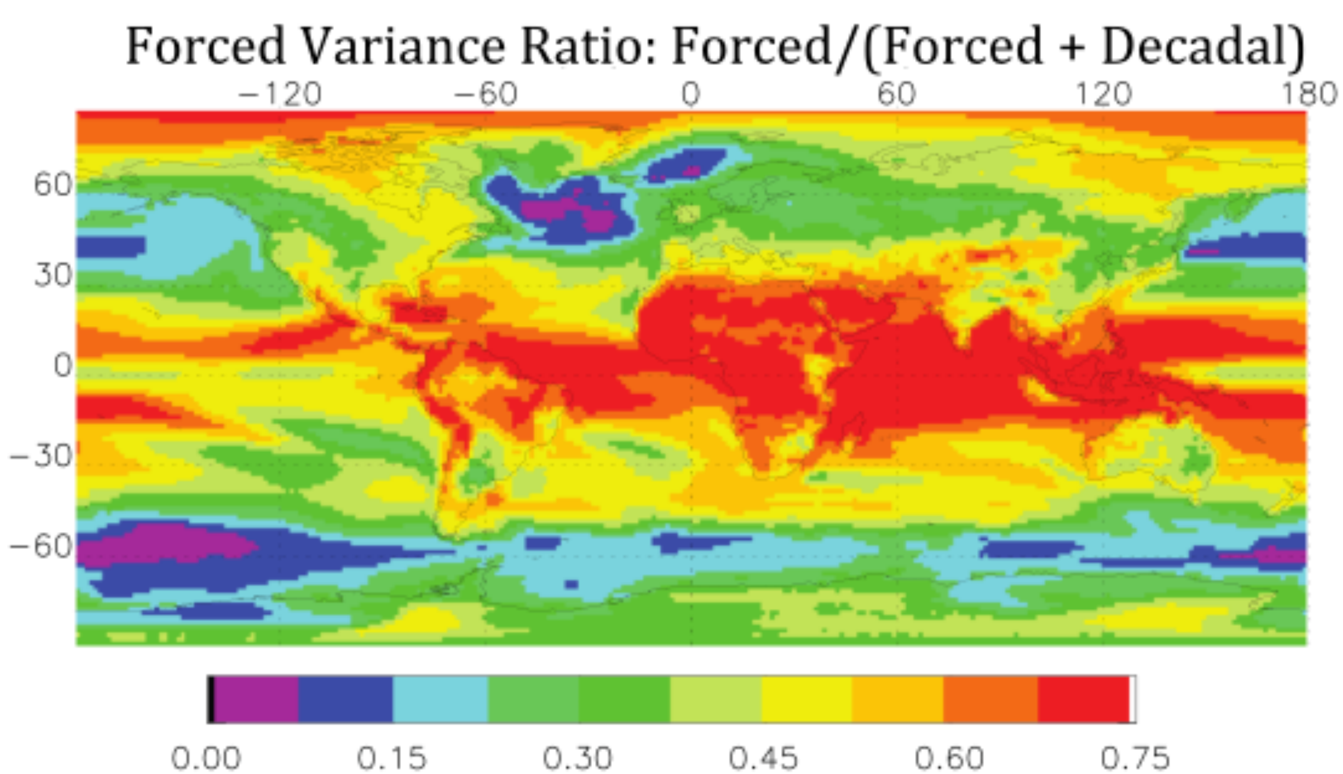
- In most of these studies digital filters have been used to detect these decadal phenomena and, in particular, the interrelationships between oceanic and atmospheric variables, a method that can taint a search for their dynamical origin and properties.

- We apply a method that does not require pre-processing of the data with digital filters. This enables describe a dynamical pattern of decadal variations in the North Atlantic climate system in a long control run of a coupled general circulation model (CESM1).

- We compare the model behavior to that of the observed North Atlantic climate system by using the method of linear inverse modeling (LIM), which does not require the use of digital filters.

North Atlantic Decadal Variability - 1



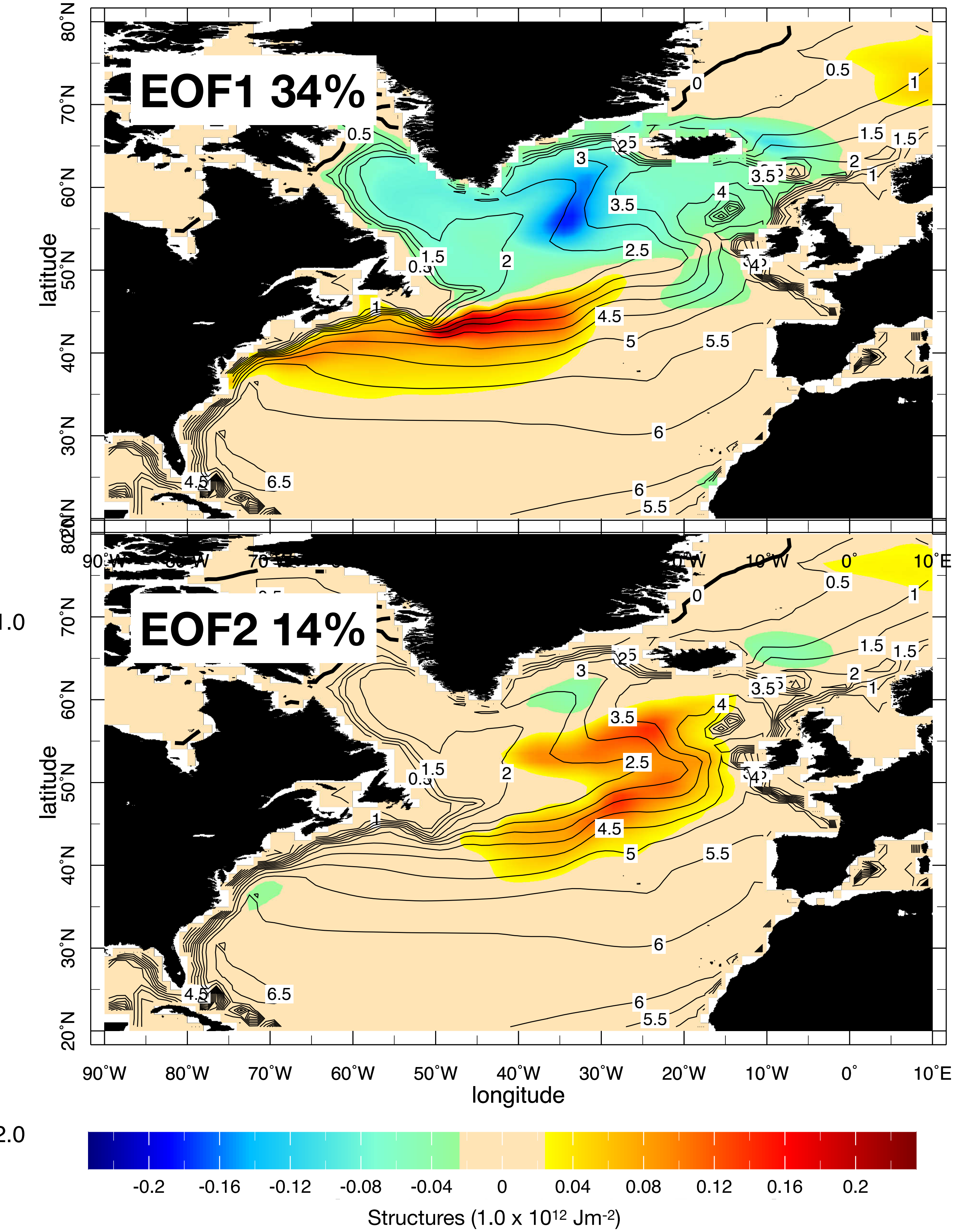


- CMIP6 multiple realization of the historical period allow us to assess the geographical distribution of the variance of decadal and longer time-scale variability (separated by using a 10-day lowpass filter) in relation to total variance when the impact of external forcing is removed and the impact of decadal variability in an externally forced climate.
- Decadal variability stands out in the North Atlantic and the southern ocean.
- Estimates based on observations are consistent with this model-based calculation.

Method

- We use upper ocean heat content (UOHC) to detect the pattern of ocean decadal variability and its interaction with the atmosphere.
- Extratropical UOHC naturally varies on multi-year time scales as it integrates the thermodynamical and importantly also the dynamical forcing of the overlying atmosphere thus will display decadal time scale phenomena as well as the role of ocean dynamics more readily than SST.
- We apply the method of linear inverse modeling (LIM) to identify quasi-periodic patterns of behavior (also referred to as principal oscillation patterns - POPs). The LIM method allows a dynamically based way to detect the presence and role of internal variability in the externally forced climate system of the North Atlantic (see for example the Newman et al. [2018] study of PDV).

PCA of CESM North Atlantic UOHC



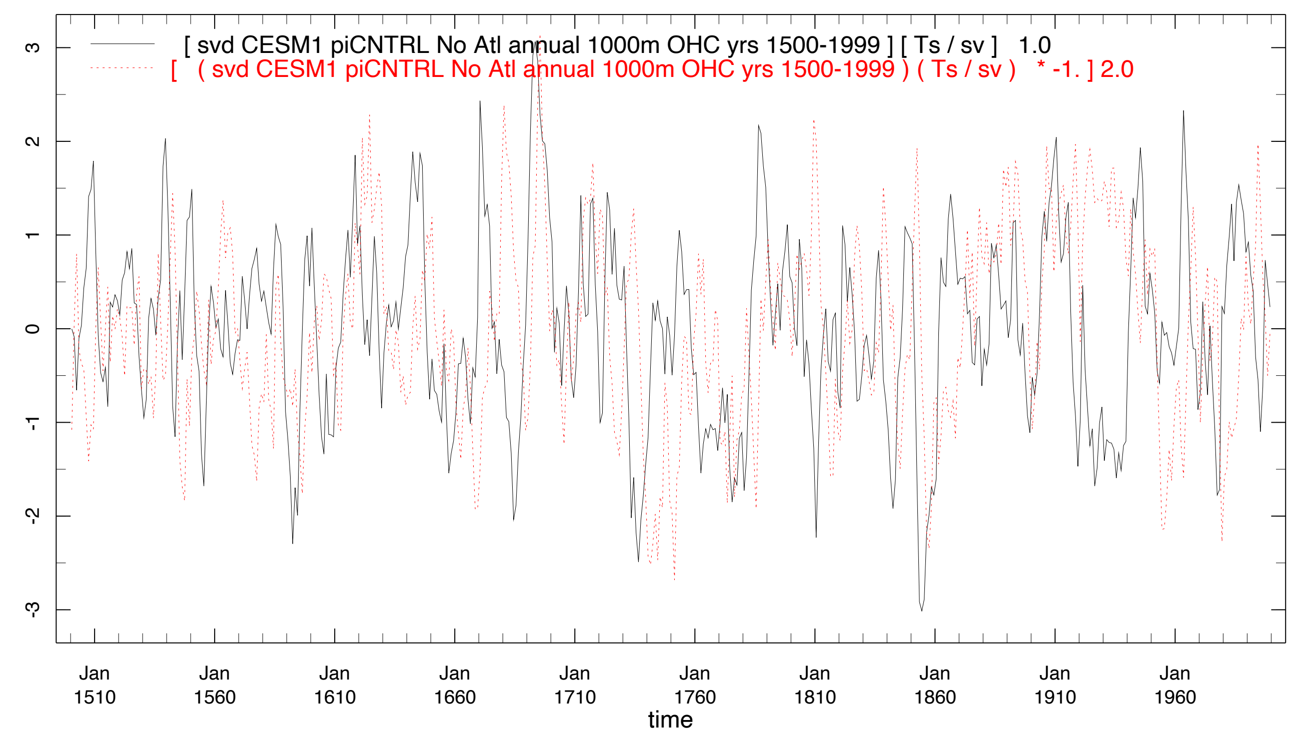
PCA of CESM piCNTRL annual mean UOHC (calculated to 1000 m in a 500 yr segment). The leading two EOFs are shown in color (units are 1E12 Jm^{-2}). The climatological UOHC is shown in contours.

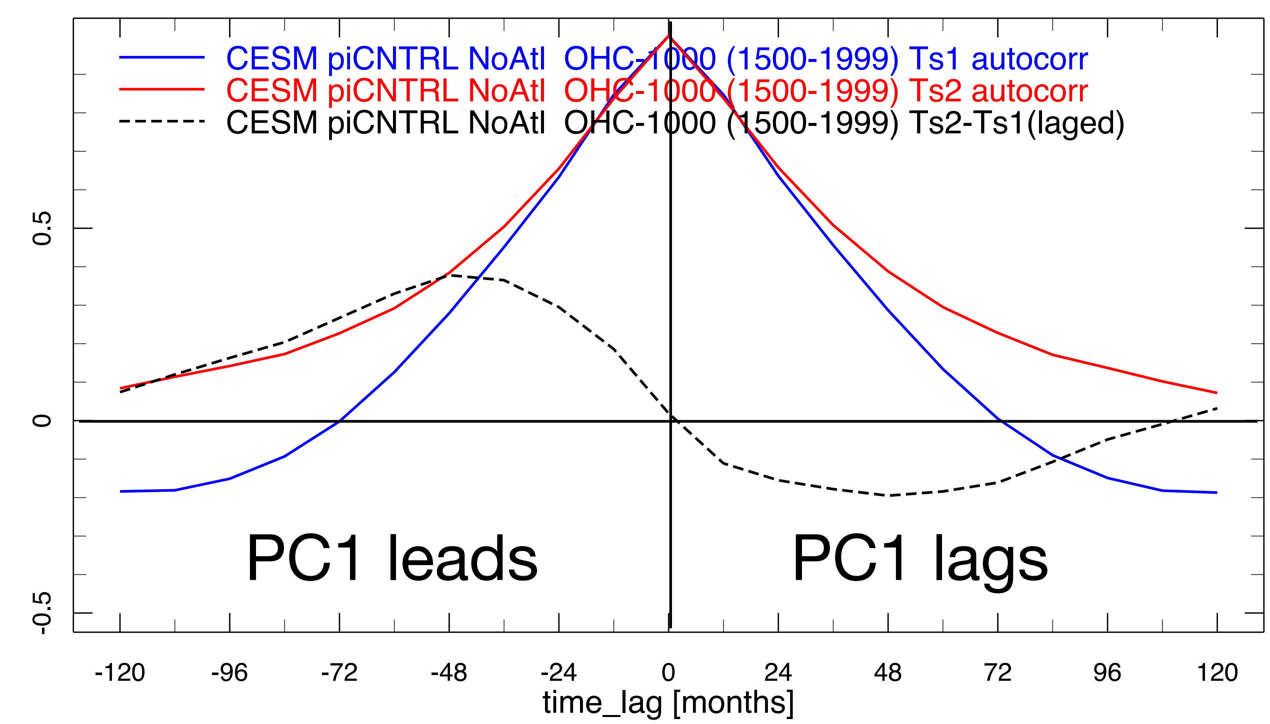
- EOF1 — a contracted, cold subpolar gyre and a northward shifted Gulf Stream Extension.
- EOF2 — a warm ocean layer flows across the subtropical-subpolar gyre boundary into the subpolar gyre.

PCA of North Atlantic UOHC - time series

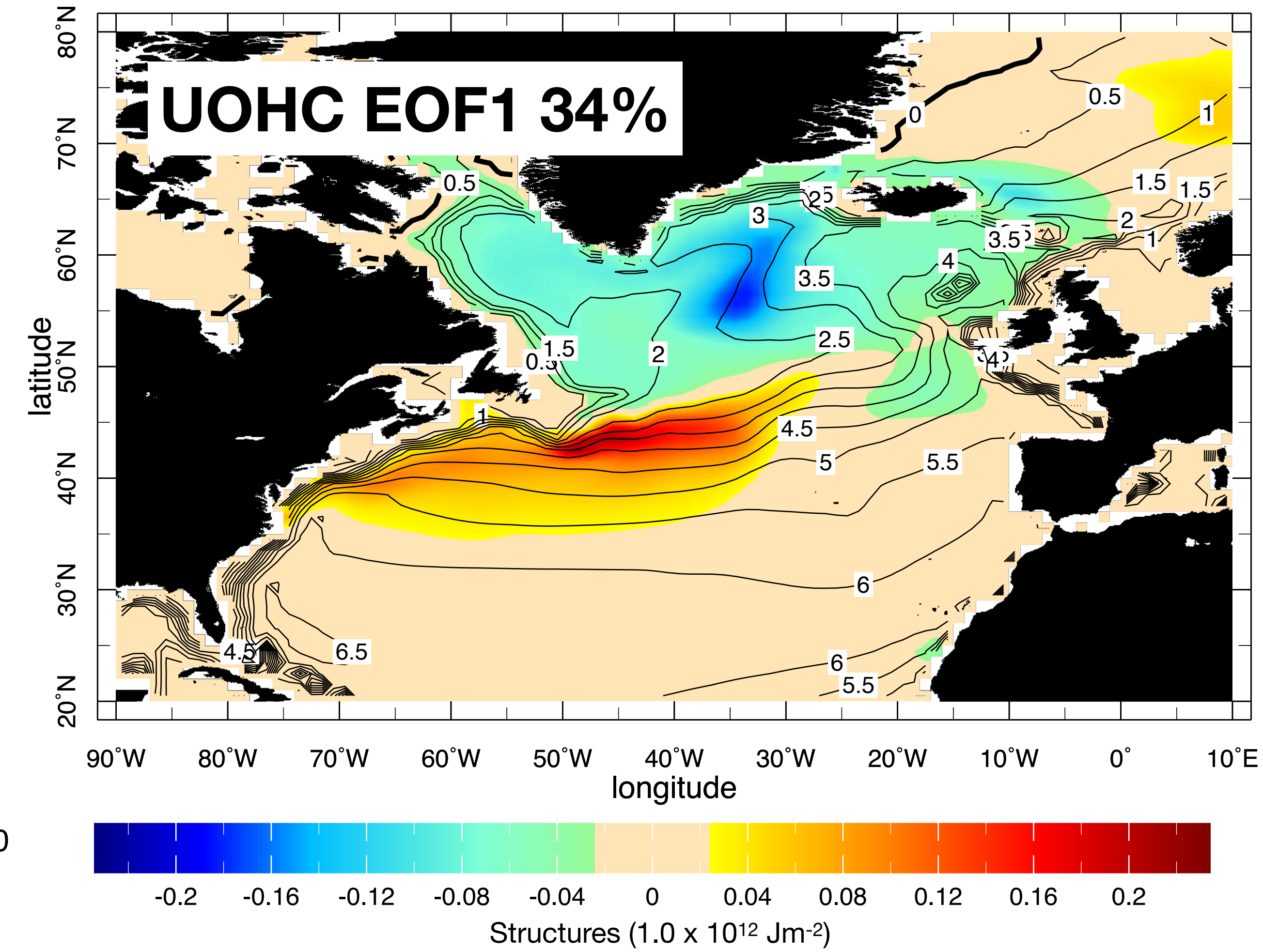
The time series (PCs) associated with the two EOFs (top) and the relationship (correlation) between them indicate a damped, quasi-periodic decadal oscillation, where about 4 years after the peak state seen in EOF1, heat is transported across the gyre boundary into the sub polar region.

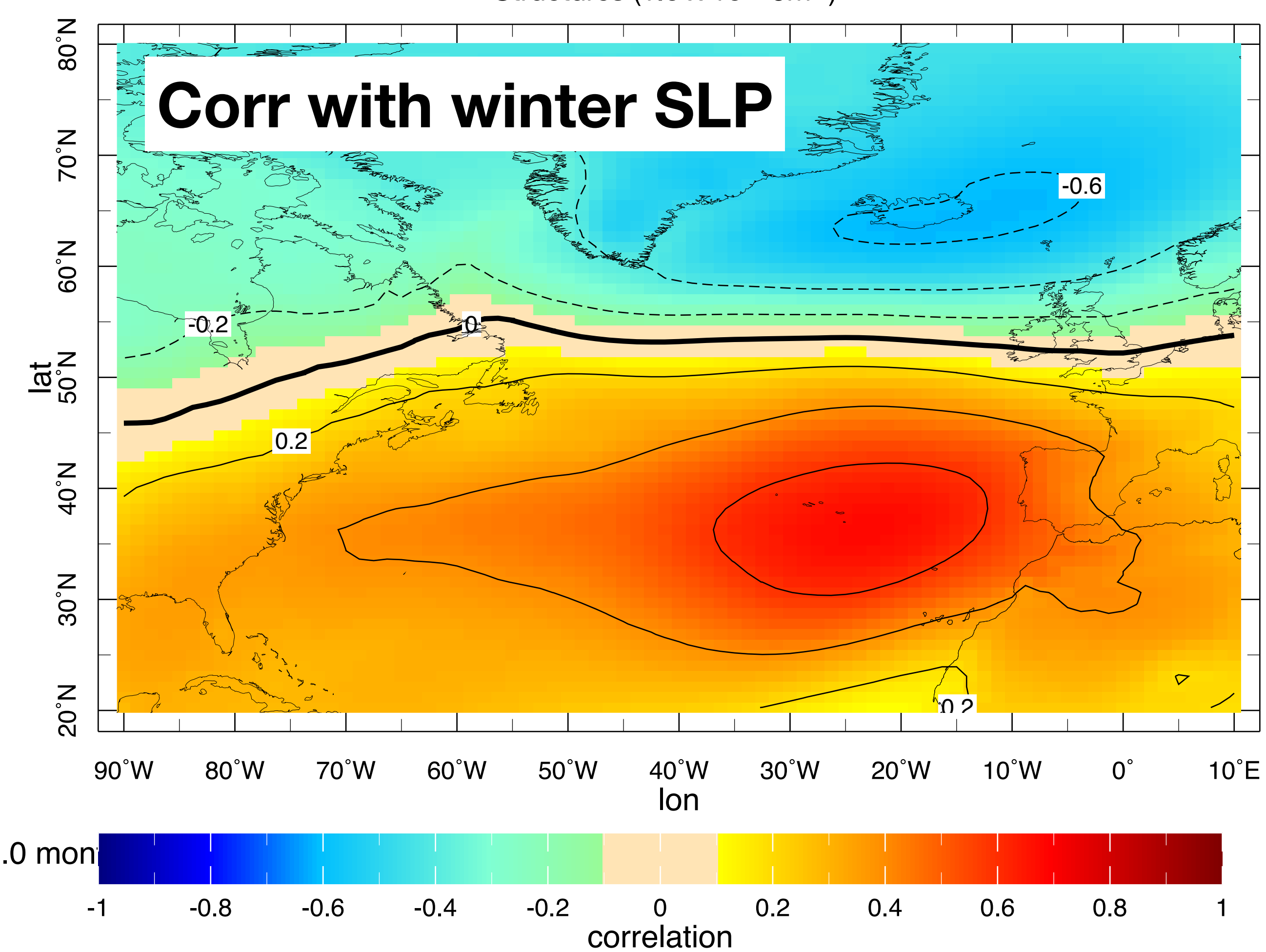
A weak negative autocorrelation exhibited by PC1 occurs ~1 decade after the peak state.



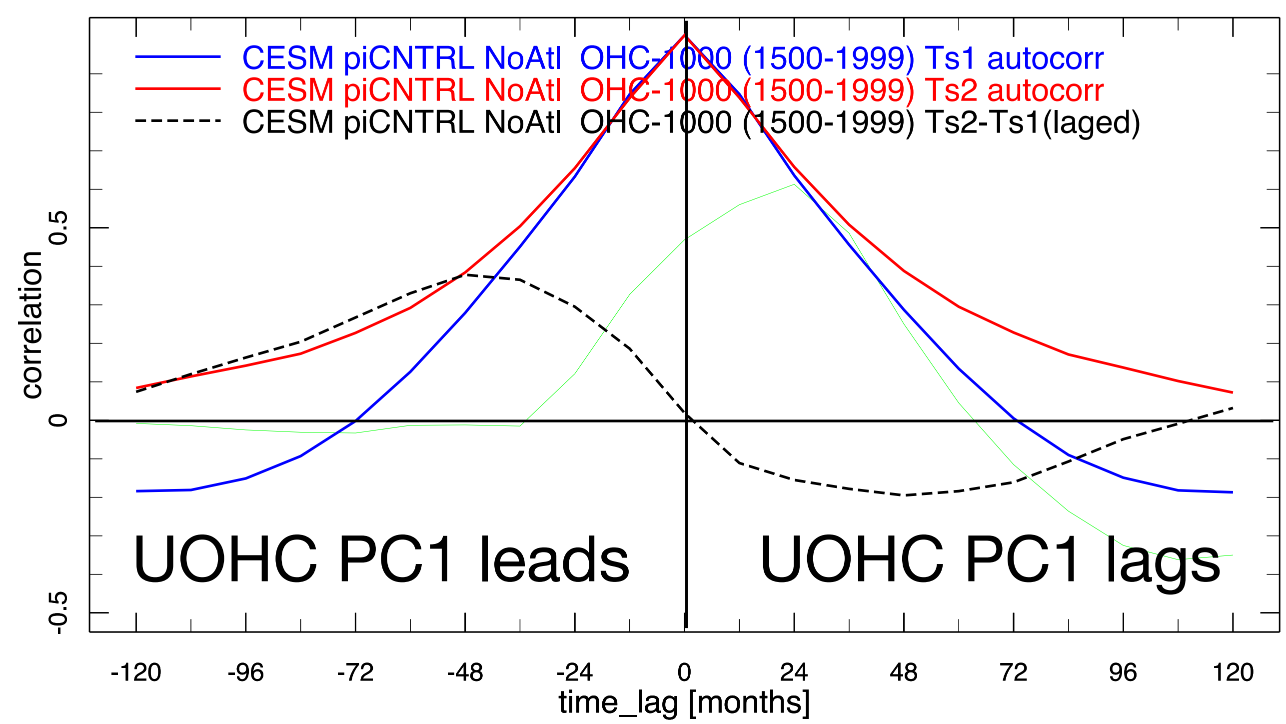


A lagged relationship with the Atmosphere





The correlation between 5-yr running mean Dec-Feb sea level pressure anomaly and PC1 of UOHC (bottom) resembles the coupled model leading EOF and the observed NAO pattern. The correlation peaks when UOHC lags PC1 of SLP by 2-3 years indicating that the UOHC anomaly is forced by the atmosphere.

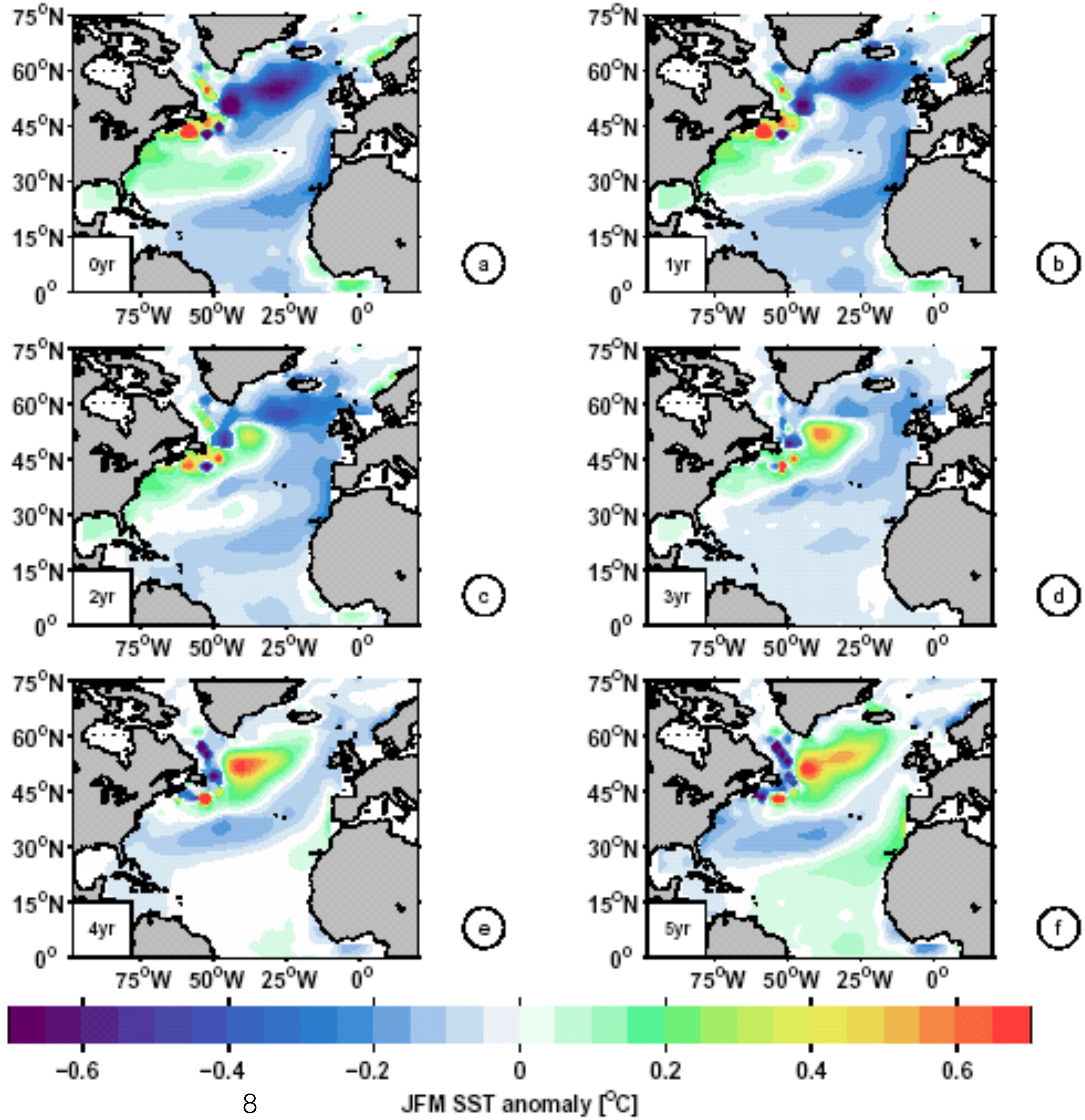


The correlation between PC1 of SLP and PC1 of UOHC is shown in green

SST response to low-frequency NAO forcing

Krahmann et al. (2001) forced a dynamical ocean model with idealized NAO wind and stress anomalies. The prescribed NAO forcing had a 12-year, sinusoidal cycle. The ocean was coupled to a simple atmospheric boundary layer model that allowed thermodynamically consistent surface A-O heat fluxes to be calculated. The ocean's circulation displayed a propagation of SST anomalies along the Gulf Stream current and into the subpolar gyre reversing the sign of SST anomalies there from the thermodynamically forced ones (panels are 1 year apart).

This behavior is similar to that exhibited by the CESM with the difference that the CESM phenomenon is strongly damped, lacking the strong periodic atmospheric forcing (not shown).

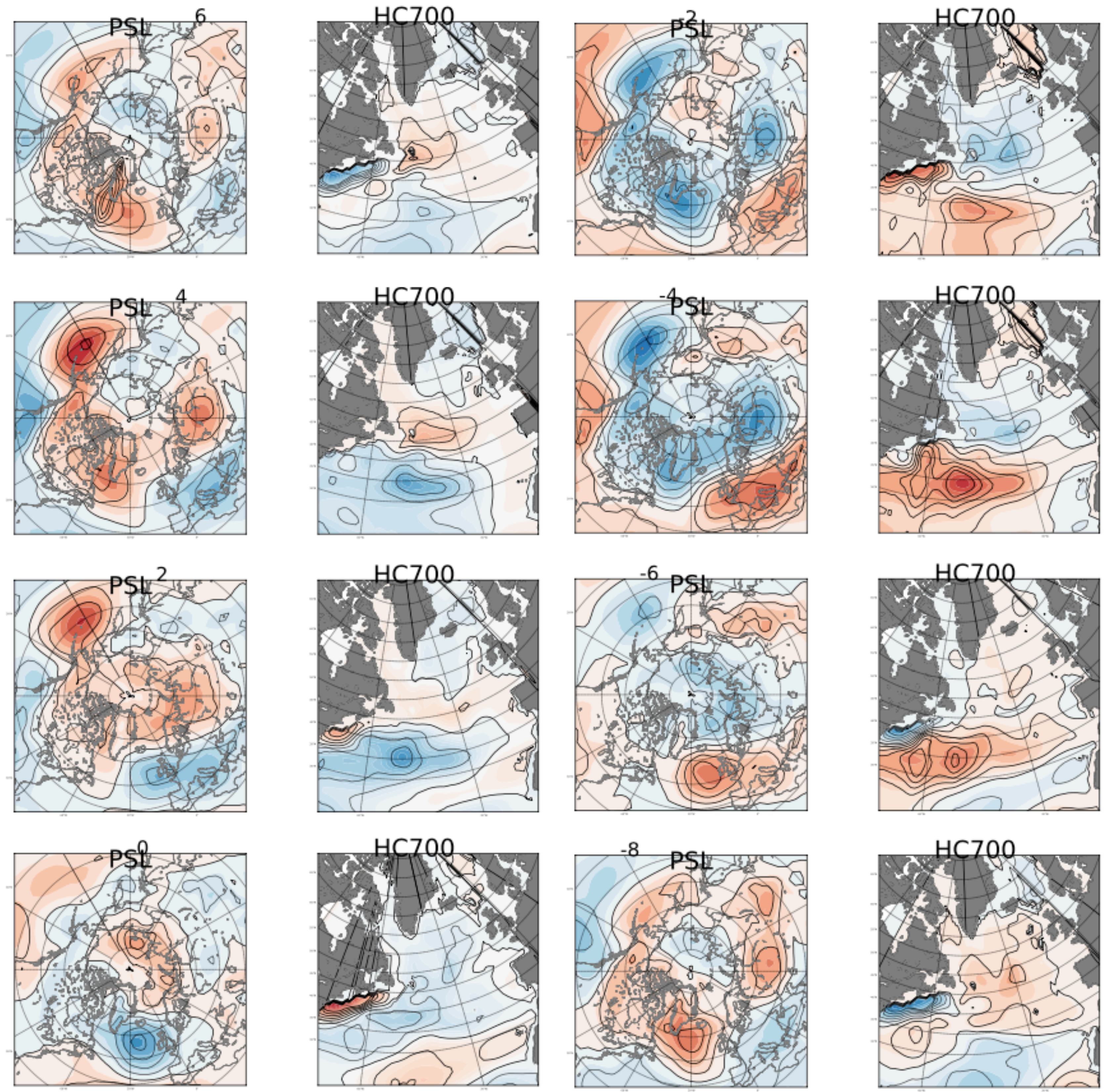


Analogous Observational Pattern

A preliminary analysis of the observations (UOHC from Ishii et al. data 1945-2012; SLP from NCAR-NCEP reanalysis) reveals a dynamical modes of variability where UOHC anomalies that develop along the subpolar-subtropical gyre boundary propagate into the subpolar gyre and contribute to reversal of the previously gyre UOHC anomaly.

The mode (with a period 13.9 yrs, and decay time of 199 yrs) emerges in a LIM fit to a matrix containing annual DJF values of the 700m UOHC anomaly and the anomalous DJF sea level pressure field one year later.

The evolution is depicted here in 2 year steps. The changes in the ocean heat content are associated with a NAO-like SLP anomaly.



Summary

- Using UOHC instead of SST enables clearer detection of the role of ocean gyre dynamics in decadal variability as SST is too strongly forced by air-sea heat flux exchange and shallow Ekman heat transport.
- The method of LIM separates the dynamical ocean “mode” even in the short time series in which external forcing and longer, multidecadal variability dominate
- The similarity between the modeled and the observed variability of the North Atlantic climate system enables use of the model to better understand the underlying dynamics of North Atlantic decadal variability, determine its impact on the climate of the surrounding land and ocean areas and study its predictability.

Thank You