Migration of deep convection center in subpolar North Atlantic around 6 ka suggested by a dinocyst proxy of mixed layer depth

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Key points:

- Variations of mixed layer depth can influence dinocyst assemblages and especially the relative abundance of *Nematosphaeropsis labyrinthus*
- An abrupt westward migration of deep convection center in the subpolar North Atlantic occurred around 6 ka BP
- Modern-like strength of deep convection in the Labrador Sea developed during the Late Holocene

1. Introduction

The ocean mixed layer is a homogenized surface layer of the ocean that directly interacts with the atmosphere.

- **Mixed layer depth (MLD)** is largest in the Nordic Seas and the Labrador Sea, where wintertime deep convection creates a convective turbulence that greatly enhances vertical mixing.
- Deep convection and the associated deep-water formation can affect ocean's uptake of heat and gases, the AMOC variability, etc.
- Little is known about past variations of deep convection.

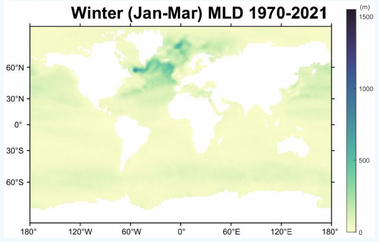

Fig 1. Winter MLD from the monthly climatology based on profile data of 1970-2021 by de Boyer Montégut (2023)

MLD impacts the marine ecosystem by affecting the average light intensity throughout the mixed layer as well as nutrient replenishment.
Can we infer past changes of MLD from dinocyst assemblage records?

2. Data and methods

- The n = 1968 database with modern distribution of 71 dinoflagellate cyst (dinocyst) taxa in surface sediments by de Vernal et al. (2020)
- MLD climatology from various datasets:
  1. World Ocean Atlas 2018
  2. de Boyer Montégut (2023)
  3. Holte et al. (2017)
- **Canonical correspondence analysis (CCA)** for assessing the relationship between dinocyst relative abundance and seasonal MLD
- Two methods of quantitative reconstruction:
  1. **Modern analogue technique (MAT)**
  2. **Weighted averaging partial least square (WAPLS)** regression and calibration
- 24 Holocene dinocyst records from the subpolar North Atlantic where deep convections occur today, for quantitative reconstructions

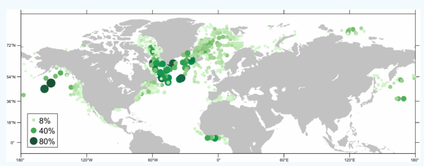

Fig 2. Distribution of *Nematosphaeropsis labyrinthus* from the n = 1968 database

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Fonds de recherche Québec
NSERC CRSNG

This study was supported by the Fonds de Recherche du Québec – Nature et technologies (FRQNT) [grant number 320994] and the Natural Sciences and Engineering Research Council (NSERC) of Canada [grant number DG/AdV].

3. Relationship between dinocyst and MLD

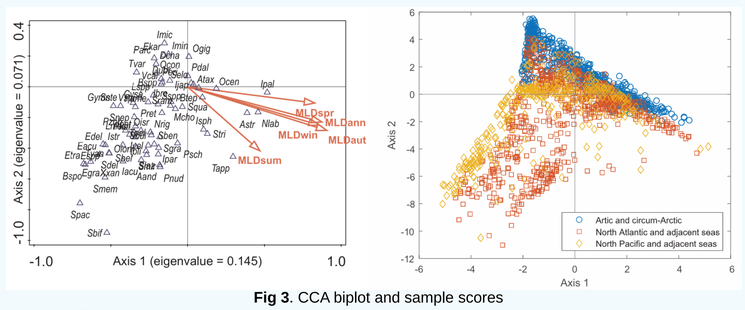

Fig 3. CCA biplot and sample scores

- Significant ($p<0.05$) correlation between MLD and dinocyst assemblage
- MLD variables explain 7% of the total variation, or 3.8% of the partial variation after removing the effect of other environmental variables (e.g., SST, SSS, sea ice)
- Strong positive correlation between winter & autumn MLD and two dinocyst species: *Atlanticodinium striaticonulum* (rare minor taxa) and *Nematosphaeropsis labyrinthus* (cosmopolitan and common)

Could MLD variations influence ***N. labyrinthus*** in particular?

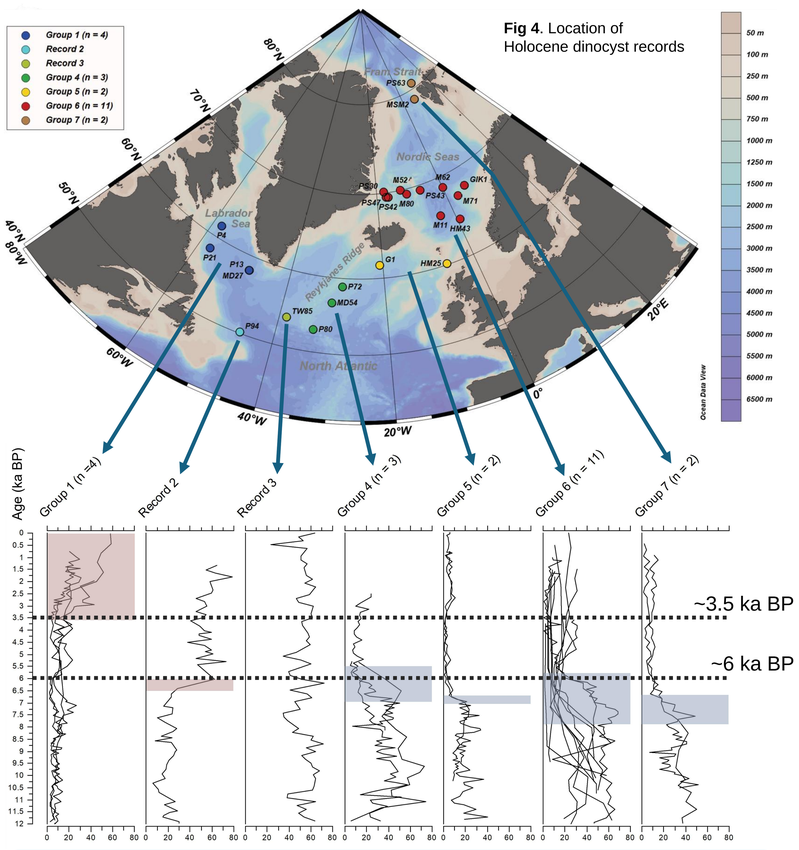

Fig 4. Location of Holocene dinocyst records

Fig 5. Regional stacks of *N. labyrinthus* percentage data

- Positive correlation → higher *N. labyrinthus* % is related to larger MLD
- Contrasting trends in the east vs. west, major transition around 6 ka BP

4. Winter MLD reconstructions

- Better performance by MAT in cross-validation
- The residuals (reconstruction – observation) suggests underestimation of MLD in the Labrador Sea
- The different MLD datasets have a similar performance

Method	MAT	WAPLS
RMSE	76.72	120.18
R^2	0.76	0.42
RMSEP	69.92	122.67
No. of analogues/ components	5	5

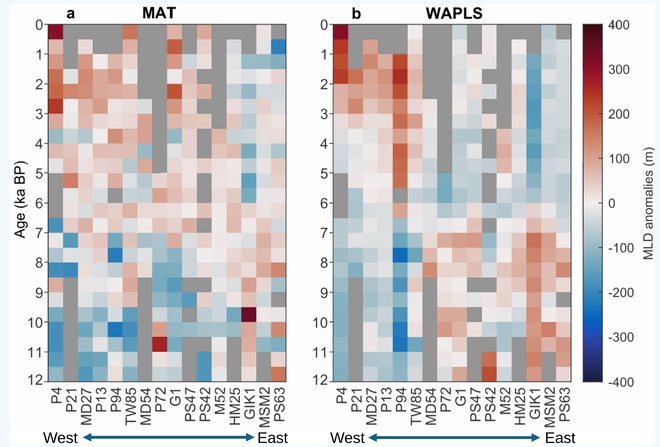

Fig 6. Reconstructed MLD anomalies relative to the overall average of each record (grey = missing value)

- Westward migration of deep convection region during the Middle Holocene
- Modern-like strength of deep convection in the Labrador Sea was established during the late Holocene

How does the reconstruction compare to model simulations?

- Same MLD criterion for model output and reconstruction: density threshold of 0.03 kg/m^3 with reference to 10 m depth.
- Average winter MLD recomputed from 15 models of PMIP
- Reconstruction using MAT and MLD data of de Boyer Montégut (2023)
- General agreement in the Nordic Seas
- Disagreement in the Labrador Sea: bias from sea ice model? Underestimation of meltwater flux from ice sheets in simulations?

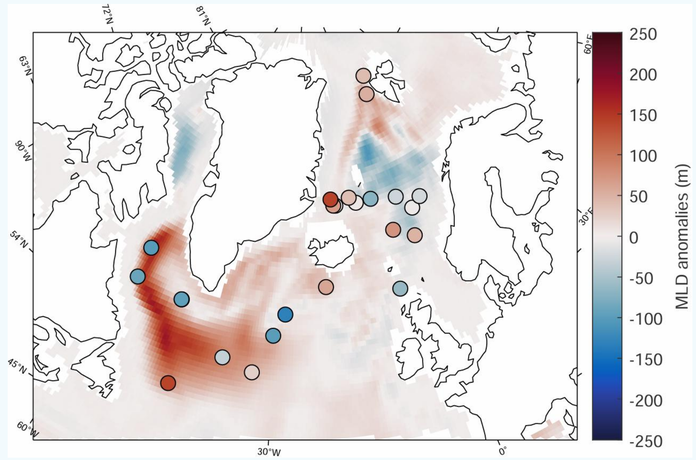

Fig 7. MLD anomalies (MH – PI) from model simulations versus reconstruction records