North Atlantic atmospheric and ocean variability over the past fifty years: dominant patterns and abrupt climate shifts

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OUTLINE

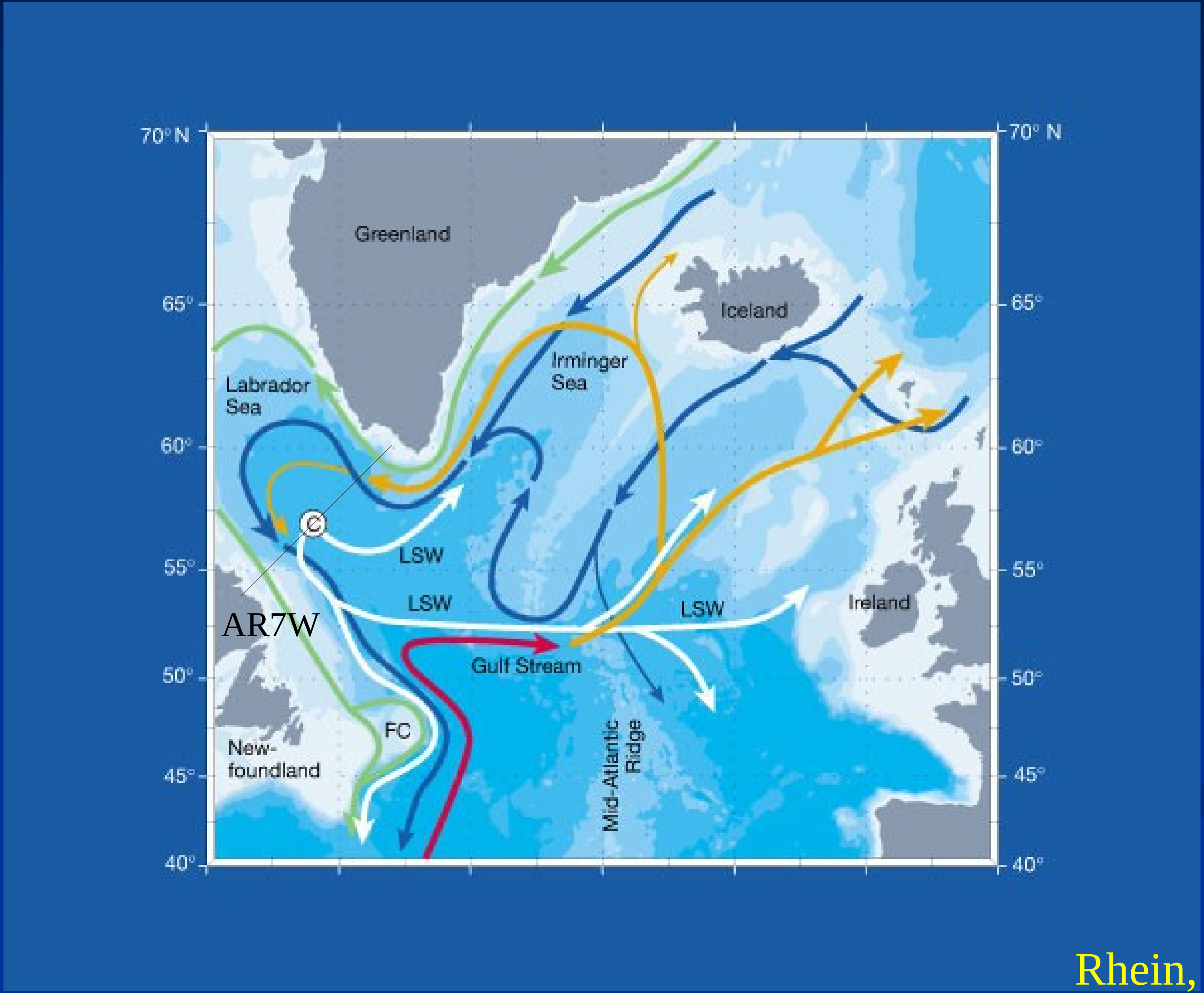
- ***Decadal climate shifts in the Subpolar North Atlantic Ocean***

- ***Quantifying past atmospheric variability:***

  (a) subseasonal weather regimes
  (b) interannual patterns

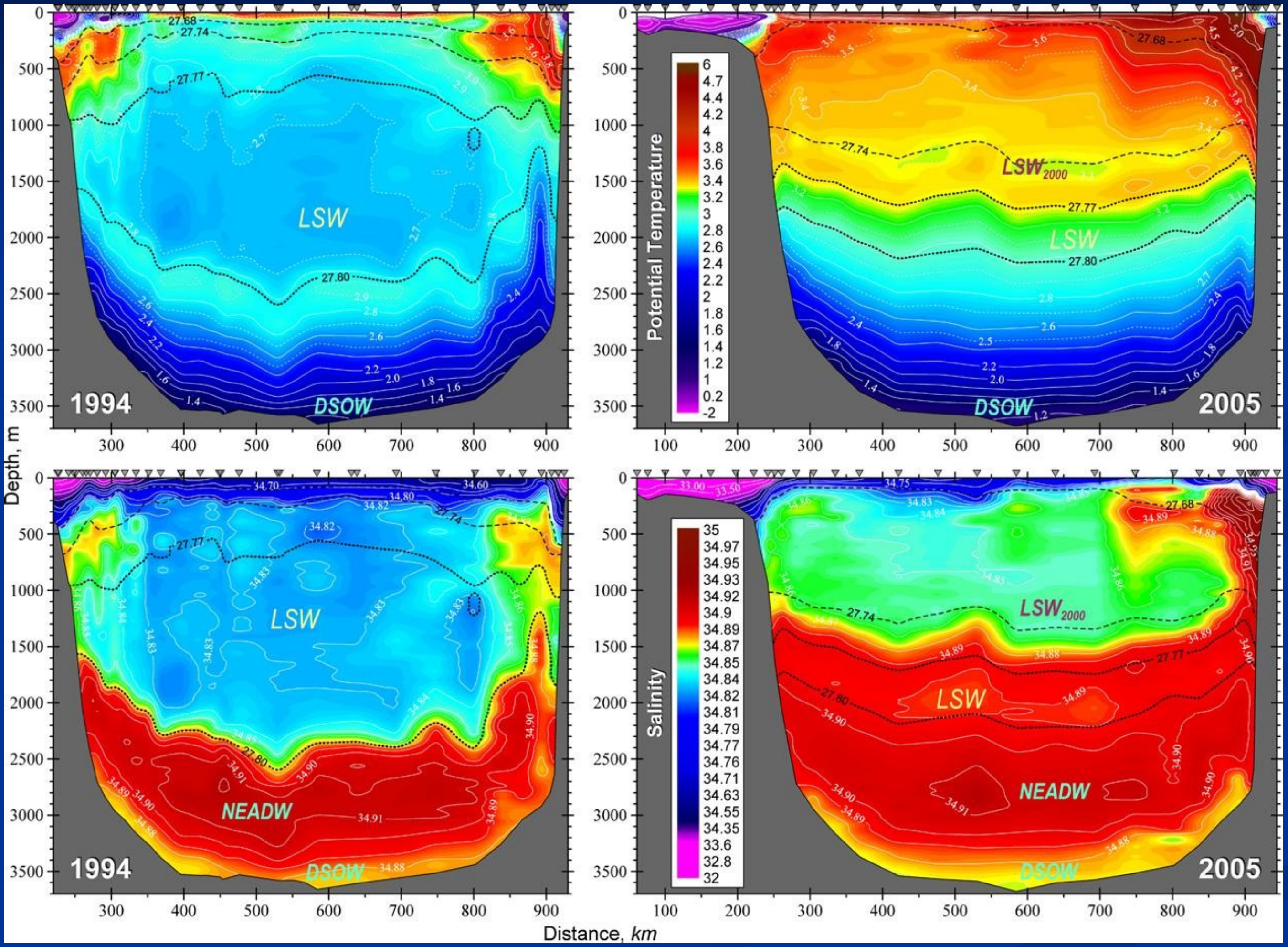
- ***Modeling decadal climate shifts in atmosphere and ocean of the Subpolar North Altantic***

Ocean Circulation in the Subpolar North Atlantic



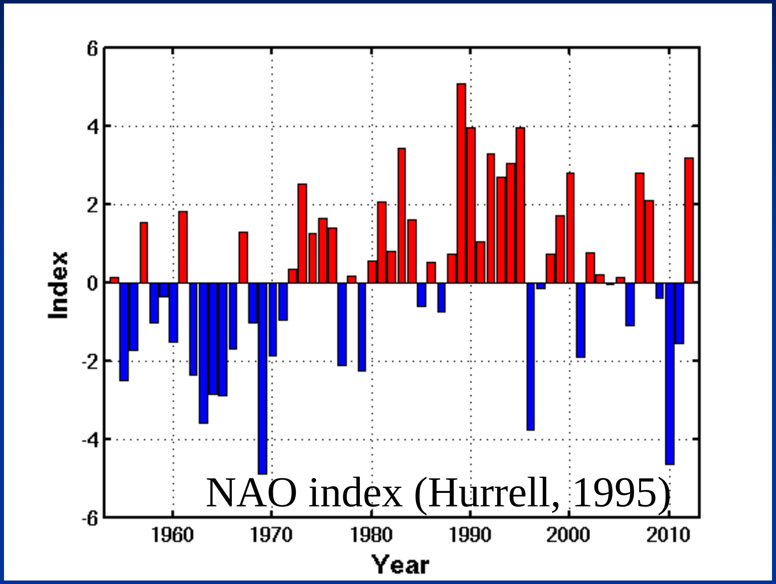
Rhein, 2000

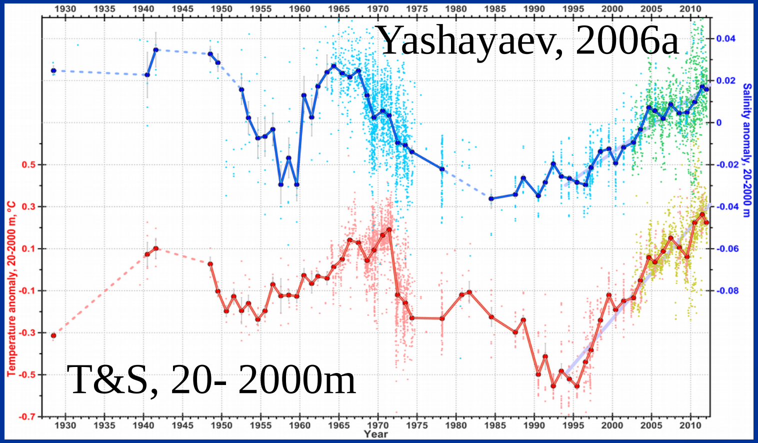
Decadal shift in the characteristics of the LSW in late 1990s

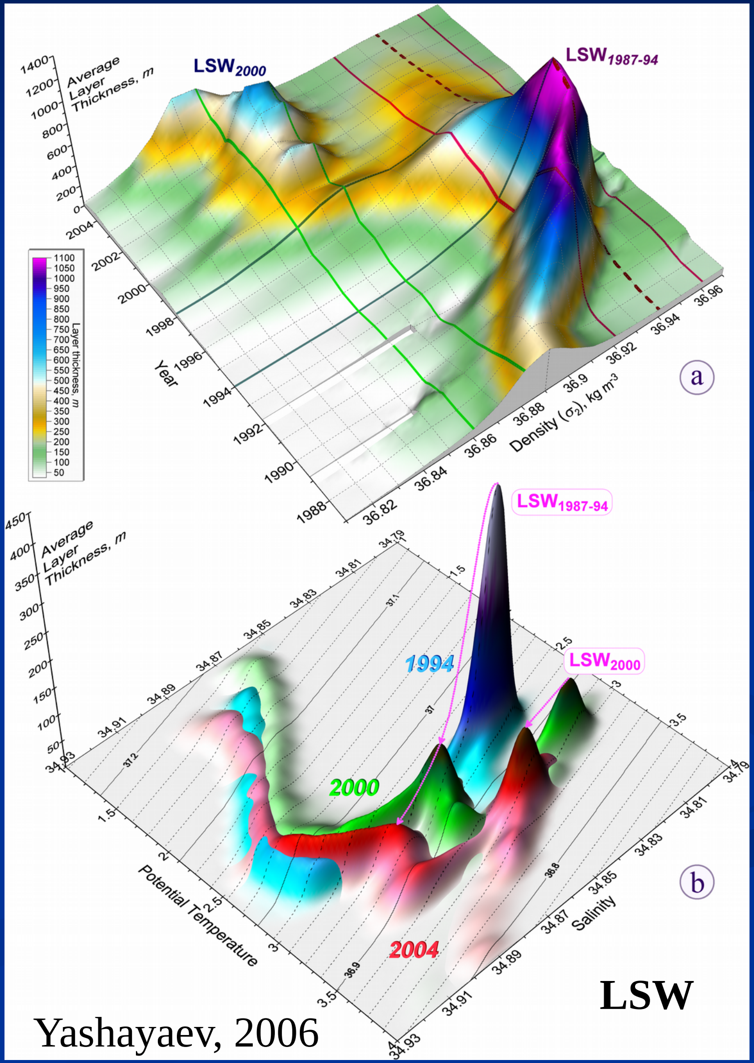


Yashayaev, 2006

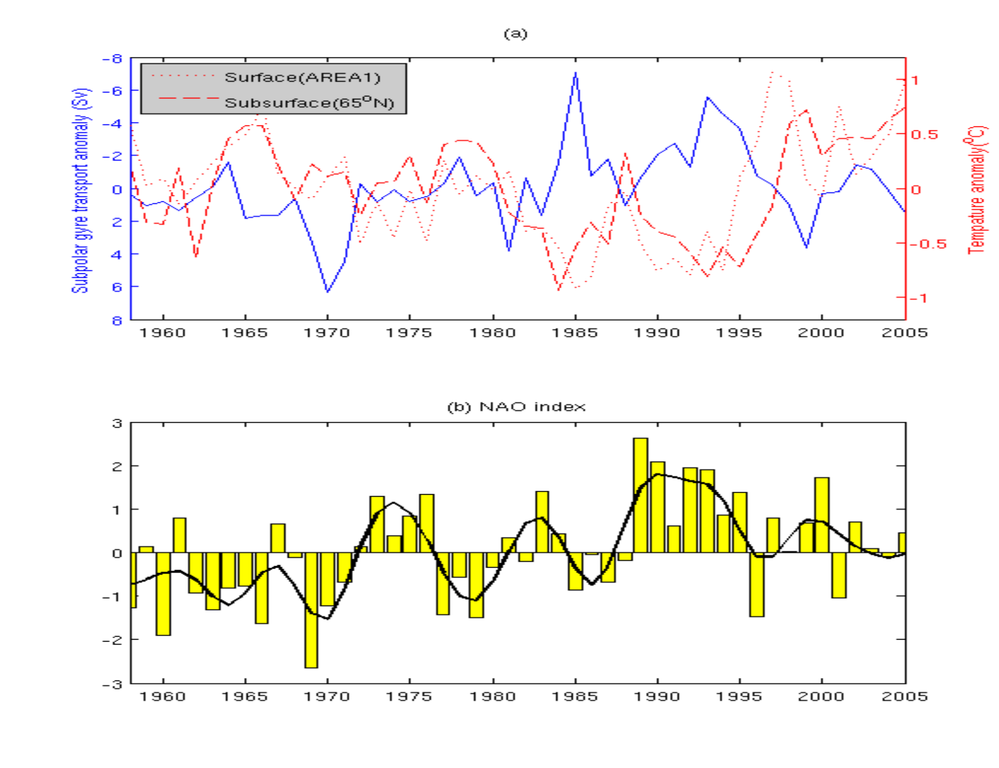
Link between the NAO and ocean variability







Ocean response to low frequency atmospheric variability



Example of Labrador Sea circulation (blue curve) and temperature (red) variability

Null hypothesis of climate variability
(Hasselmann , 1976)

There are two components of the coupled ocean - atmosphere system:

(1) the high frequency atmospheric component, and

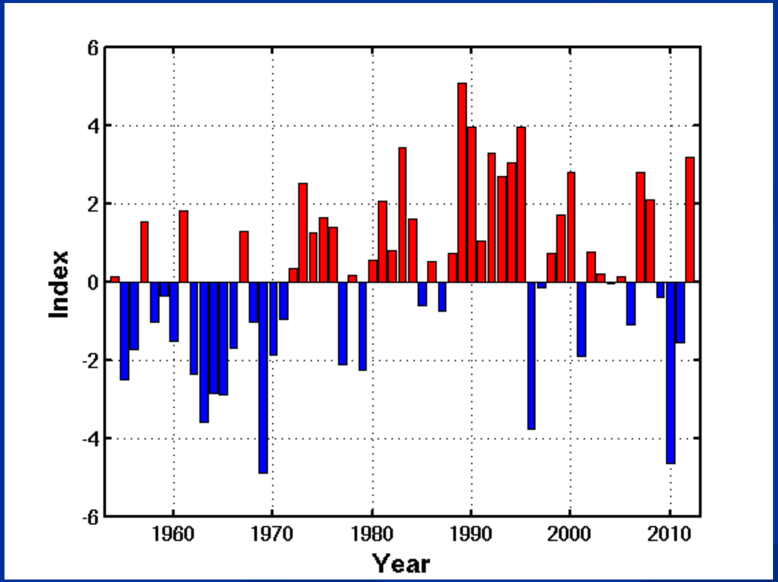
(2) the low frequency oceanic response.

The surface layer ocean variability is driven by the long term integrated impact of high frequency surface fluxes.

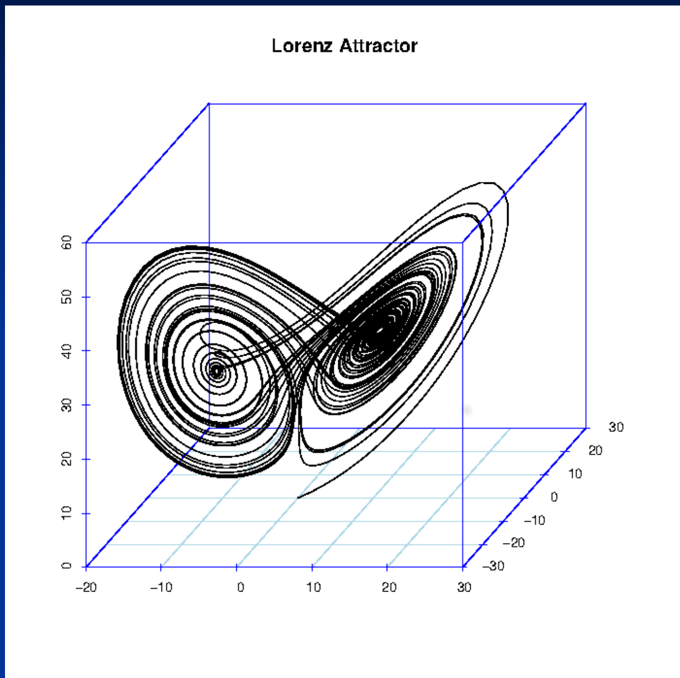
Multiscale dynamics of the NAO

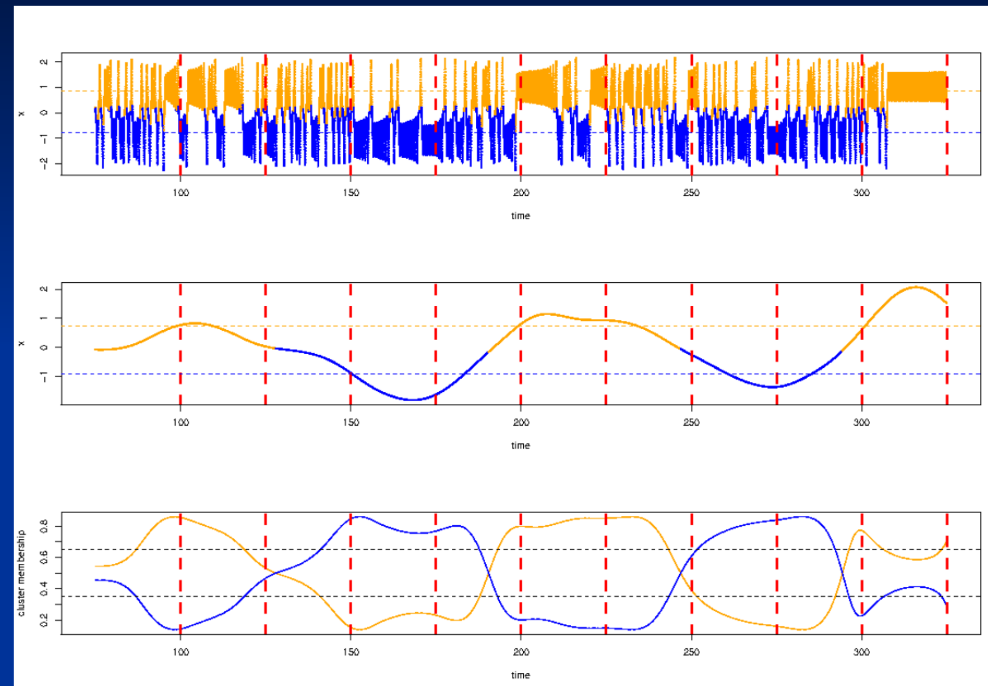
The persistence of the low frequency NAO index on interannual and decadal time scales does not imply that the NAO "also tends to persist in the same phase for long.

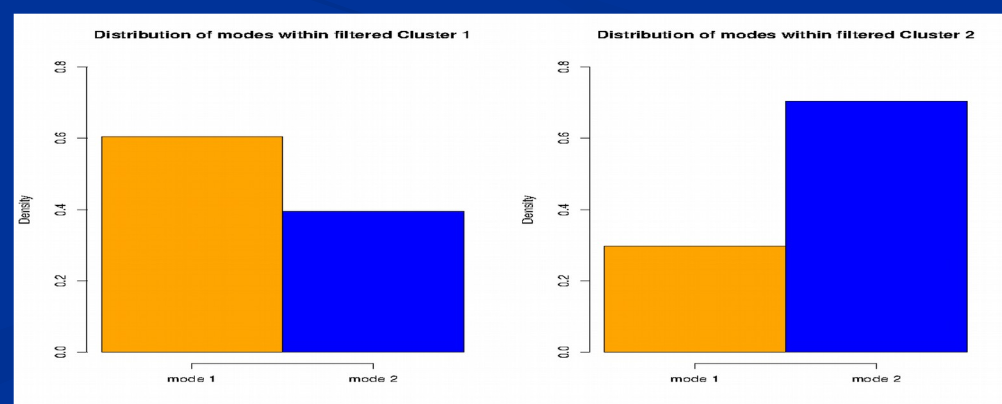
To the contrary, it is highly variable, tending to change its phase from one month to another, and its longer-term time-average behavior reflects the combined effect of residence time in any given phase and its amplitude therein". **(Deser and Hurrell, 2009)**



Example: The Lorentz system







Changes in the system dynamics, whether resulting from internal variation in the coupled Systems or larger climatic changes, will manifest themselves through shifts in frequency, residency, and transition statistics between attractors/attractor-modes (Corti et al. , 1999),

Method of the study

- We assume that the North Atlantic atmosphere ocean is a coupled dynamical system that exhibits chaotic variability on many time scales with complex feedbacks between its components (Monahan et al. , 2010).

- We study we use clustering analysis in analysis of the patterns of the North Atlantic atmospheric variability on inraseasonal-to-decadal time scales and the patterns of the ocean’s response.

- The data used in this study are NCEP atmospheric reanalysis and ocean model simulations for the recent fifty years.

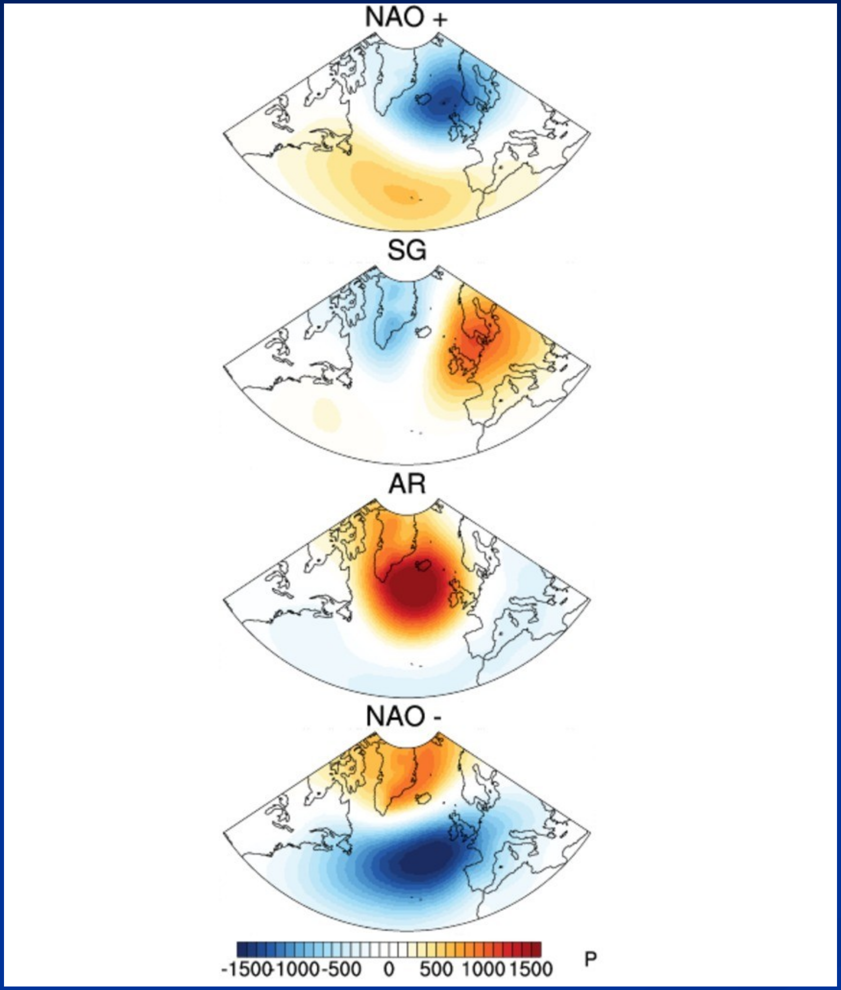
Clustering method

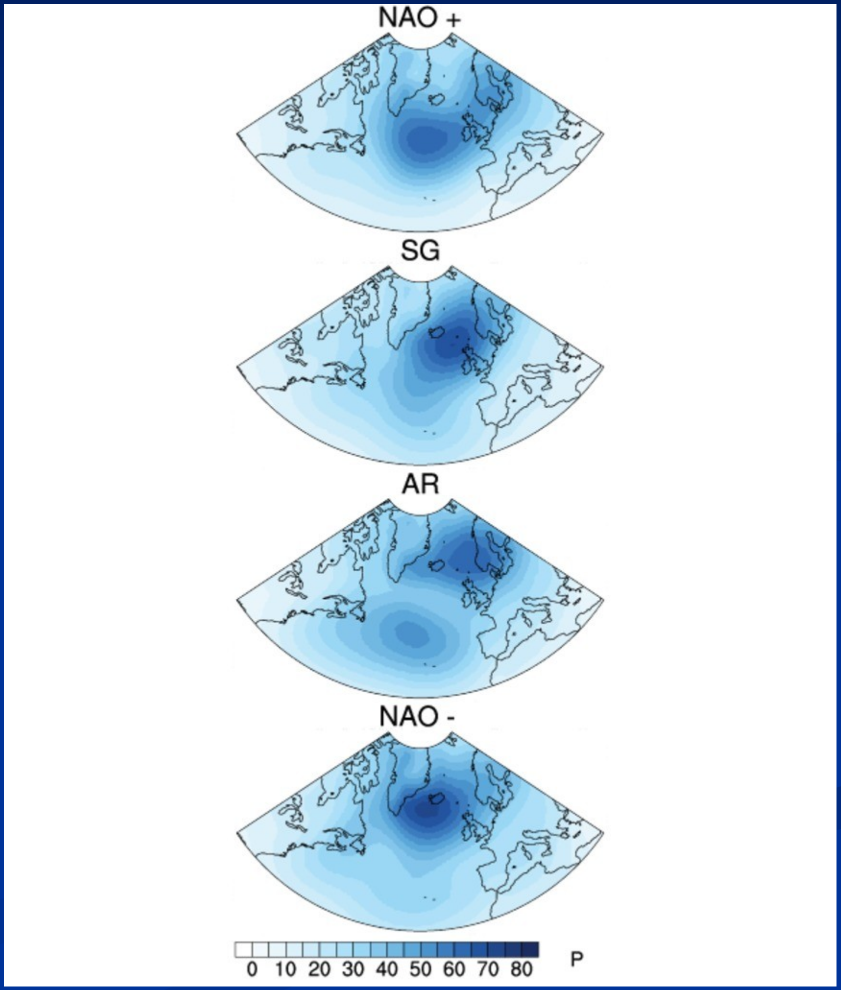
- We use Gaussian Mixture Models (GMMs), to classify daily winter December-January-February (DJF) SLP anomalies for 1948-2012, taken from NCEP atmospheric reanalysis data (Kalnay et al. , 1996).
- The dimensionality of the data set is first reduced by performing PCA and retaining the leading ten PCs, which explain 81% of the variance.
- We use a Bayesian approach to classification to create an ensemble of possible classifications supported by the data. The robustness of the estimated centers is studied here in terms of the ensemble standard deviation of these centers.
- Fuzzy clustering method is used to classify the interannual patterns

The weather regimes

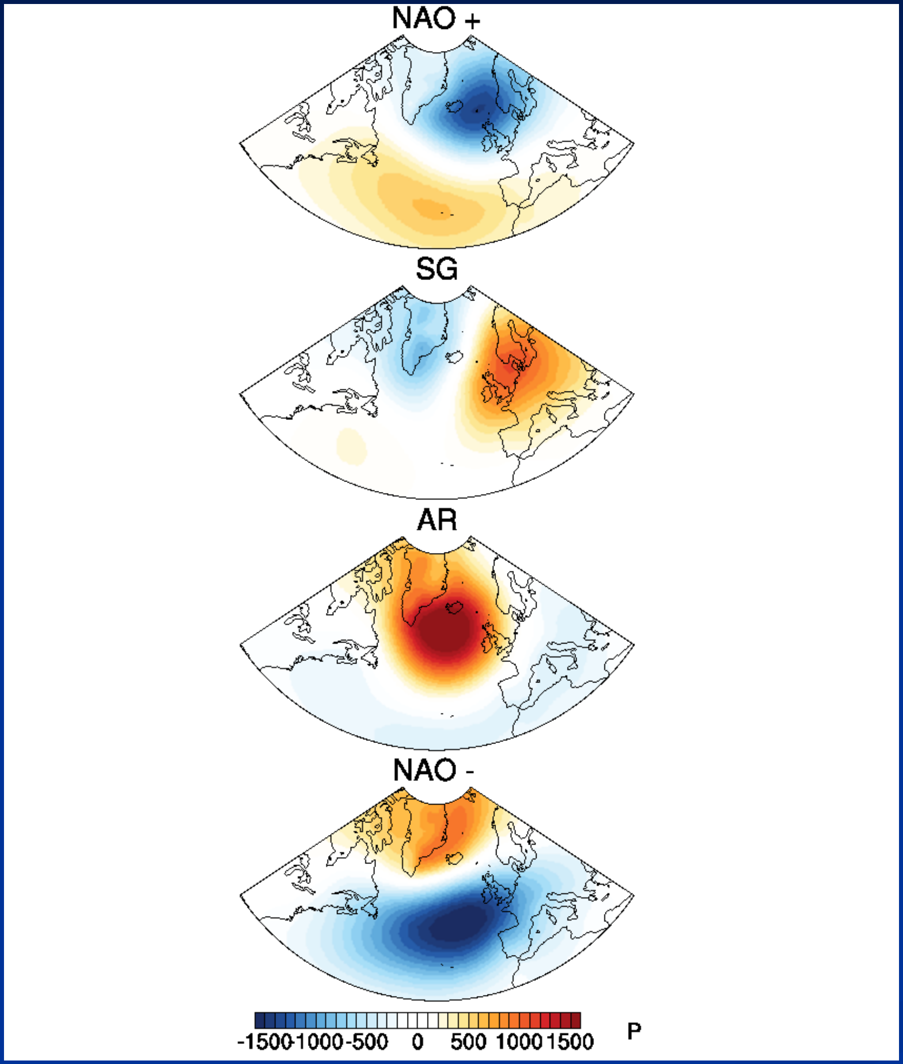
- Atmospheric patterns (Großwetterlagen) can persist on time scales longer than the typical life time of atmospheric weather events and disturbances (**Baur et al.,1944**).
- Atmospheric regimes are interpreted as quasiequilibrium states or attractors in the atmospheric phase space.
- When a state of the atmosphere in the phase space is close to one of the attractor stationary points, a disposition for certain types of activity persist over periods longer than the individual weather disturbances.
- The persistence of such states is explained with the balance between the dynamical tendencies and the eddy-mean flow interaction for the states which are close to the stationary points **(Molteni et al. , 2006**).

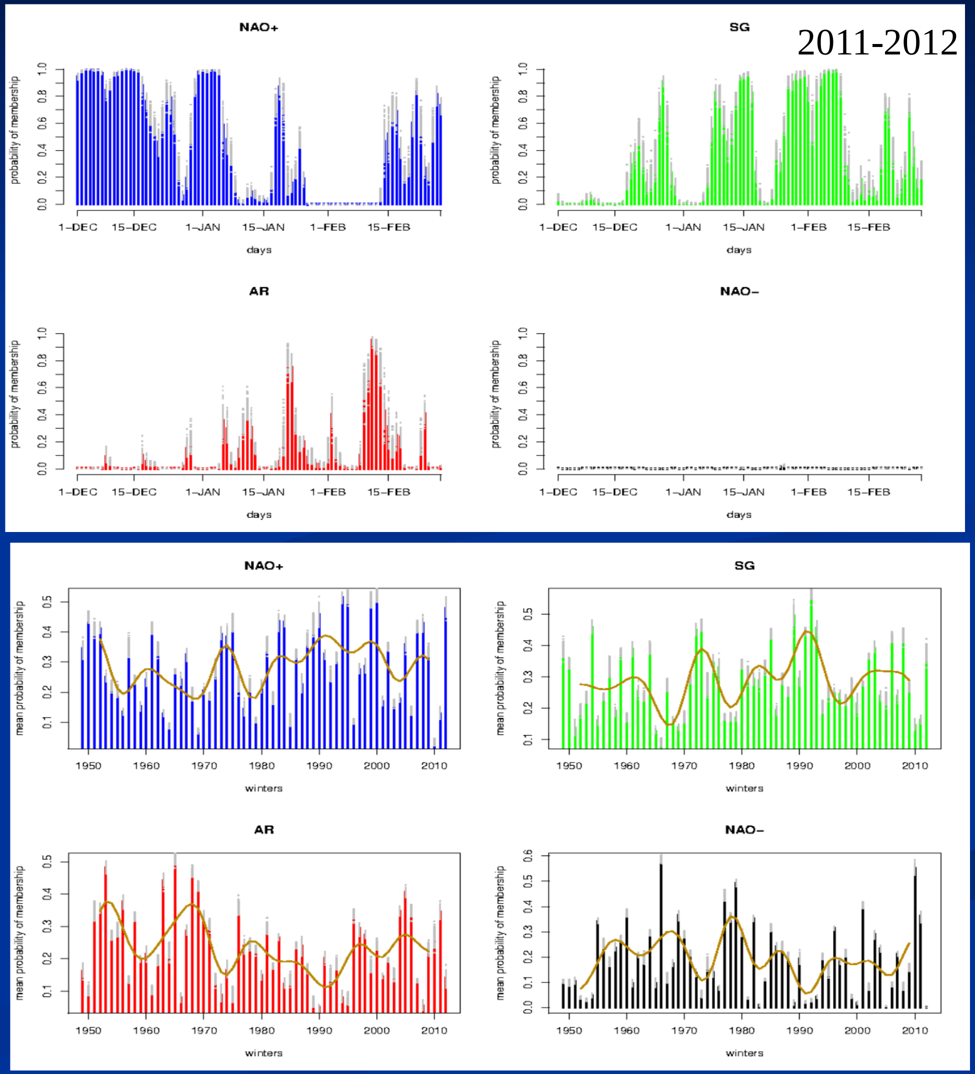
Weather regimes of the North Atlantic





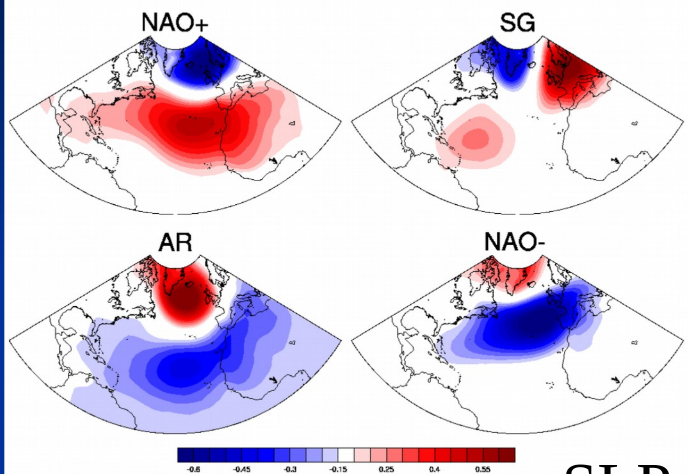
Weather regimes of the North Atlantic





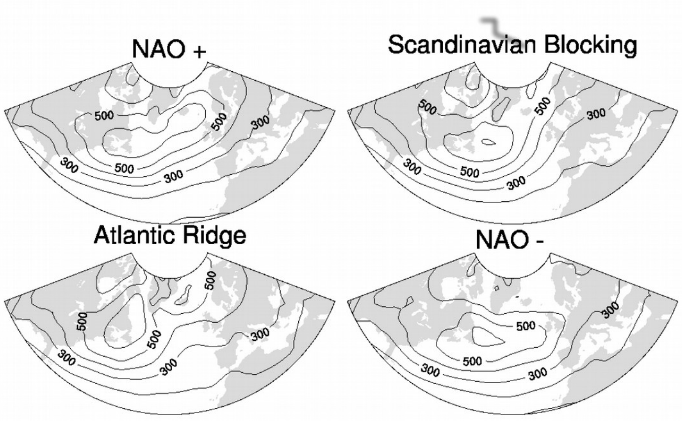
see also Cassou et al. (2008)

Correlation with surface atmospheric characteristics



SLP

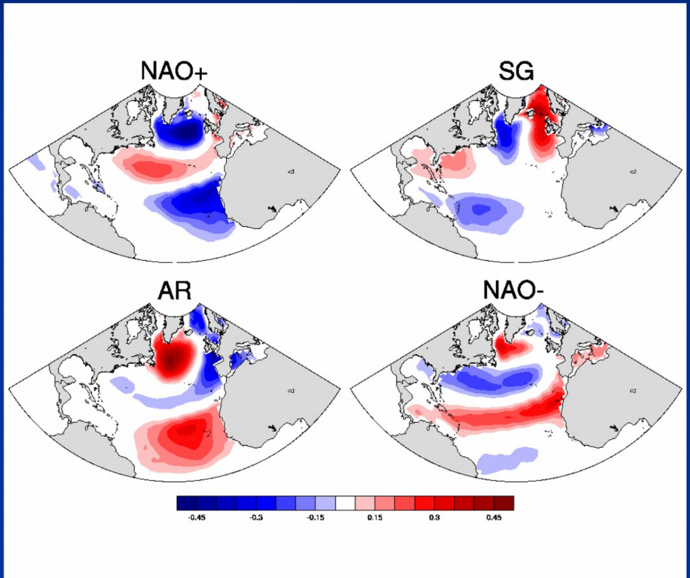
Moore et al. (2013) also demonstrated that combinations of multiple EOFs describe shifting of centers of activity for the NAO



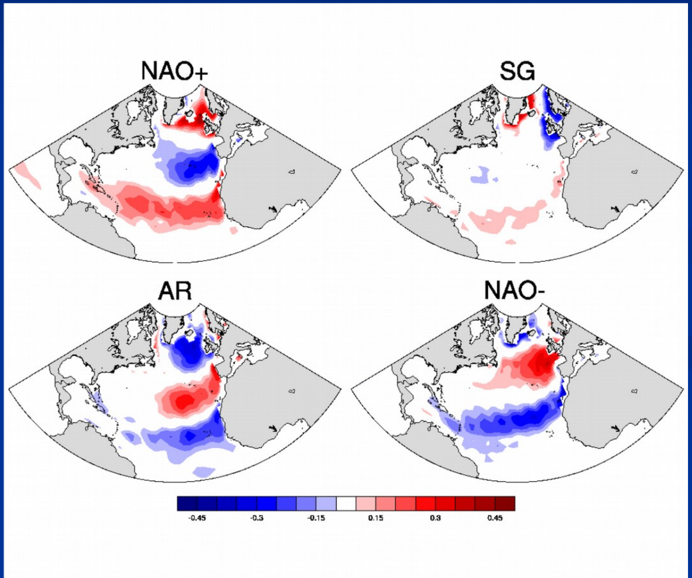
Standard deviation of SLP

The standard deviation of SLP, bandpass filtered to capture the 2-7 day signal (typical life-span of extratropical cyclones), for time periods dominated by each of the four regimes. A period associated with a given regime is defined as the collection of days where the probability of belonging to that regime is higher than that of the other three.

Correlation patterns of surface fluxes



Surface turbulent heat flux



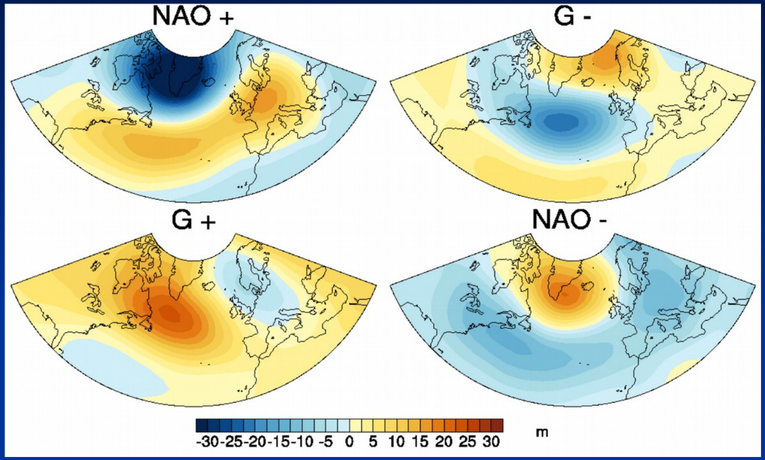
Wind stress curl

Interannual Patterns

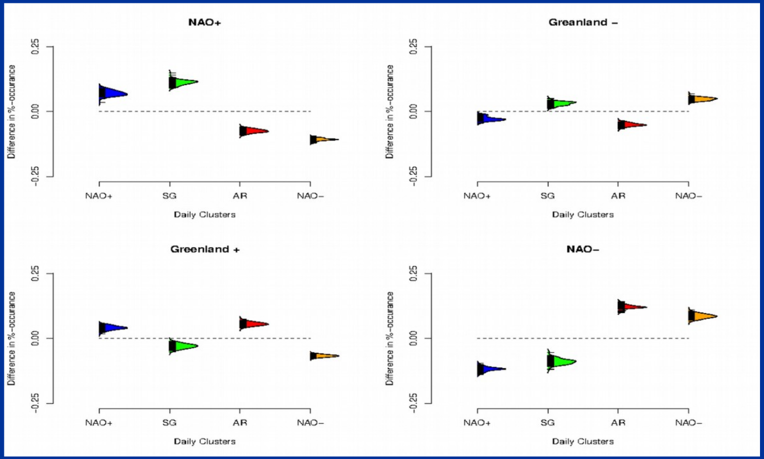
Long term patterns of atmospheric variability are a remnant of the high frequency variability (**Wunsch , 1999**).

The changes in NAO phase and related climate variability manifest through shifts in the frequency, residency, and transition statistics of natural patterns of North Atlantic variability on subseasonal time scale .

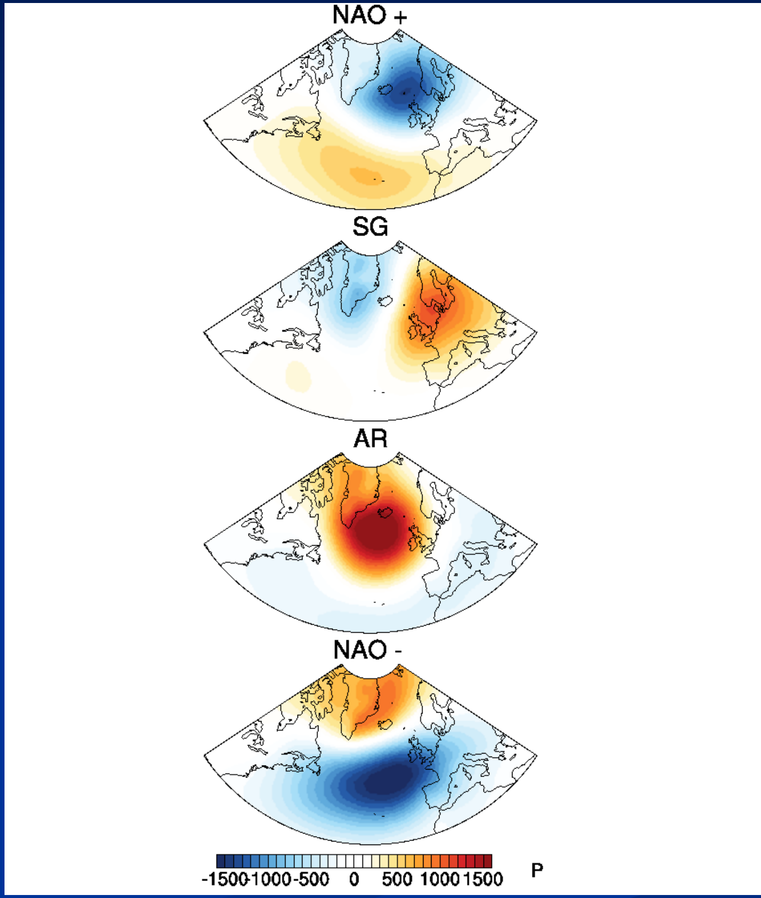
Interannual Patterns



Interannual patterns

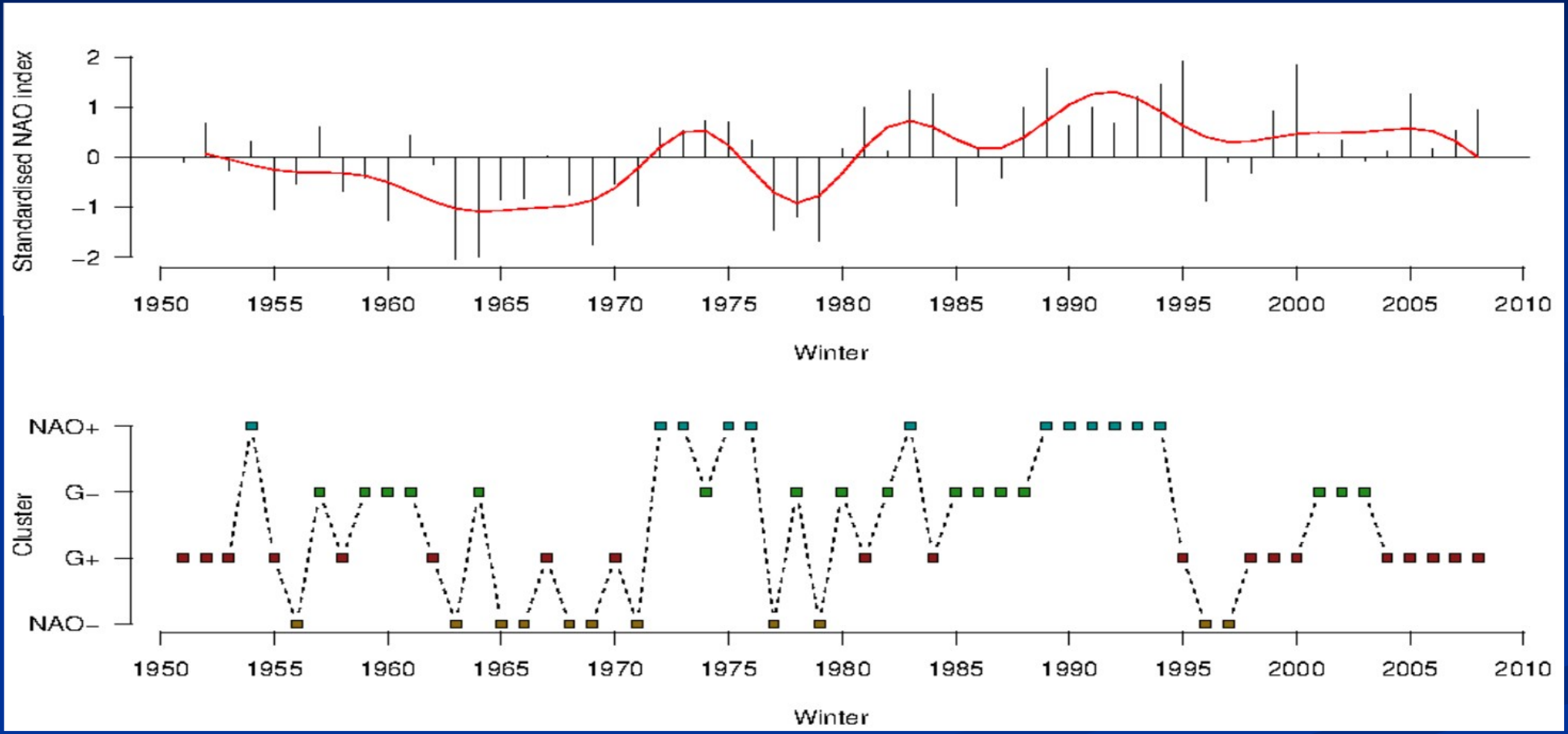


Frequency of occurrence for the weather regimes for each interannual pattern

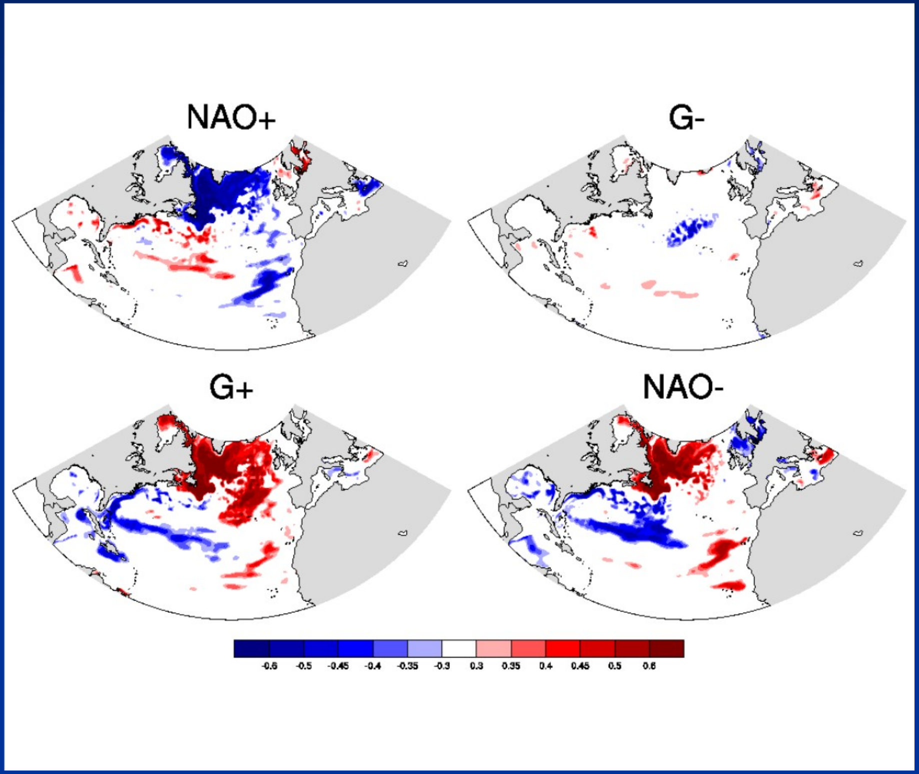


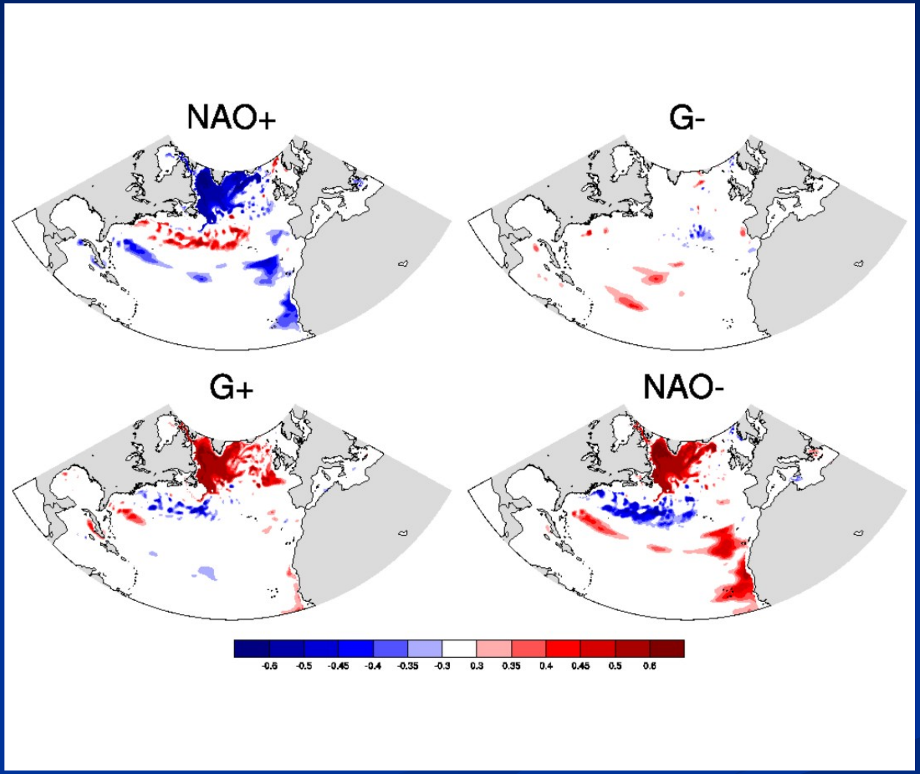
Weather regimes

NAO index and dominant winter clusters



Correlation maps of ocean heat content





Surface 200m layer

Intermediate 200m-2000m layer

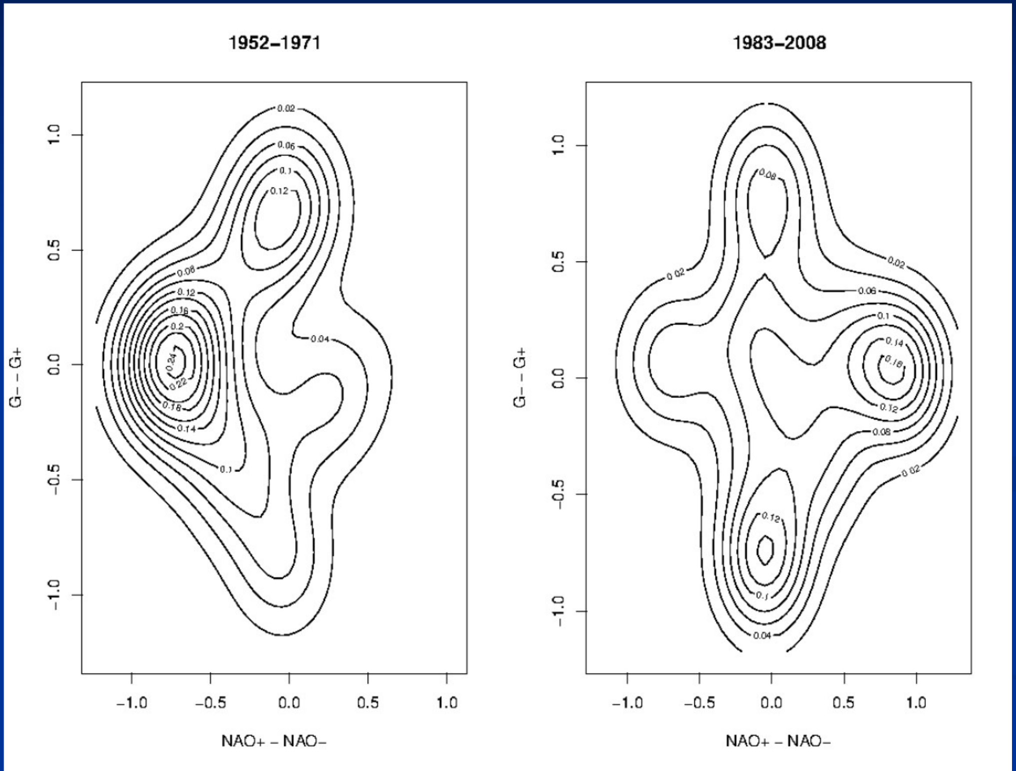
Long term shifts in atmospheric dynamics

- Changes in the system dynamics, whether resulting from internal variation in the coupled systems or larger climatic changes, will manifest themselves through shifts in frequency, residency, and transition statistics between attractors/attractormodes (**Corti et al. , 1999**), provided that the changes are moderate.

- If alternatively the external forcing changes are large (as defined by the thresholds of the individual systems) shifts in external forcing can change the structure (or existence) of the attractors/modes themselves (**Lorenz ,2006**).

- Currently it is believed that the near-future evolution of the climate state will be within the first category (**Terray et al. , 2004**).

Decadal shift in the space of interannual indexes



Percent probability (derived from kernel density estimates) of the interannual regime difference indexes for the time period of (a) 1952-1972 (left) and (b) 1983-2008 (right)

Generating forcing for ocean climate modeling: a simple approach

- For the purposes of ocean modeling, Lohmann et al. (2008) and Zhu and Demirov (2011) created deterministic forcing series typical of positive and negative phase NAO atmospheric variability.

- The forcing was constructed as a sum of the monthly mean characteristics for the specific phase of NAO and the deviation from the monthly mean taken from a specific subjectively chosen year.

- The weakness of this method is that atmospheric weather conditions in years with persistent NAO phase are highly variable and change from year to year.

Generating forcing for ocean climate modeling: weather generators

- Tang et al. (2001) developed a generator of atmospheric characteristics based on so called Hybrid Coupled Models (HCM) which include two way coupling between a general circulation ocean model and an empirically derived atmospheric regression model.

- We use in the North Atlantic simulations a different approach is required because the dominant atmospheric variability in this region does not owe its existence directly to the air-sea interaction (Vallis, 2007).

Development of a weather generator for the North Atlantic

- The atmospheric variability in the mid-latitudes of the North Atlantic is trigerred by transient waves, meandering of the jet stream, and the instability and breaking of planetary waves (Wallace,2003).

- The local processes that govern the mechanisms of circulation regimes such as the NAO are nonlinear and chaotic and show strong links to global planetary circulation variability.

Development of a weather generator for the North Atlantic

- The weather generator of the North Atlantic is developed to represent properly the statistical characteristics of these processes.

- More specifically, we focus on developing a stochastic model capable of reproducing the intrinsic variability of dominant regional patterns in climate, unresolved processes, and the interactions between them.

Weather generator for the North Atlantic

- The primary level is essentially a Hidden Markov Model (HMM), Cappe 2005. The HMM makes discrete stochastic transitions between predetermined states based on prescribed transition probabilities. These transition probabilities are determined by a ”hidden state”.
- For the model presented here the ”hidden states” are determined by classification of the large-scale interannual paterns trends over the North Atlantic.
- Each weather regime has an associated set of discrete states and transition probabilities for the intra-seasonal behaviors of the sub-polar region described above

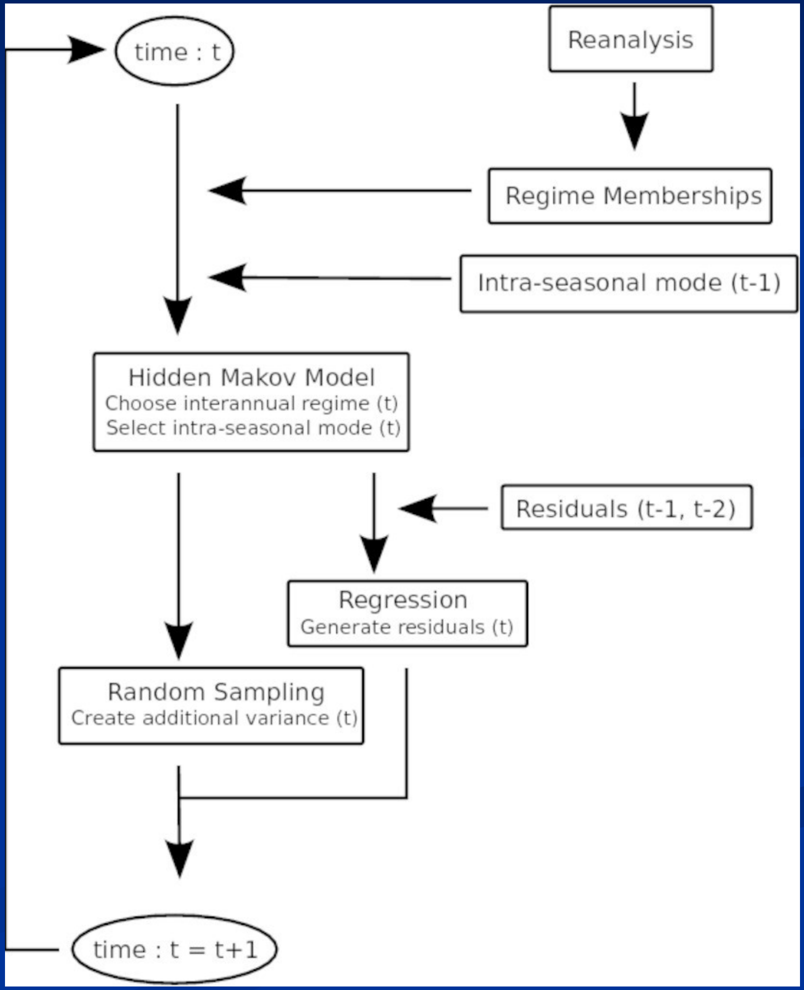
Development of a weather generator for the North Atlantic

Stochastic simulations generate the trajectories of the intra-seasonal component given indicators of the long term trend of interannual variability:

$$x_{full\,state} = x_{interannual} + x_{seasonal} + x_{intra-seasonal}$$

The intra-seasonal is computed as:

$$x_{intra-seasonal} = x_{weather\,regimes} + x_{residual} + x_{noise}$$



Conclusions

- The subseasonal weather regimes are foundational components for describing atmospheric variability.
- However, that it is not sufficient to describe the occurrence of these features individually, but rather in what combinations they appear over time (see also Moore et al., 2013).
- As such, we use the interannual behavior of the data to identify variation in the distribution of the subseasonal patterns over the examined time period.

Conclusions

- We use the resulting interannual clusters as an indicator of these shifts in the distribution of observed events, within the four element phase space of all the subseasonal clusters.
- While this is in many ways only a ‘first pass’ examination of the complex behavior of the system, this study represents an attempt to describe the long term SPNA atmospheric variability from the perspective of multi-scale process analysis.

Thank you!