Interannual to decadal variability in a FESOM model setup, model data comparison of LSW Layer thicknesses

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Introduction

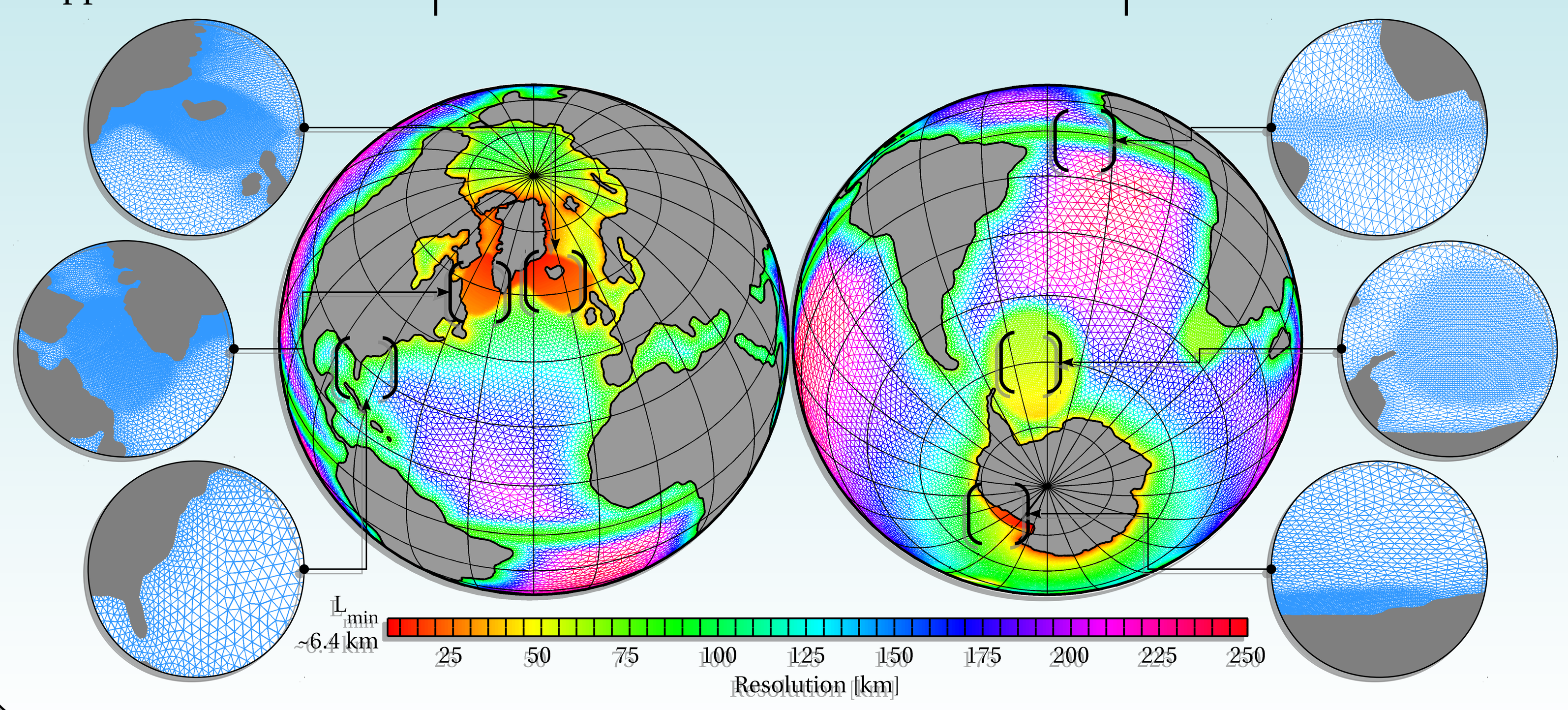
The climate in the Atlantic region is essentially influenced by the Atlantic meridional overturning circulation (AMOC) which carries warm waters into northern latitudes and returns cold deep water southward across the equator. An important aspect in driving the AMOC is the deep-water mass formation at northern latitudes, but climate scenarios for the future indicate that deep-water formation rate in the North Atlantic could weaken during the 21st century due to global warming. Geological records already indicate that the ocean circulation had almost ceased several times in the geological past due to abrupt changes in the climate. We aim to determine the processes that are responsible for the fluctuations in the deep-water mass formation rates, on interannual to decadal timescales, by using a coupled finite-element sea-ice ocean model. We use this model with a special focus on the deep-water mass formation in the Atlantic Ocean (e.g., Greenland Sea and Labrador Sea), Southern Ocean (e.g., Weddell Sea and Ross Sea) as well as other important upwelling regions (e.g., Equator, coastal regions).

Global Model Setup

Methodology:
- Use Finite Element Sea Ice-Ocean Model (FESOM, developed at Alfred Wegener Institute)
- Solve primitive equation under Boussinesq approximation

Mesh:
- Unstructured triangular surface mesh (53.382 surface nodes, 101.827 triangular surface elements)
- 41 vertical levels
- 3D tetrahedral elements (~1 Mio. 3D nodes, ~6 Mio 3D elements)

Forcing Data:
- CORE v2.0
- SODA (sea surface salinity, 1958-2004)
- Random CORE v2.0/SODA
- ECHOG T106



Principal Oscillation Pattern (POP)

- Identify a linear system with limited degree of freedom that fit best to the data.

$$\frac{dx(t)}{dt} = A\,x(t) + r(t)$$

- Normal modes of linear system characterized by eigenvectors $\mathbf{p}_k$ of the system matrix A:

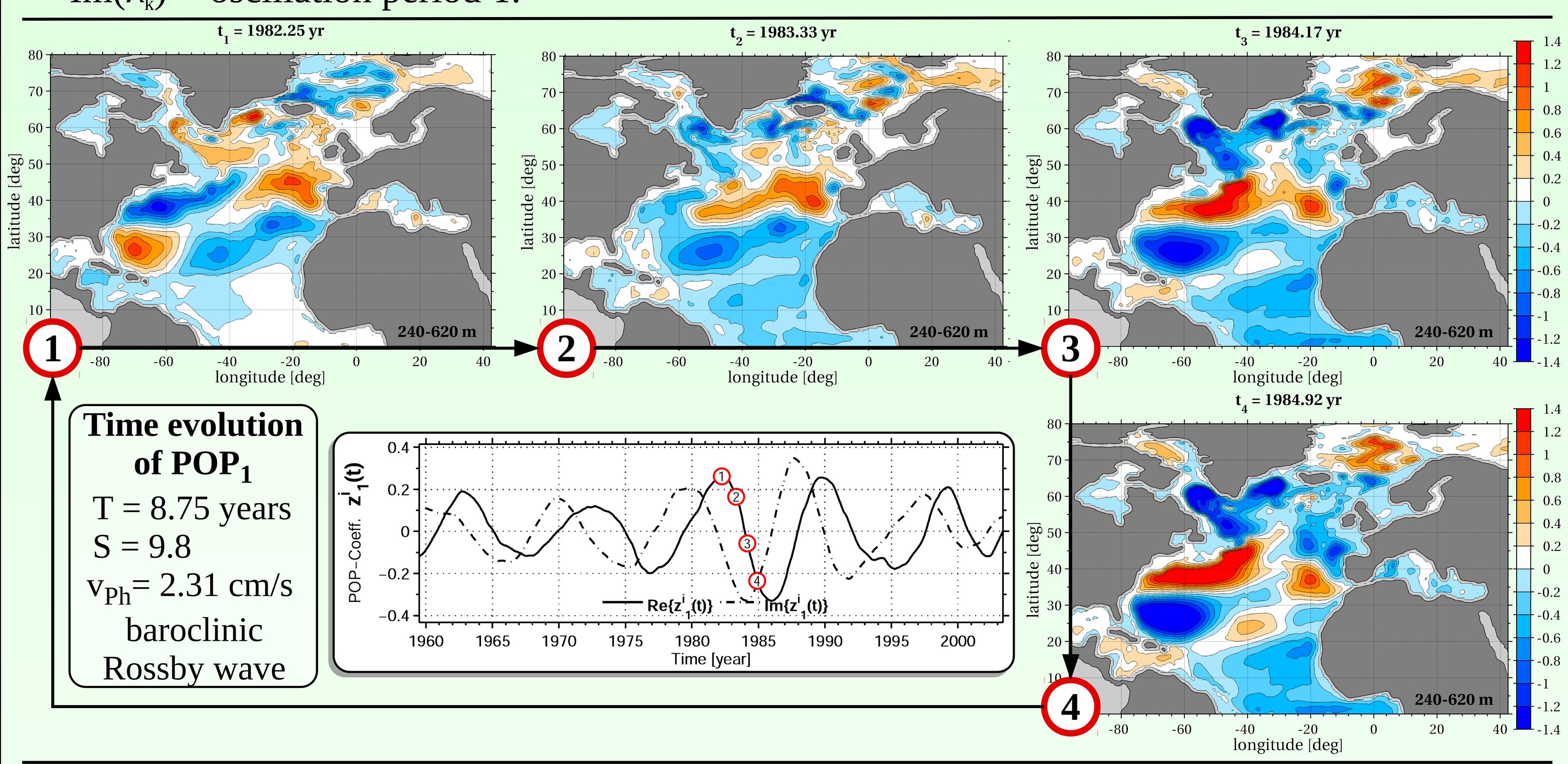
$$A\,\mathbf{p}_k = \lambda_k\,\mathbf{p}_k$$

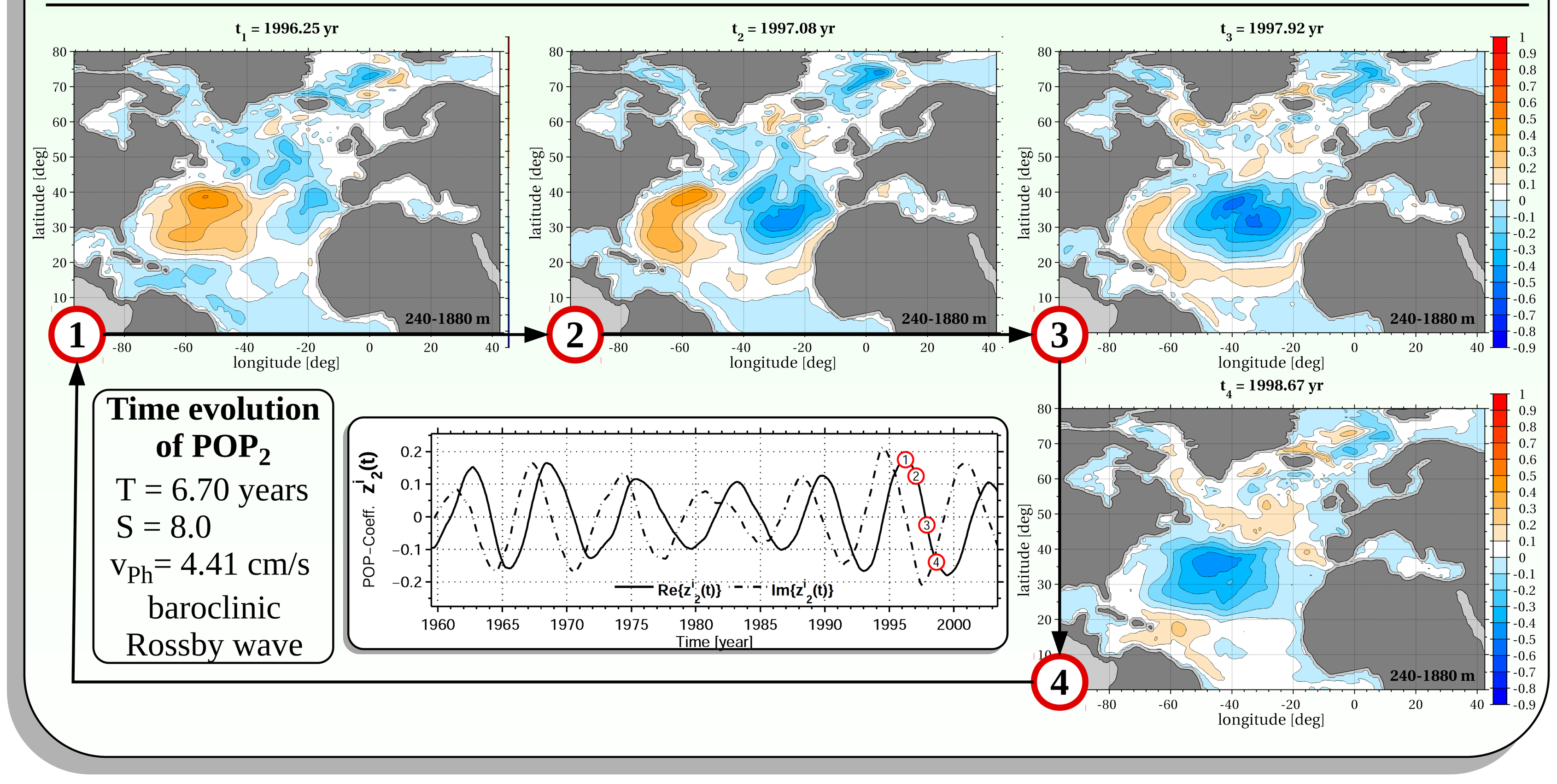
- $\mathrm{Re}(\lambda_k) \rightarrow$ damping time τ, $\mathrm{Im}(\lambda_k) \rightarrow$ oscillation period T.

- 3D POP analysis of temperature between 0 m-3600 m in the North Atlantic Ocean.
- Data are detrended, normalized, monthly cycle is removed, a 3 year-running mean filter is applied.
- To reduce the DOF 12 EOFs are used which explain 96.8% of the total variance.

	S	T[yr]	τ[yr]	coh	φ
1	9.8	8.7	85.7	1.0	90.3
2	8.0	6.7	54.1	1.0	86.5
3	2.7	11.1	30.3	1.0	89.3
4	2.3	14.1	32.9	0.8	90.1
5	0.7	23.7	17.0	0.3	97.1
6	0.6	30.5	18.0	0.1	81.3

- Stability parameter : S=τ/T

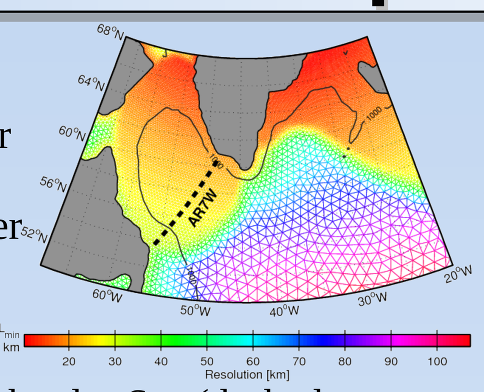




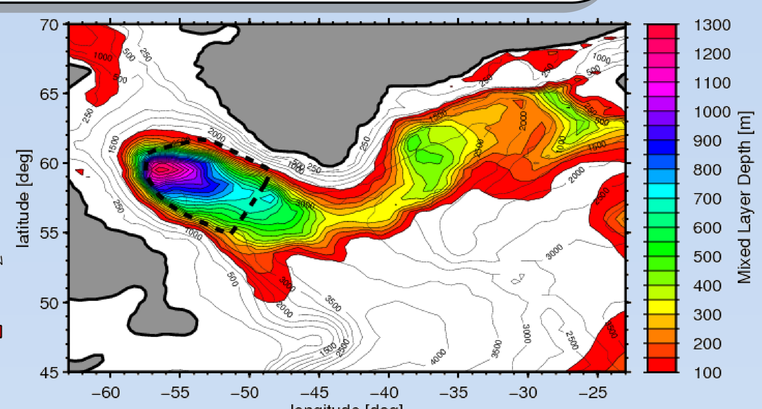
- P. Scholz, G. Lohmann, Q. Wang, S. Danilov, Evaluation of a Finite-Element Sea-Ice Ocean Model (FESOM) set-up to study the interannual to decadal variability in the deep-water formation rates, 2013, Ocean Dynamics, doi:10.1007/s10236-012-0590-0
- P. Scholz, G. Lohmann, M. Ionita, D. Kieke, M. Rhein, Validation of Labrador Sea Water formation in a global Finite-Element Sea-Ice Ocean Model setup, based on a comparison with observational data, 2013, in preparation
- P. Scholz, G. Lohmann, M. Ionita, M. Dima, Interannual to Decadal variability in a Finite-Element Sea-Ice Ocean Model (FESOM) setup, 2013, in preparation

Labrador Sea deep-water masses

- Analyse temporal evolution of the Labrador Sea hydrography as well as of the upper and deeper Labrador Sea Water (uLSW, dLSW).

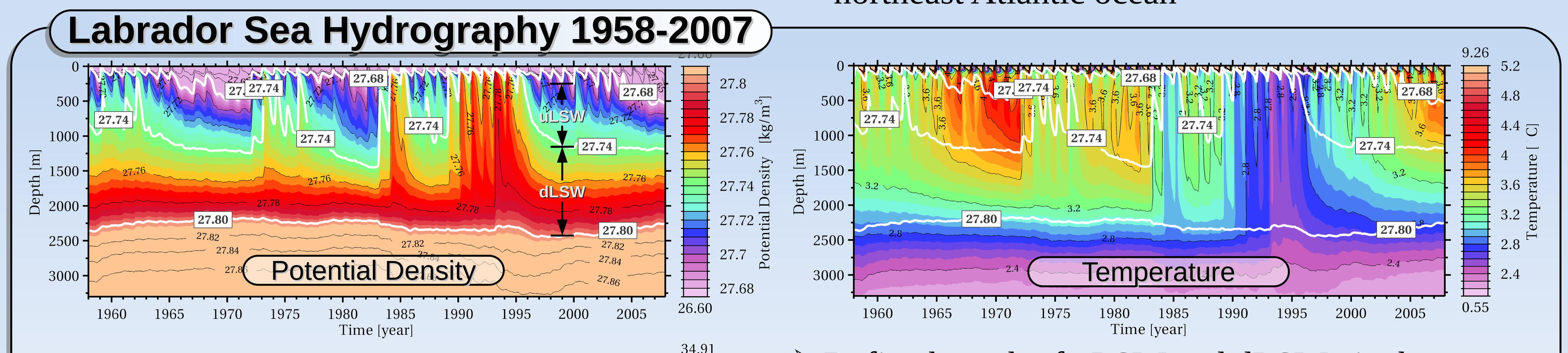


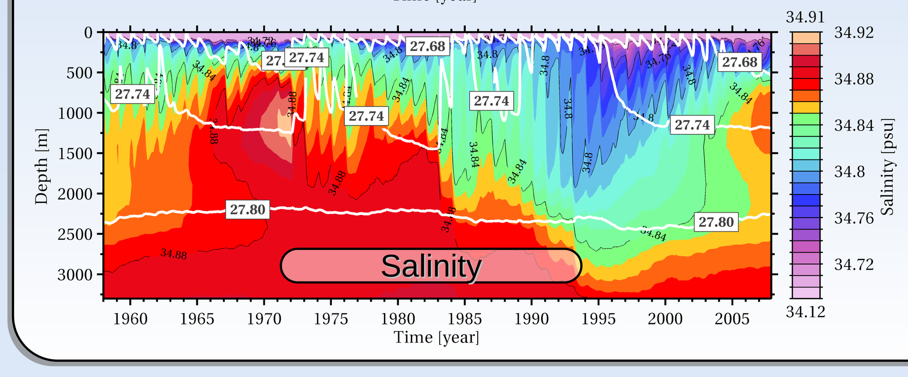
- Define an index in the Labrador Sea (dashed contour line) where the bottom depth >2700m, that includes main deep convection area.



- Winter (DJF) mean mixed layer depth for the period 1988-2007 and bottom topography in the northeast Atlantic ocean-

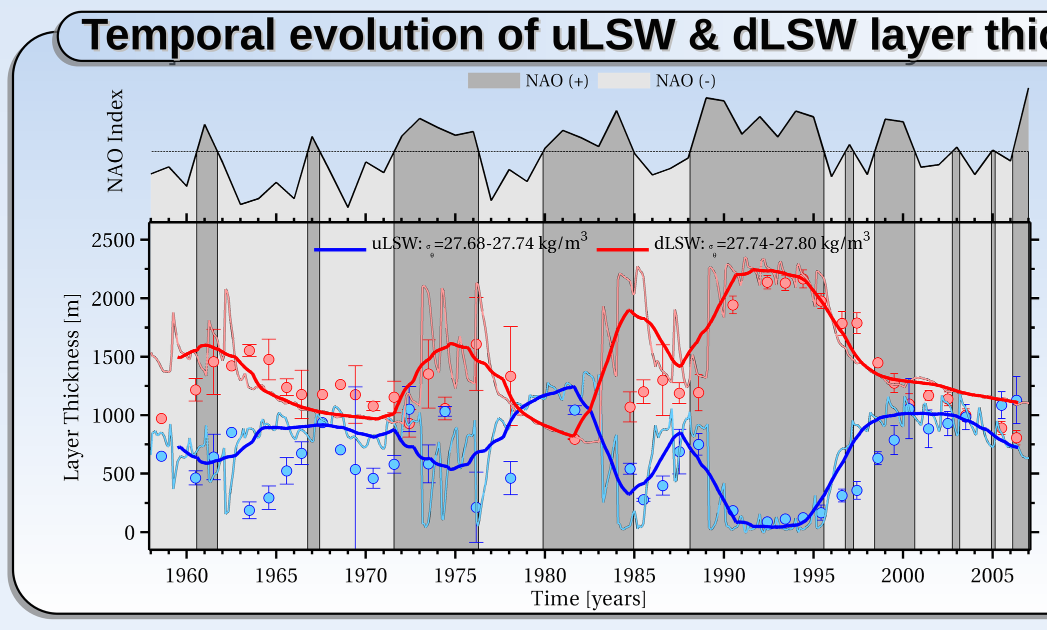
Labrador Sea Hydrography 1958-2007





- Define branch of uLSW and dLSW via the isopycnals (σ_θ=27.68, 27.74, 27.80 kg/m³, white lines).
- uLSW: σ_θ= 27.68-27.74 kg/m³, dLSW: σ_θ= 27.74-27.80 kg/m³ (Kieke et. al. 2006).
- Different phases of increased and reduced deep convection in the Labrador Sea.

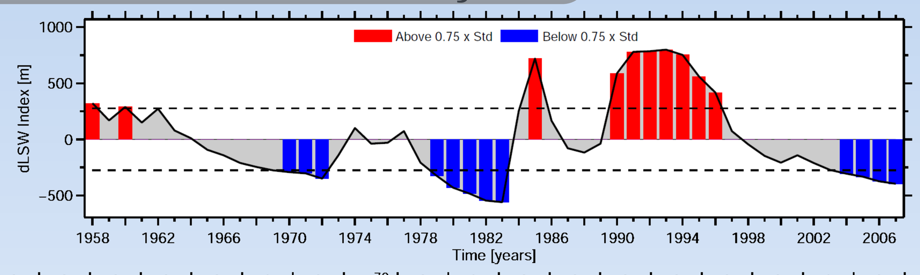
Temporal evolution of uLSW & dLSW layer thickness



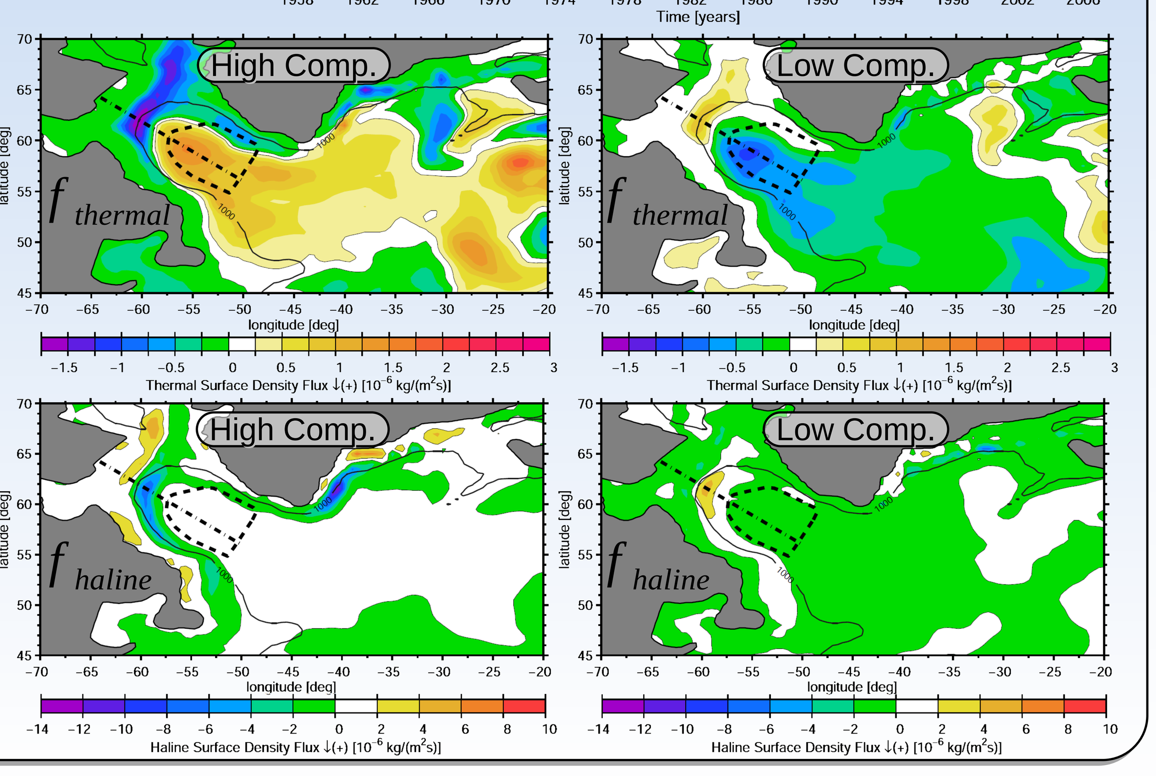
- Monthly modeled (—), 3 year-running-mean filtered (**—**) and observed (○,Kieke et.al. 2006, Rhein et. al. 2011) **uLSW** and **dLSW** layer thickness
- Winter seasonal **NAO(+)** and **NAO(-)** index.
- Several phases of increased (decreased) dLSW (uLSW) layer thickness.
- Maximum (minimum) dLSW (uLSW) layer thickness in the early 1990s.

Composite Map Analysis of dLSW index and surface density flux

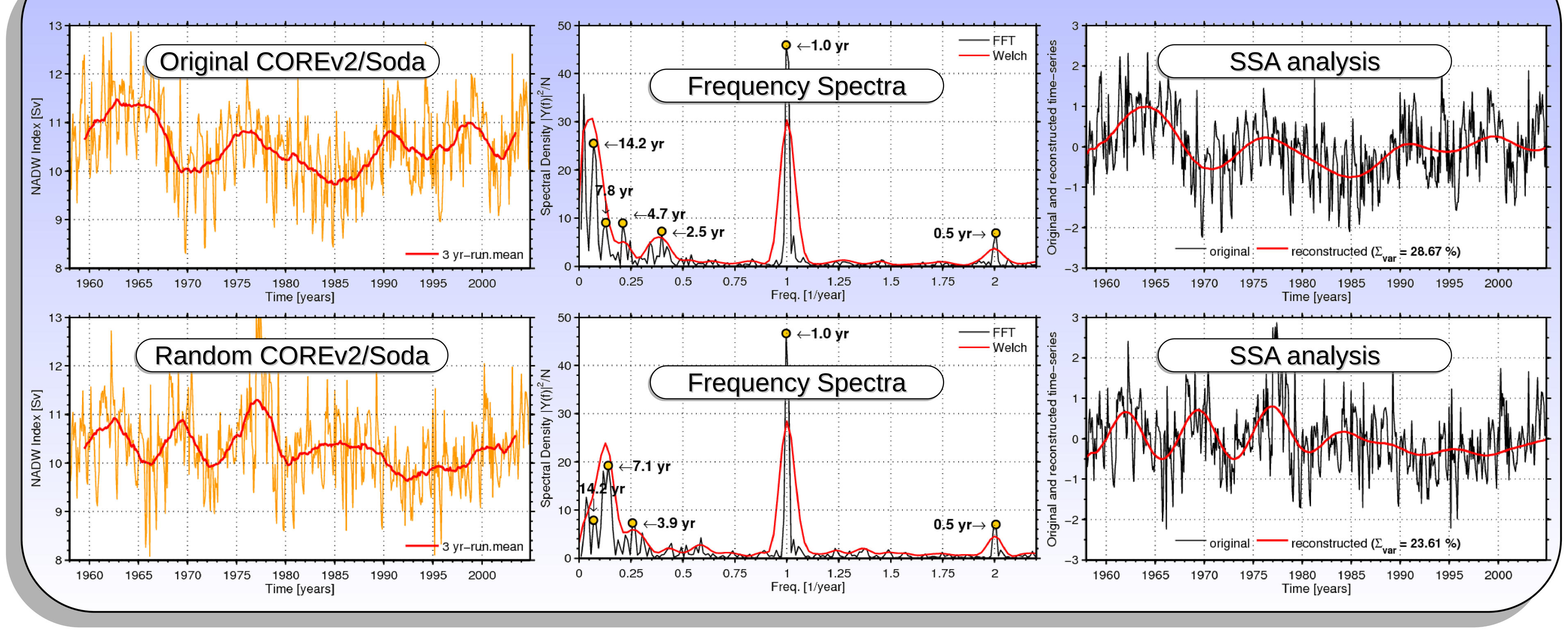
$$f_\rho = \underbrace{-\alpha\frac{Q_{net}}{C_p}}_{f_{thermal}} + \underbrace{\beta\,\rho\,S\frac{Fw_{net}}{1-S/1000}}_{f_{haline}}$$



- High and Low composite maps of the winter dLSW index with the thermal and haline contribution of the surface density flux.
- During high dLSW formation central Labrador Sea in the model is dominated by $f_{thermal}$.
- Contribution of f_{haline} in the model are limited to the position East/West Greenland current and Labrador current.
- Central Labrador Sea mostly shielded from haline contributions, only minor interaction.



Variability NADW index



Conclusions

- The NADW index of the original forcing run has a strong periodicity of about 14.1 yr (accounts for 28.7% of variance), whereas the random forcing shows a strong periodicity ~7.1 yr (accounts for 23.6% of variance).
- The random forcing run could prove that the 14.1 yr periodicity is related to the atmospheric forcing, while 7.1 yr periodicity is related to internal modes of the ocean.
- We are able to simulate several phases of increased deep convection in the central Labrador Sea. The comparison of modeled and observational dLSW/uLSW layer thickness is in good agreement.
- POP analysis revealed two exceptional stable interdecadal modes that can be attributed to propagating Rossby wave structures.