Paleo-lake simulations for extreme seasonality changes during the late deglaciation

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Overview

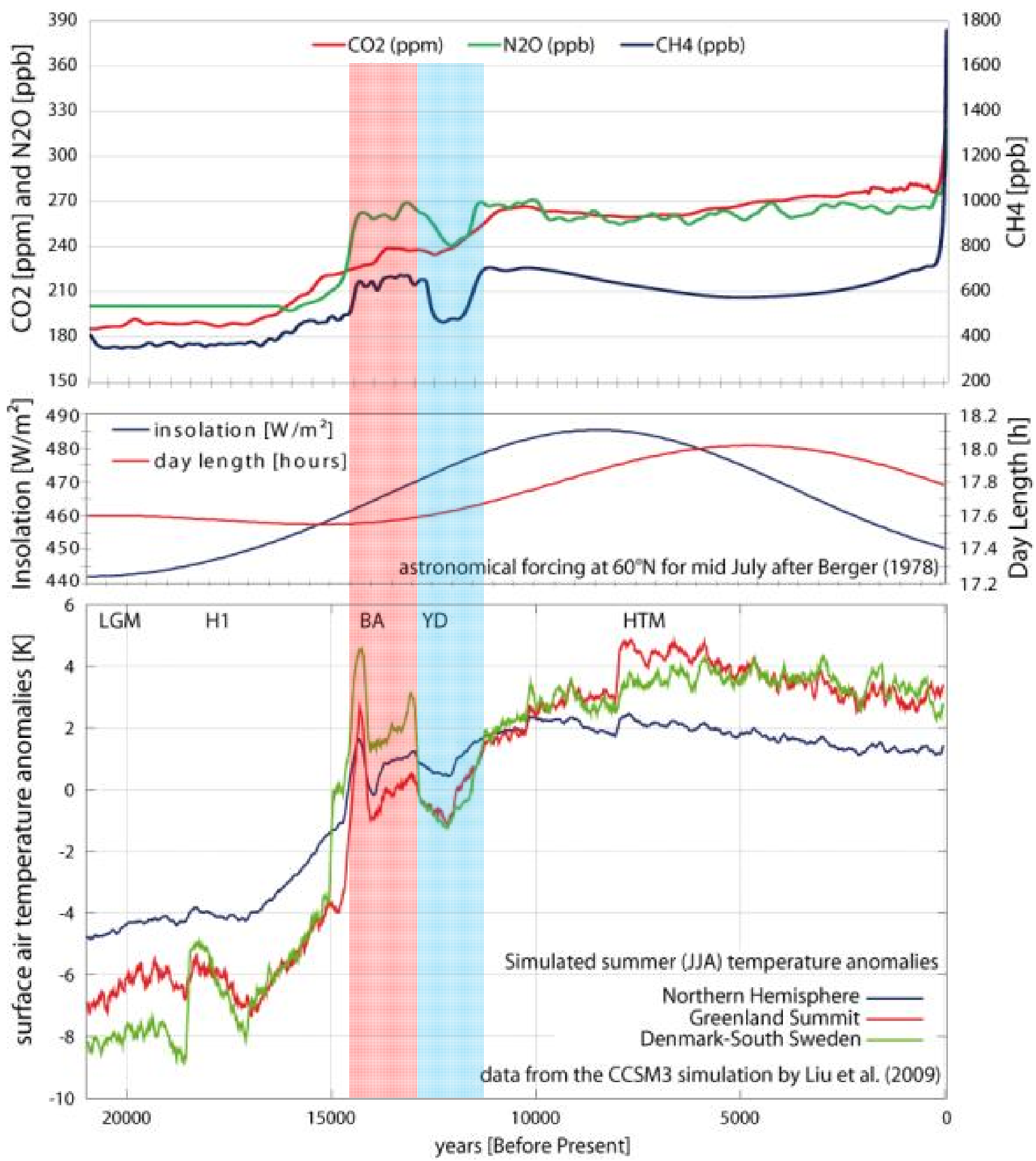
- 1. Introduction
  - Paleoclimate of the late Deglaciation
- 2. Paleo lake records
- 3. Climate model simulations

- 4. Paleo-lake modeling
- 5. Discussion

1. Introduction

Abrupt climate shifts during the late Deglaciation

Transient simulation of deglaciation + Holocene



TraCE simulation (AOGCM = CCSM3)

- deglaciation through gradual **increase in summer insolation**
- ice instabilities and **meltwater pulses** trigger non-linear responses
- North Atlantic: **AMOC slowdown**
- **rapid shifts** of Bølling-Allerød and Younger Dryas

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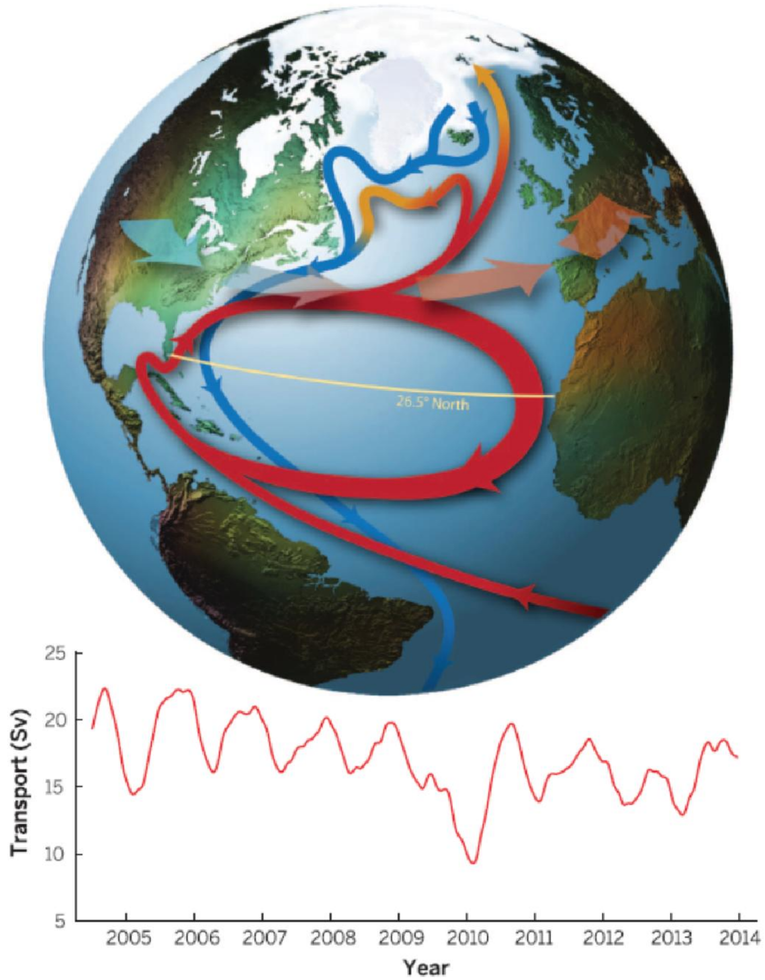
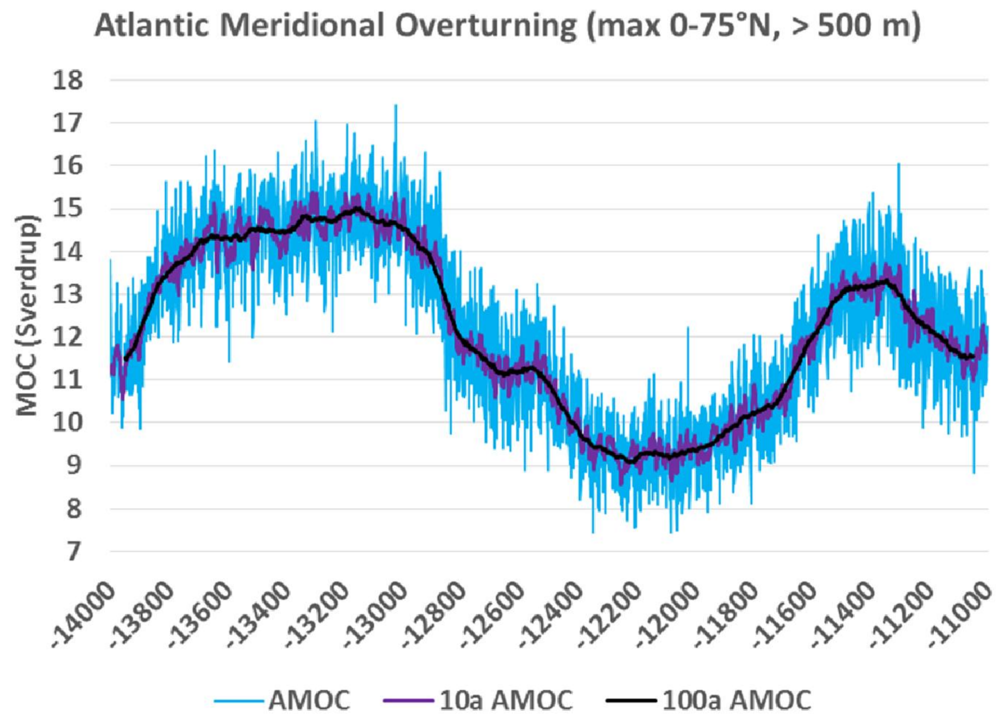
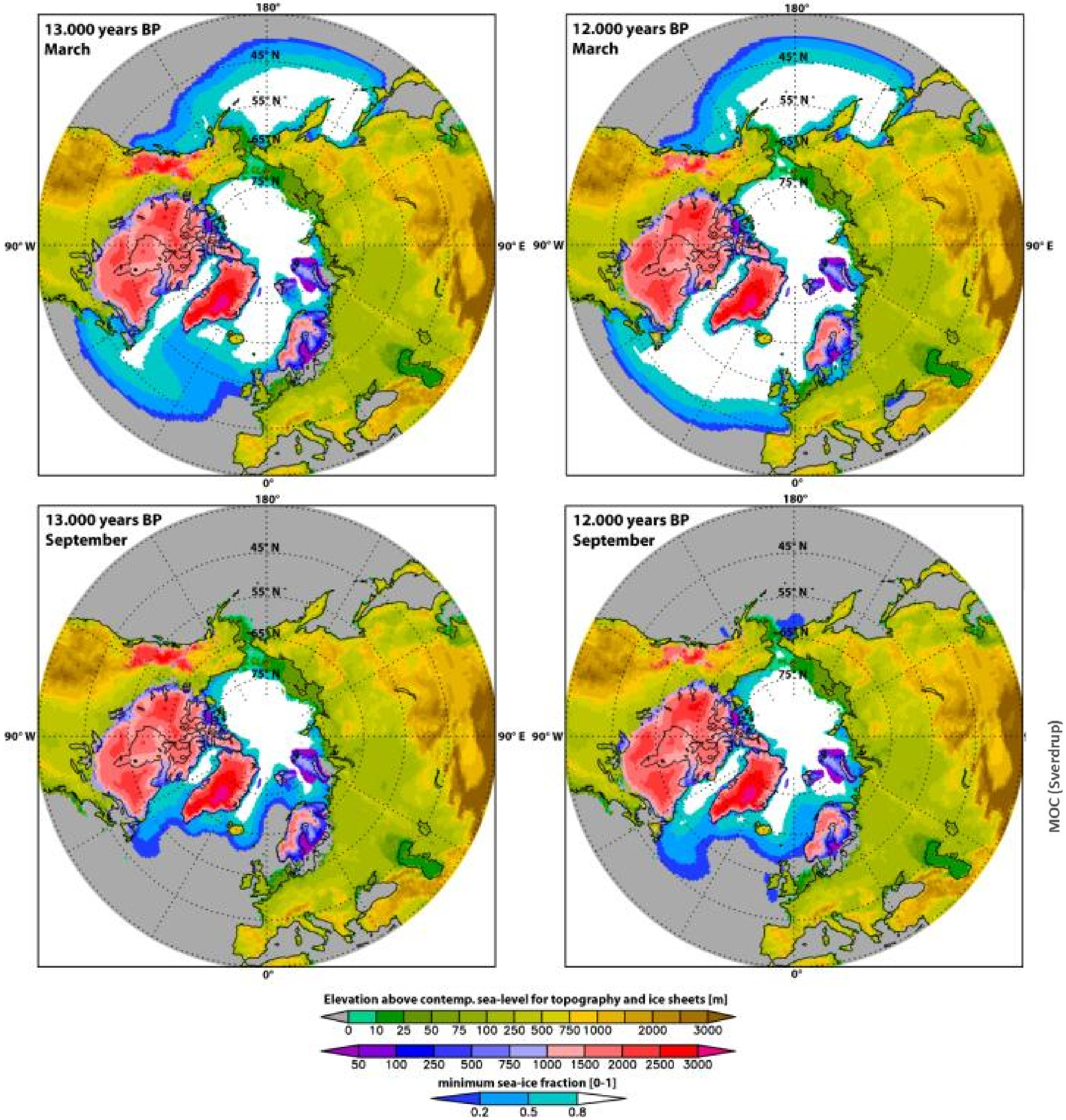
Atlantic Meridional Overturning Circulation



Srokosz & Bryden (2015), Science





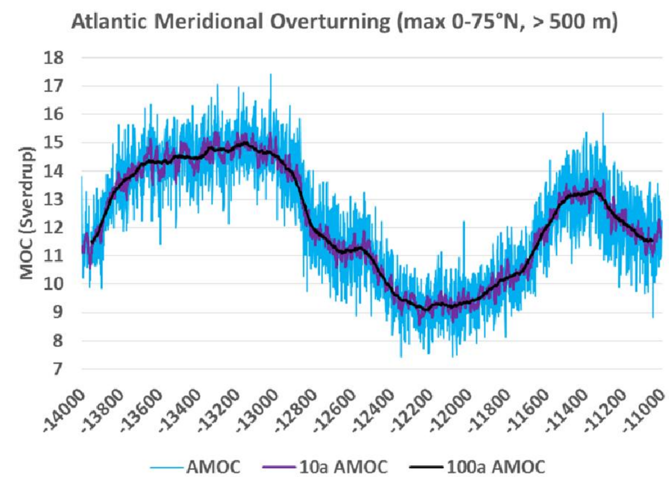
Boundary conditions

1) Topography & Ice Sheets

GLAC1b by Lev Tarasov

2) SST and sea-ice fraction

TraCE (CCSM3, He 2011)



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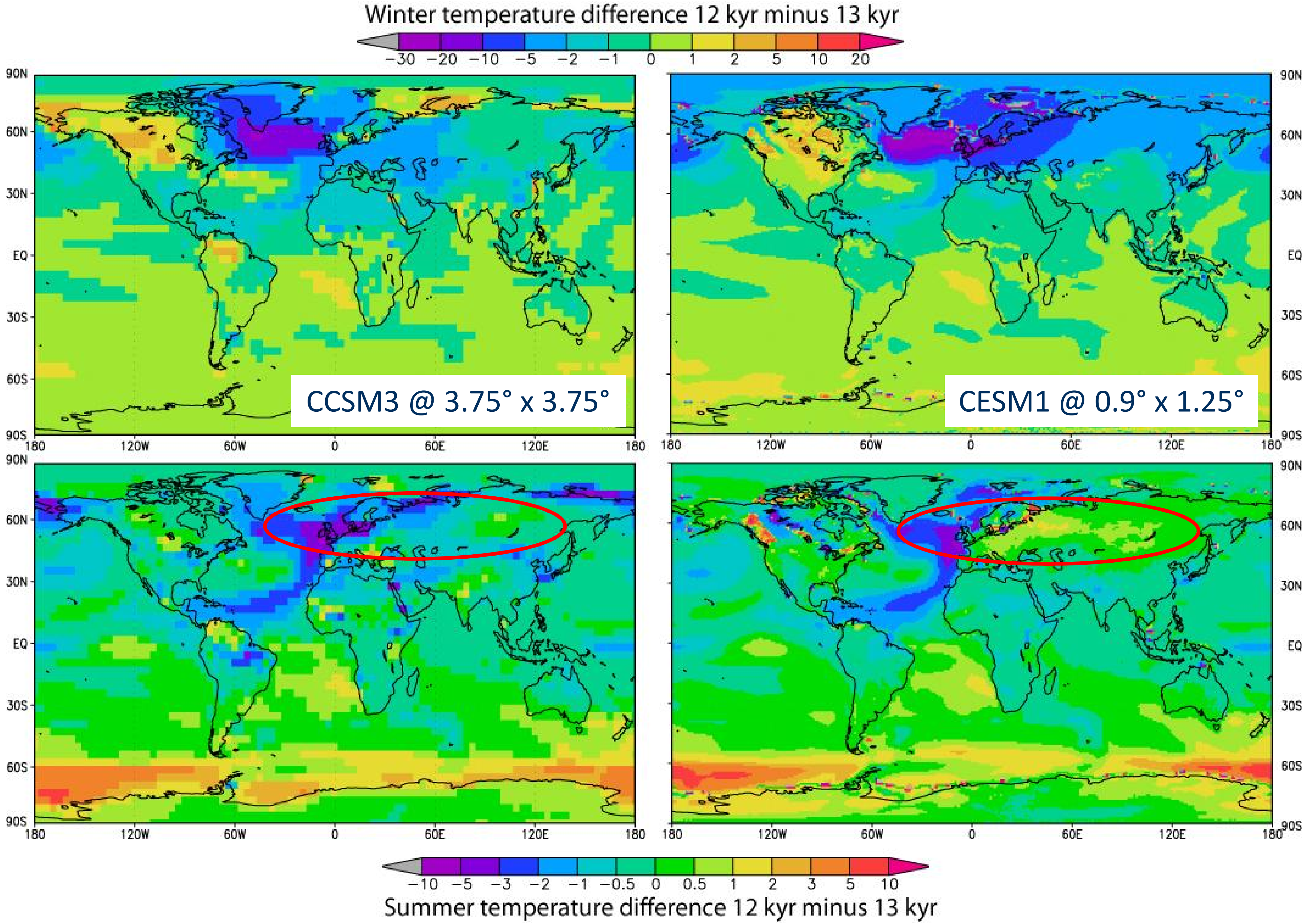
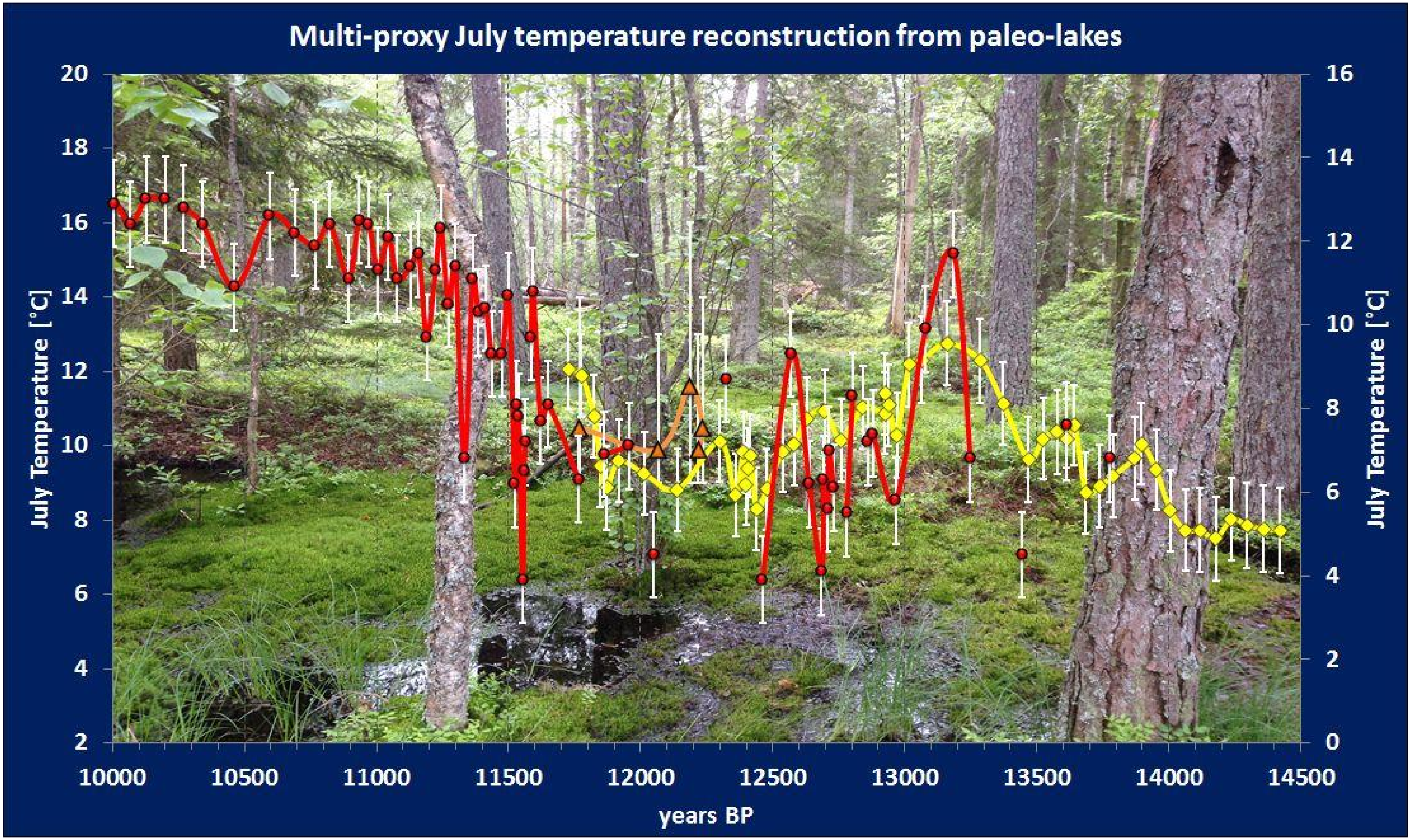

Winter temperature difference 12 kyr minus 13 kyr
−30 −20 −10 −5 −2 −1 0 1 2 5 10 20
CCSM3 @ 3.75° x 3.75°
CESM1 @ 0.9° x 1.25°
90N 60N 30N EQ 30S 60S 90S
180 120W 60W 0 60E 120E 180
−10 −5 −3 −2 −1 −0.5 0 0.5 1 2 3 5 10
Summer temperature difference 12 kyr minus 13 kyr

Research Questions

- **Problem 1: Climate simulations**
  - cold ocean = cold summers (CCSM3)
  - cold ocean = warm summers (CESM1)
  - Which ΔT_{summer} fits to ΔAMOC?
  - Is ΔAMOC the only forcing behind rapid shifts?

2. Paleo-lake records

Some examples…



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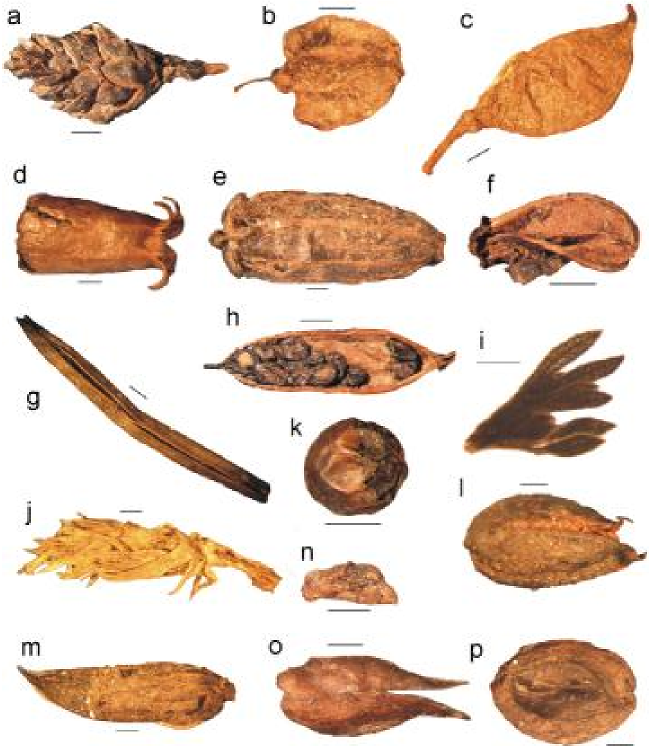
Lake temperature compilation for T_{July} (N=150)

- **Group 1:**
  - chironomids (N=28)
  - coleoptera (N=4)
  - cladocera (N=1)

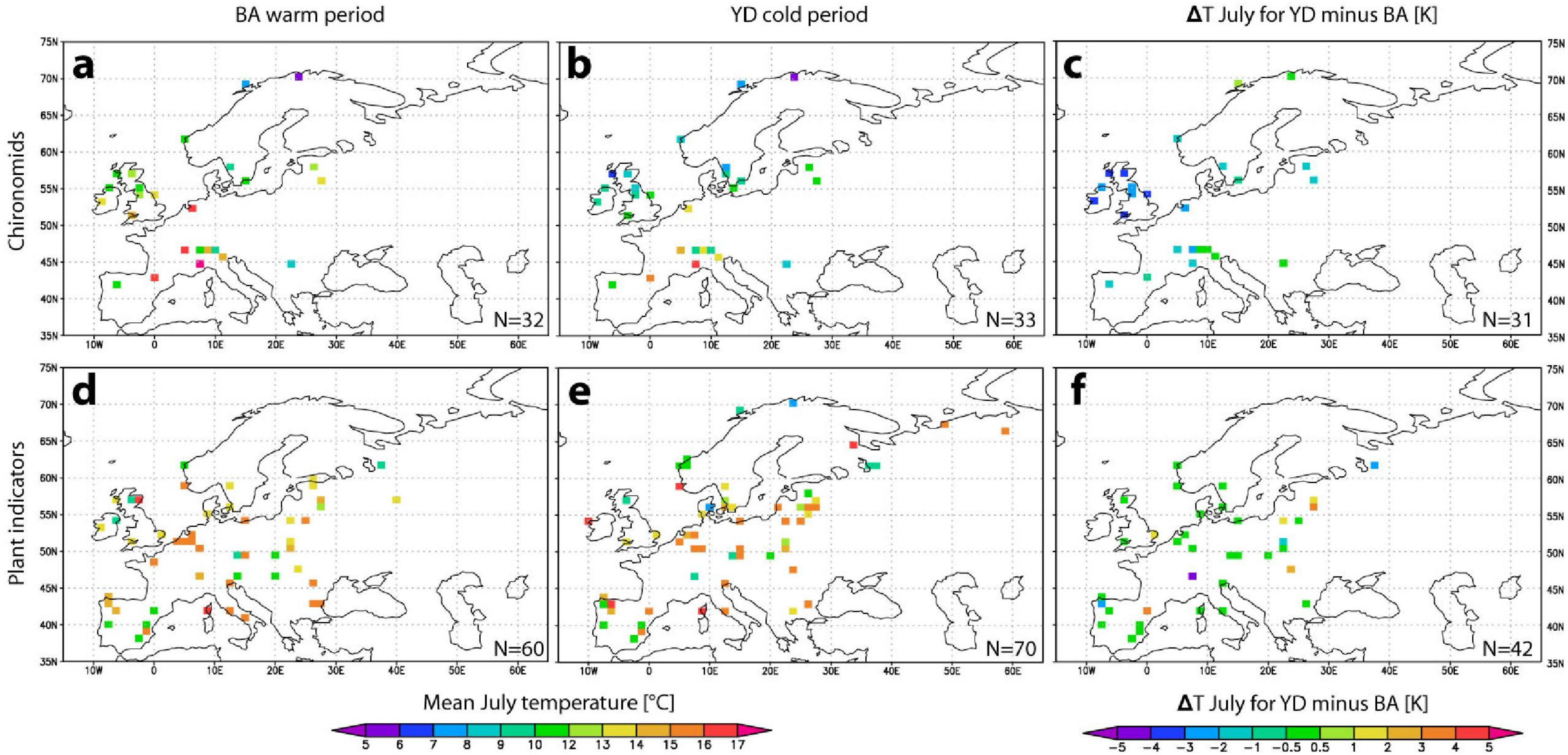
Wikimedia, *chironomus plumosus*

- **Group 2:**
  - NEW! *climate indicator plant species*
  - aquatic pollen & plant macrofossils (N=101)
  - trees (N=16)
  - temperature estimates according to Väliranta et al. (2015)



Zazula et al. (2007)

Lake records T_{July}: chironomids vs. plants



Research Questions

- **Problem 1: Climate simulations**
  - cold ocean = cold summers (CCSM3)
  - cold ocean = warm summers (CESM1)
  - Which ΔT_{summer} fits to ΔAMOC?
  - Is ΔAMOC the only forcing behind rapid shifts?
- **Problem 2: Proxy data for T_{July}**
  - aquatic pollen & plant macrofossils = warm summers
  - Chironomids = cold summers (W-E gradient)
  - Hypothesis: *water temperatures diverge from air temperatures due to extreme Δseasonality*
- **Solution(?): Paleo-lake modeling of Δseasonality**
  - Hypothesis: ΔAMOC → Δseasonality?

3. Climate model simulations

Use the Community Earth System Model 1 to create lake model forcing data

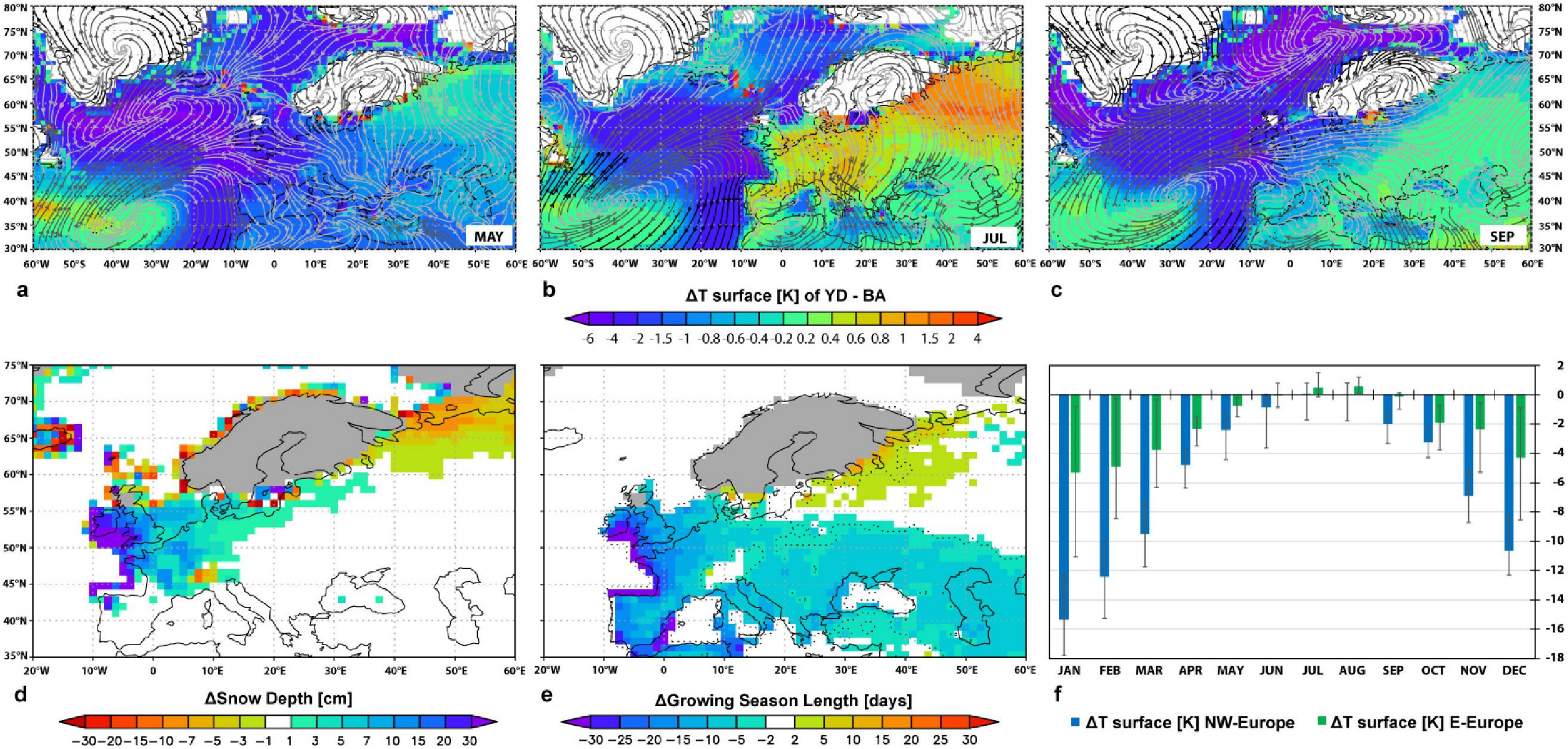
CESM1 simulations for 12kyr vs. 13kyr

NCAR UCAR | CESM COMMUNITY EARTH SYSTEM MODEL — *earth* • modeling • *climate*

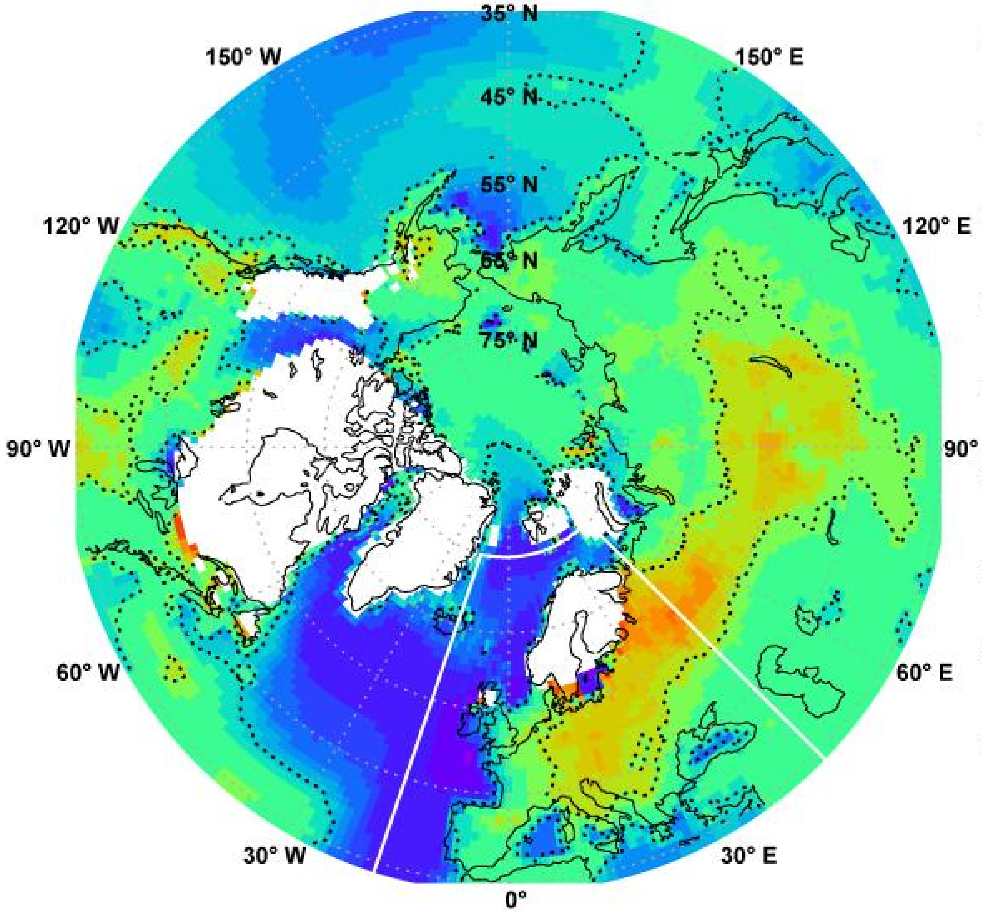
Model version	CESM 1.0.5
Component set	F_1850 (CAM4/CLM4/CICE/DOCN)
Resolution	**0.9° x 1.25° horizontal**, 26 vertical levels, finite volume
Topography	**GLAC2** (Tarasov et al., in prep), added on USGS GTOPO30 ICE-5G (Peltier 2004), ICE-6G (Peltier et al., 2014)
Forcing	**prescribed SST/Ice fraction** from TraCE (Liu et al., 2009; He 2011)
	orbital and GHG according to PMIP protocol

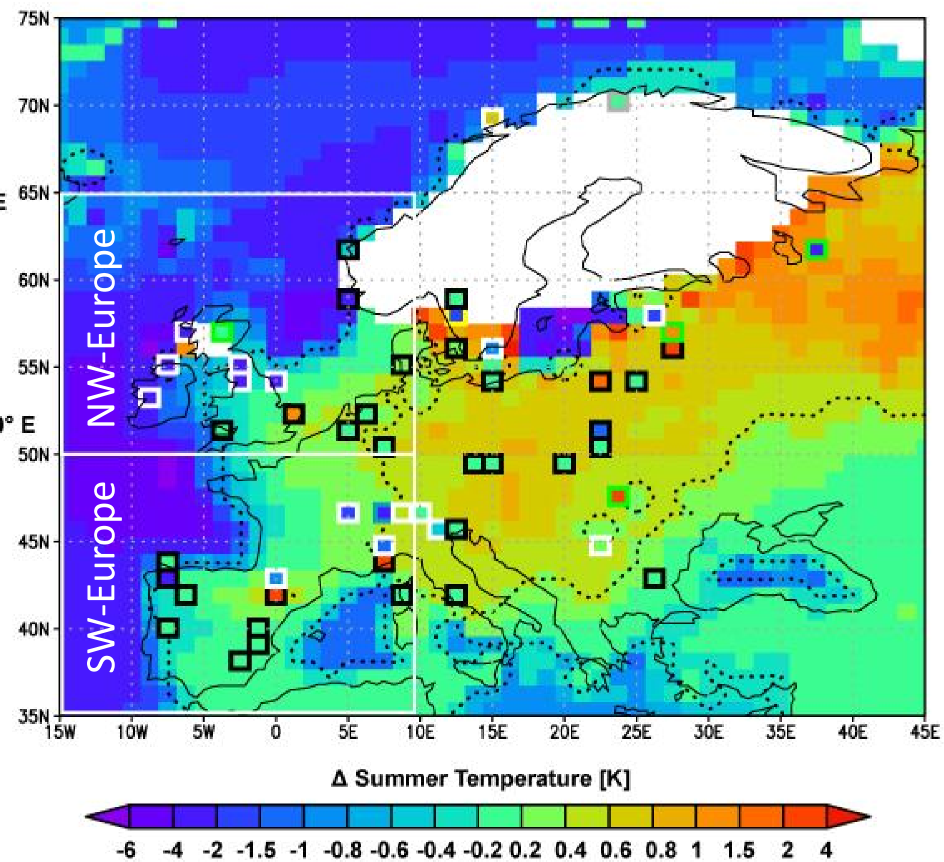
Model is available under http://www.cesm.ucar.edu/models/cesm1.0/

ΔT summer response = Δseasonality?



ΔT summer response [K] of YD-BA





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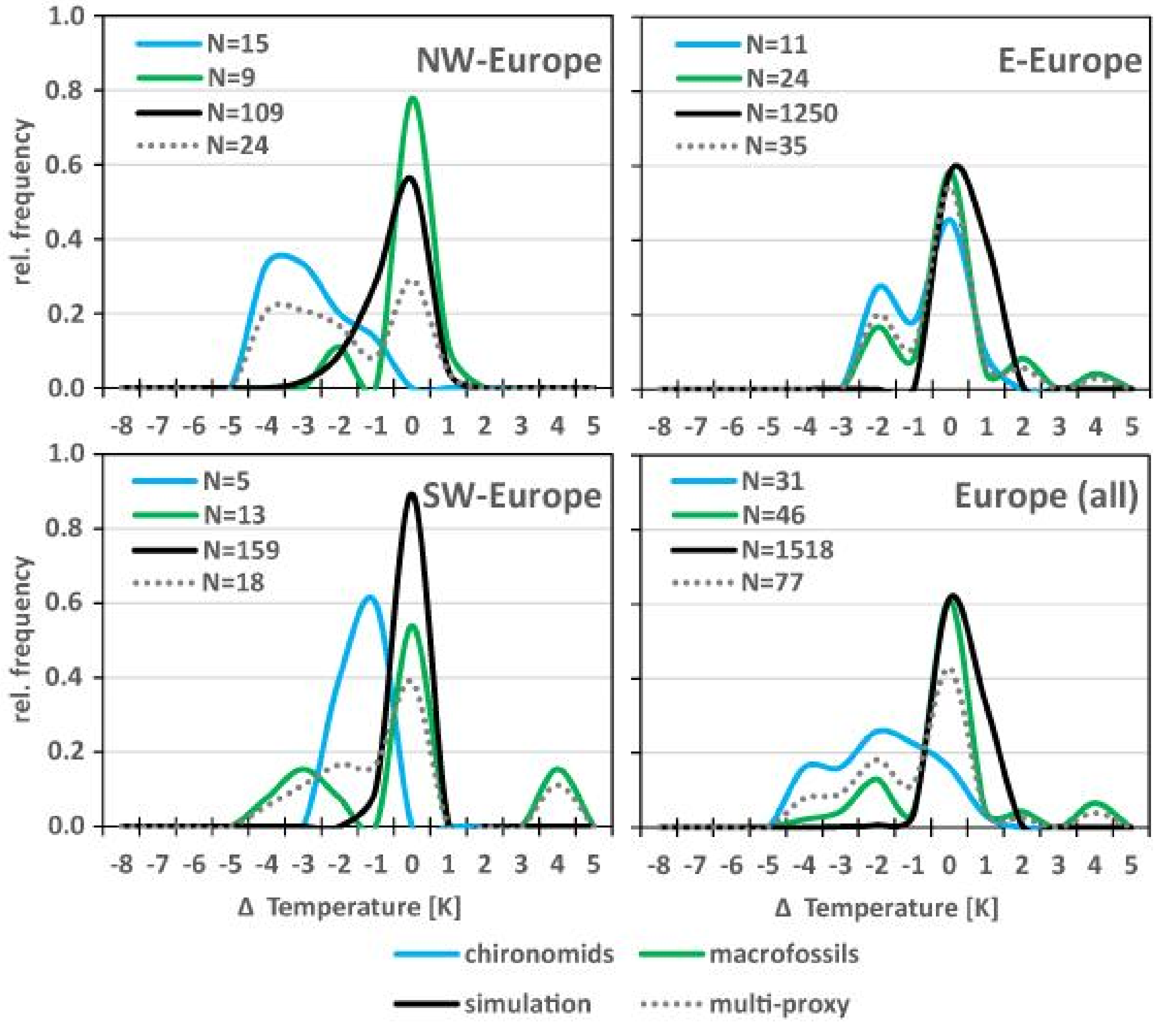

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4. Paleo-lake modeling

Linking climate with lake temperatures

FLake and PROBE

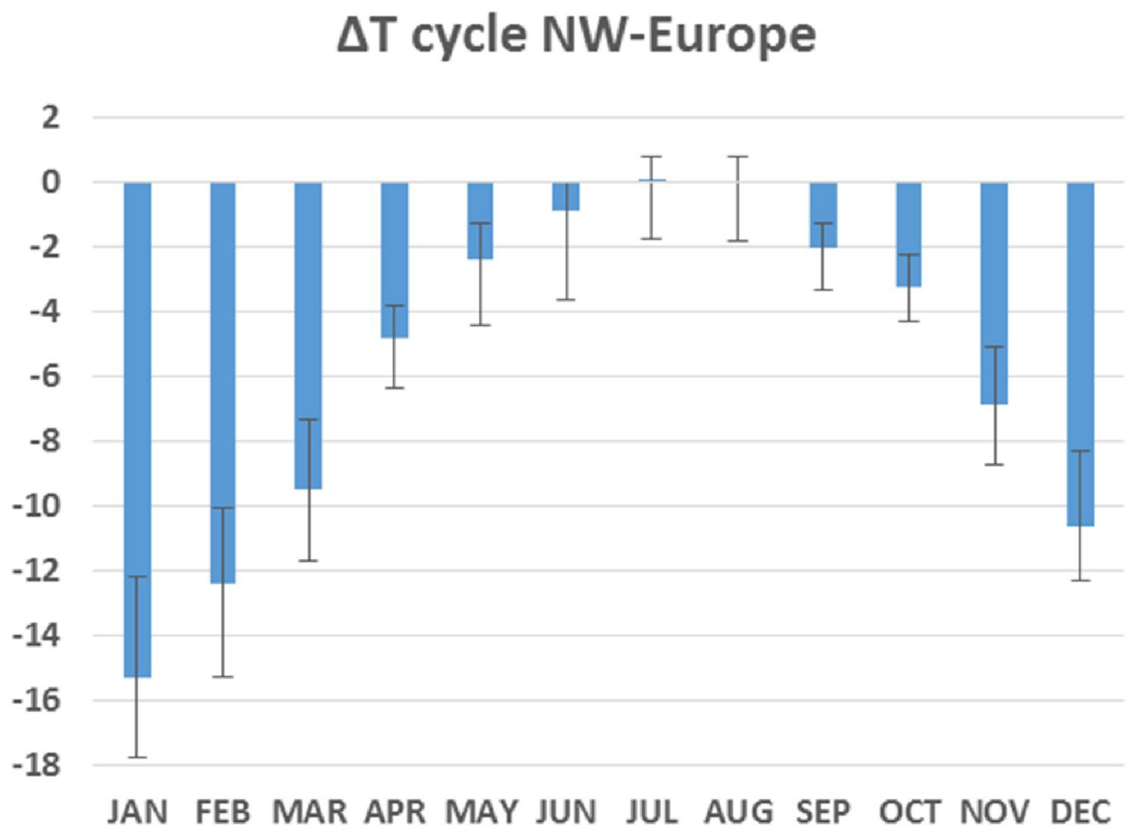
- **FLAKE (0-D bulk model)**
- Mironov (2008)
- two-layer parametrisation
- concept of self-similarity for vertical profile
- validated for shallow lakes
- stand-alone version used here
- forcing by CESM1 output

- **PROBE (1D-model)**
- Sahlberg (1983, 1988, 2003)
- dynamic eddy viscosity calculated by a two equation turbulence model, k-ε model & the hypolimnic eddy diffusivity formulation which is a function of the stability frequency.
- validation for shallow lakes unclear (?)

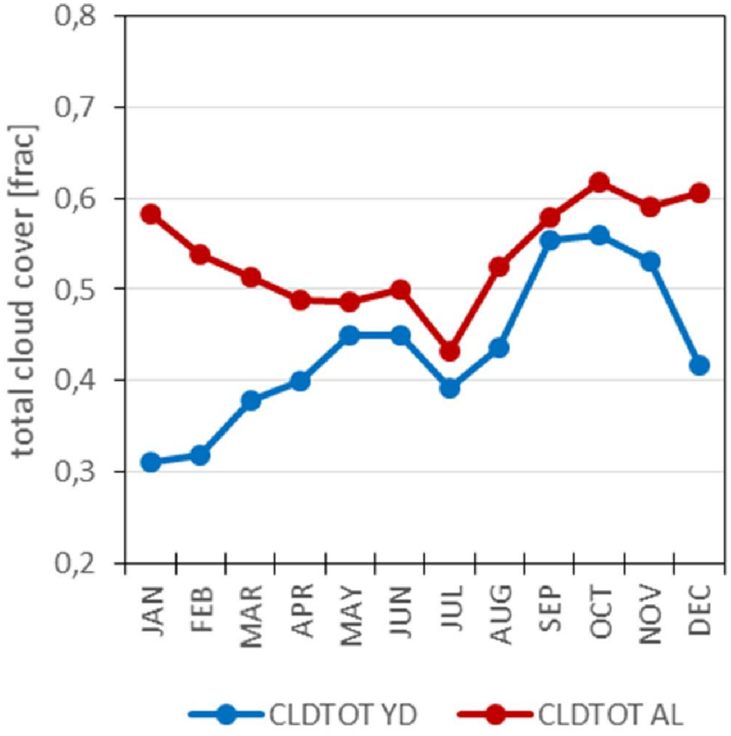
Forcing for lake model (Mironov 2008)

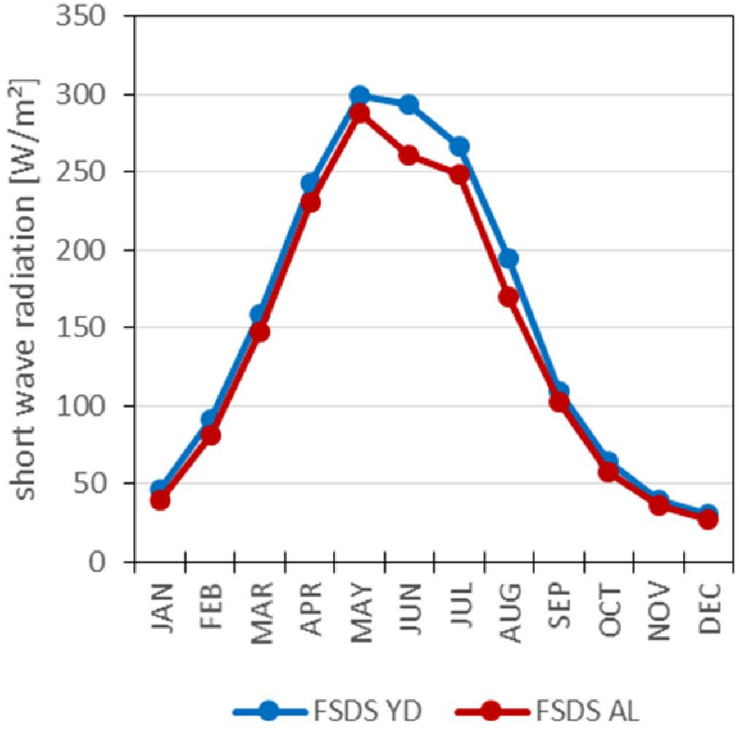
- parameters: lk_depth=5, extinction_coeff=0.3 [1/m] (transparent), lat = 56 °N
- initial conditions: upper mixed layer = bottom = 4°C, mixed layer thickness = 3 m
- timestep= daily mean (or 3 hours)
- net radiation at lake surface = **FSDS** [W/m²] downwelling SR radiation at surface
- near surface temperature T_a [°C] = **TREFHT**, set z=2 m
- wind speed **U10** [m/s], set z=10 m
- cloudiness **CLDTOT** [%], set low cloud -1 (missing), z=2 m
- air humidity [mb] $E_v = E_s * RH/100$ with
  - $\frac{dEs}{dT} = \frac{Qv}{Rv}\frac{Es}{T^2}$ [hPa/K] → $Es = E0 \cdot e^{\left(\frac{Qv}{Rv}\left(\frac{1}{T0}-\frac{1}{T}\right)\right)}$ [hPa]
  - assume Q_v = *const*, solve with August-Roche-Magnus
  - **RH** = relative humidity [%], T = **TREFHT** [K]

Change in seasonality



Cloud cover & short wave radiation





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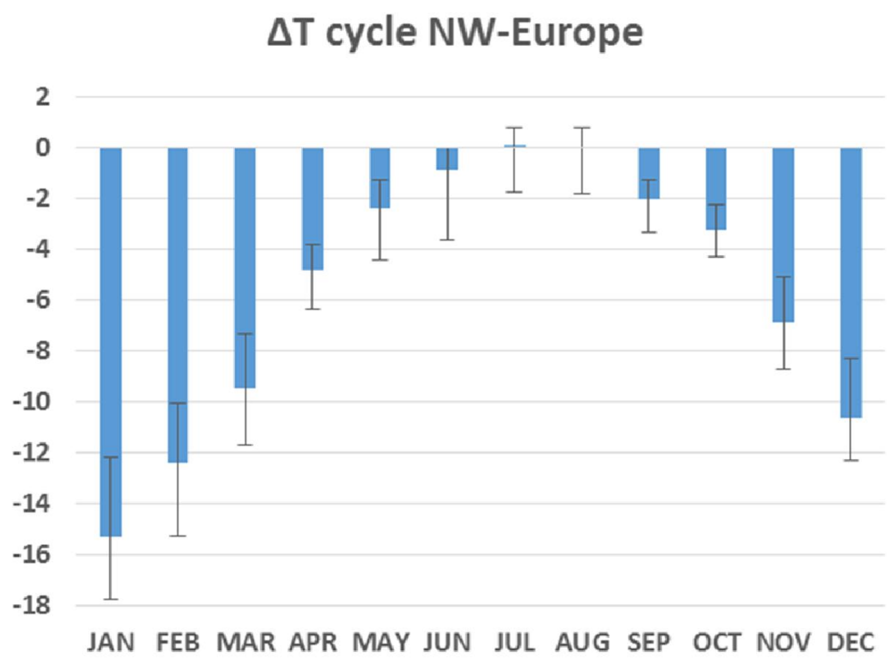
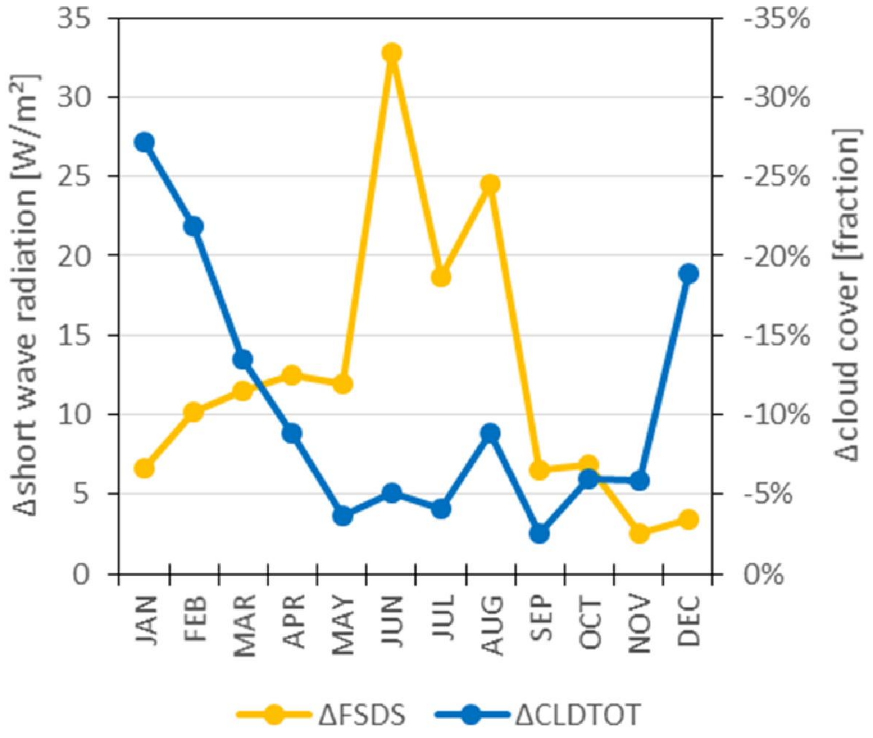
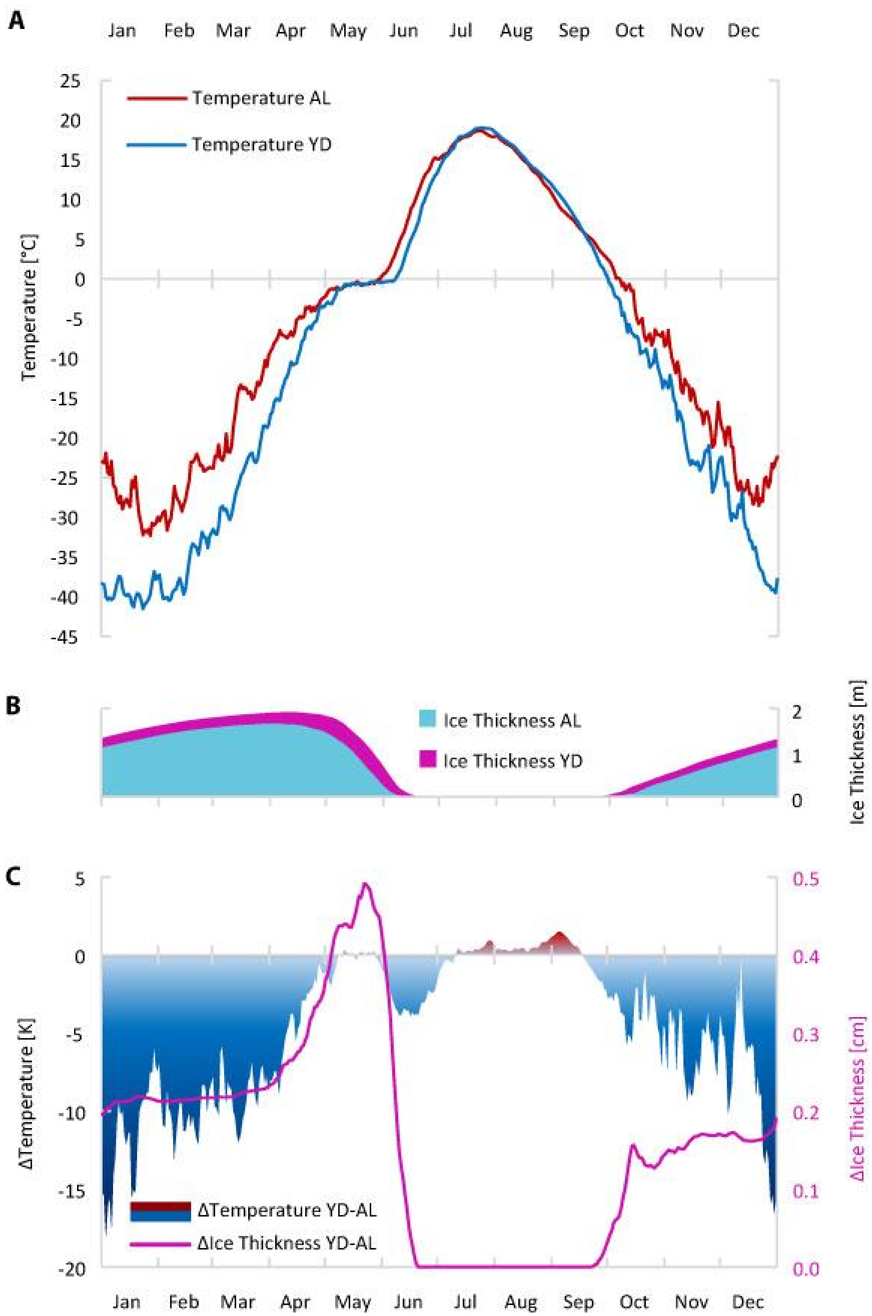
Δforcing



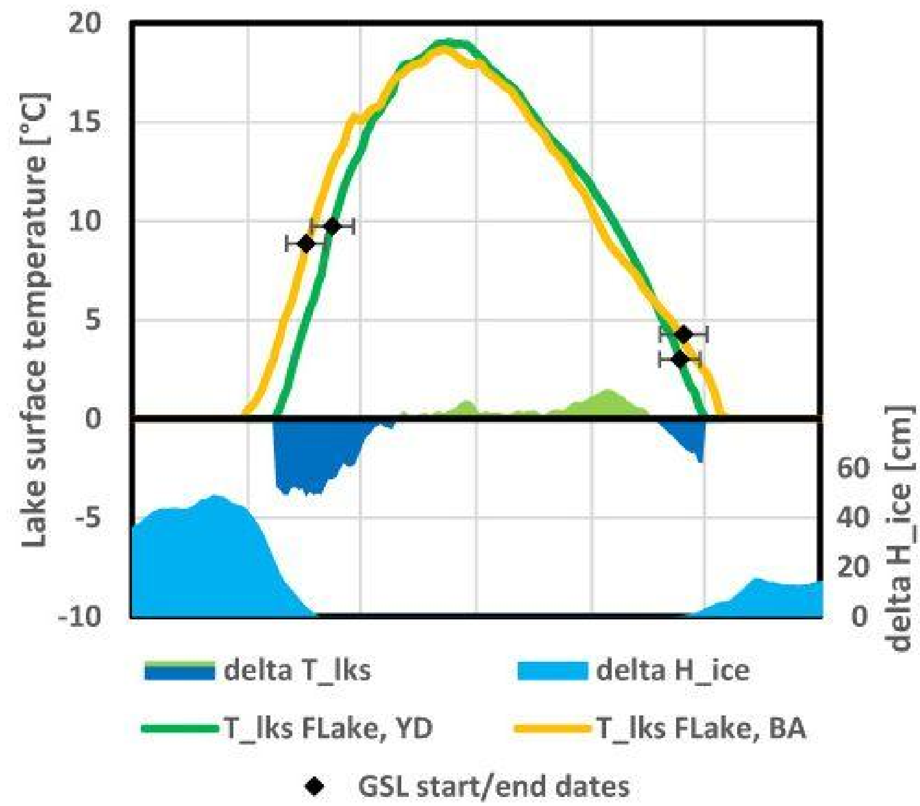
ΔT cycle NW-Europe
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC



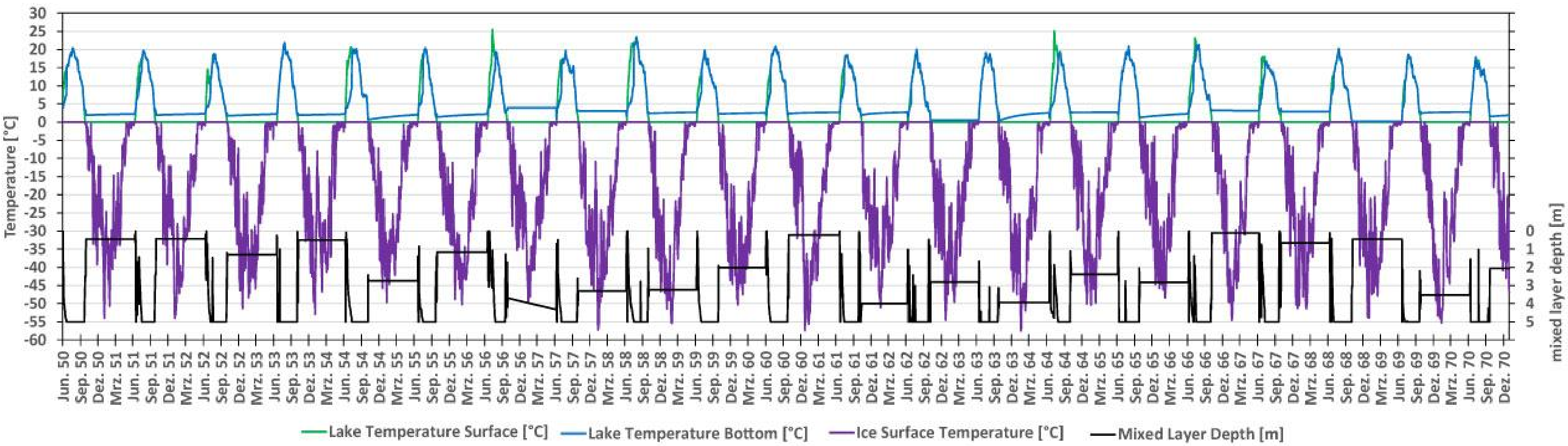
Δshort wave radiation [W/m²]
Δcloud cover [fraction]
35
30
25
20
15
10
5
0
-35%
-30%
-25%
-20%
-15%
-10%
-5%
0%
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
ΔFSDS
ΔCLDTOT



Hässeldala simulation



Hässeldala during the Younger Dryas

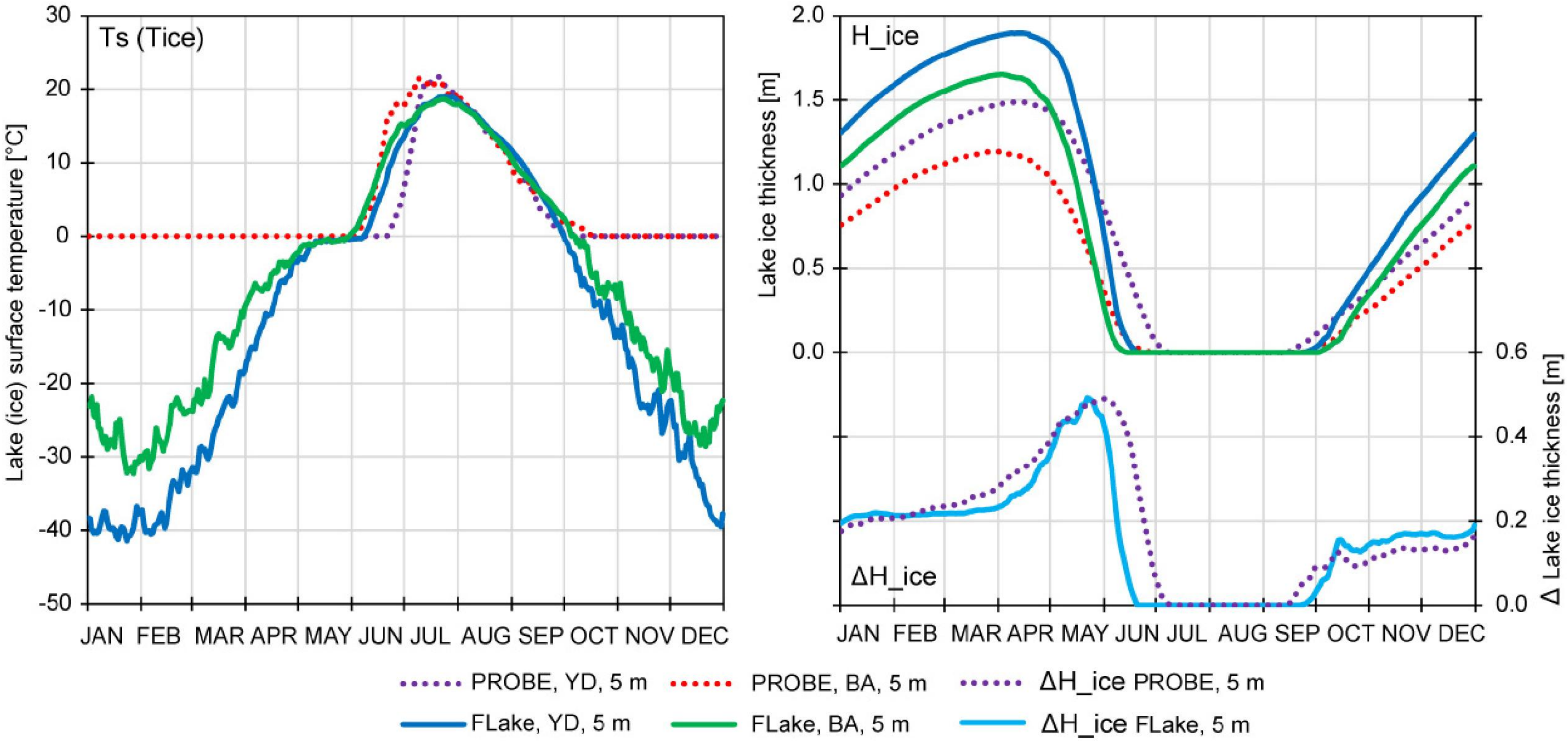


5. Discussion

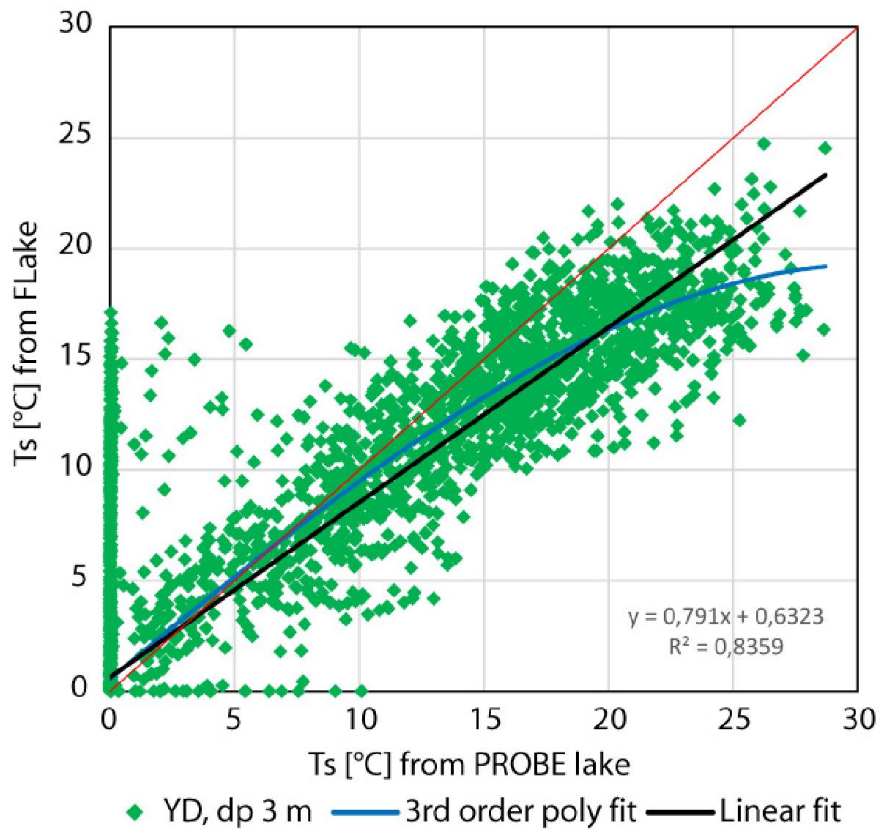
Lake model comparison &

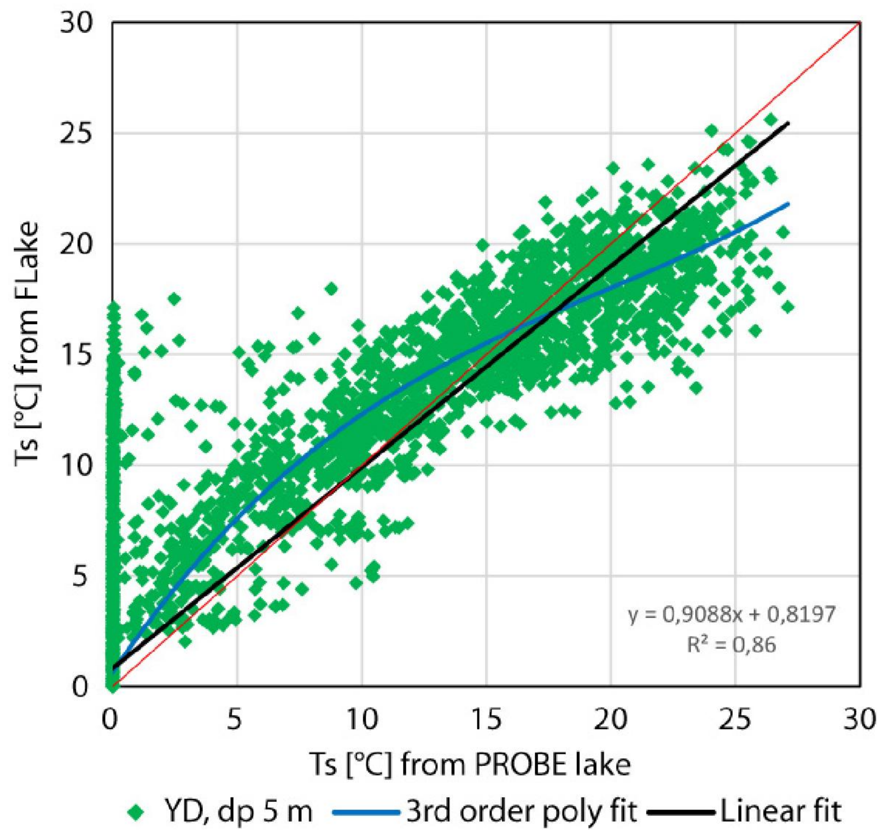
Role of stratification/depth for ΔT

Comparison FLake vs. PROBE for Ts

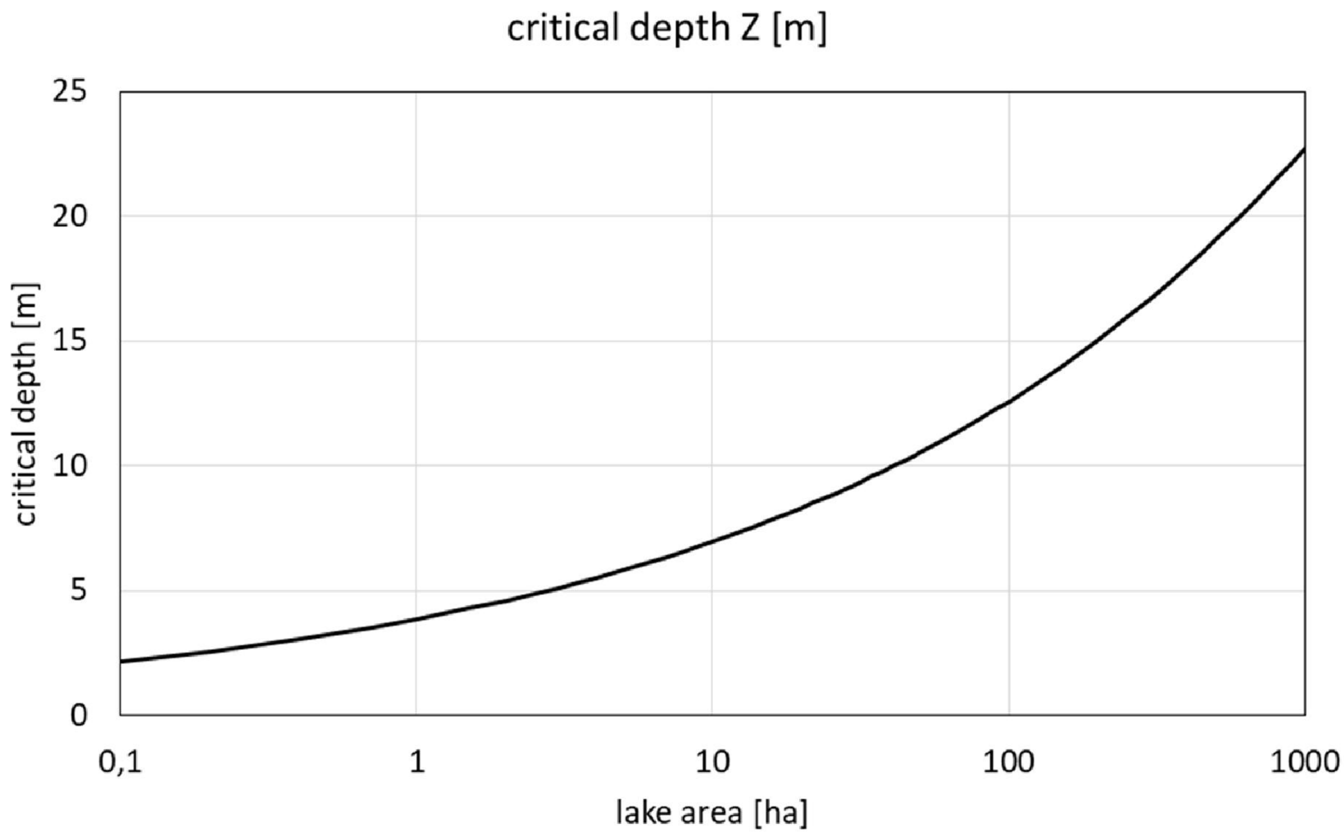


Comparison FLake vs. PROBE for Ts



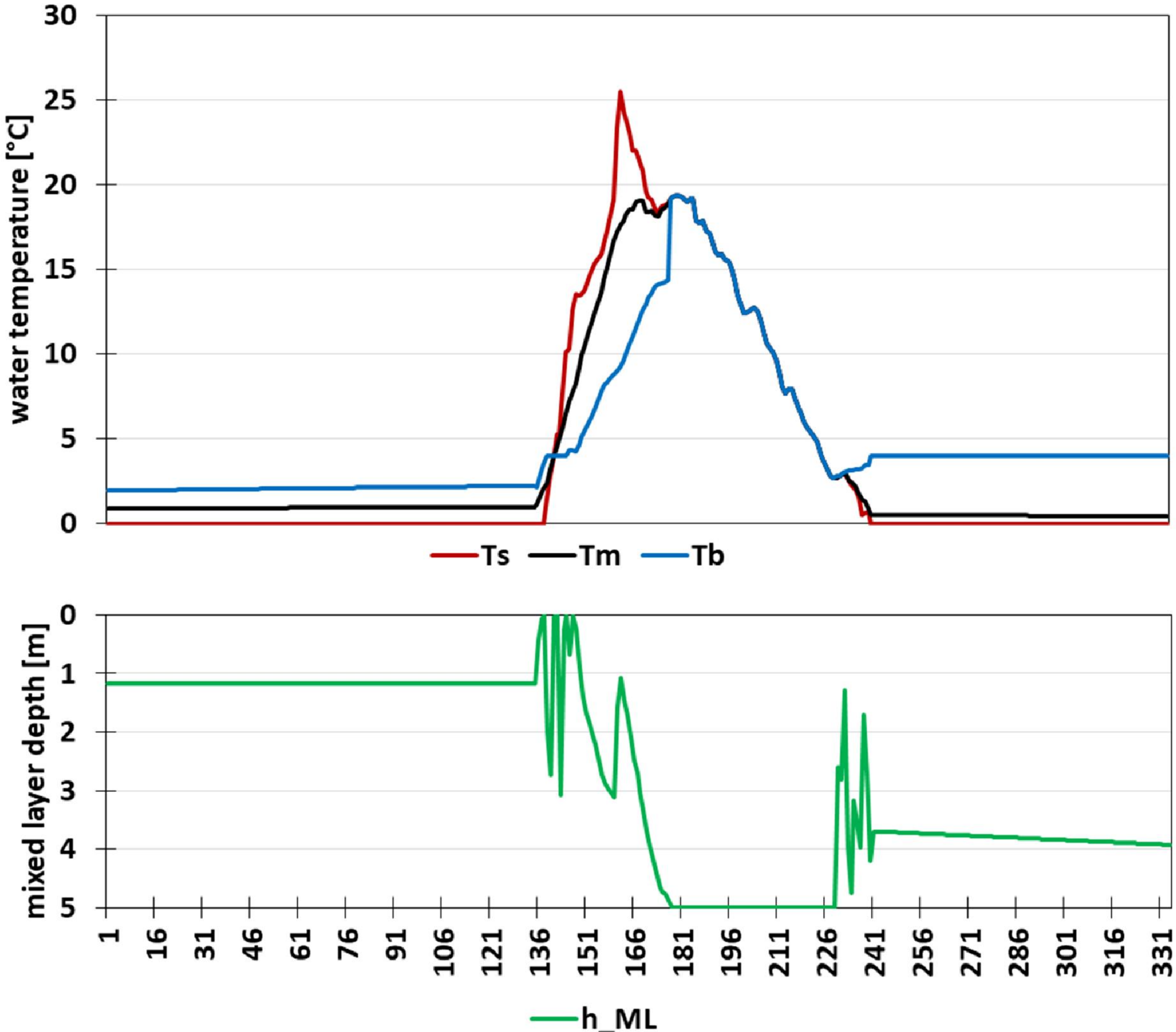


The role of stratification (small lakes)



Larsen & MacDonald (1993): $Z_{critical}$ [m] = 3.85 x $A^{0.257}$ [ha]

The role of stratification (ΔT_{Summer})



&LAKE_PARAMS
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fetch_lk = 4.0E+03
sediments_on = .TRUE.
depth_bs_lk = 5.0
T_bs_lk = 1.79
latitude_lk = 55.0

extincoef_optic = 0.3

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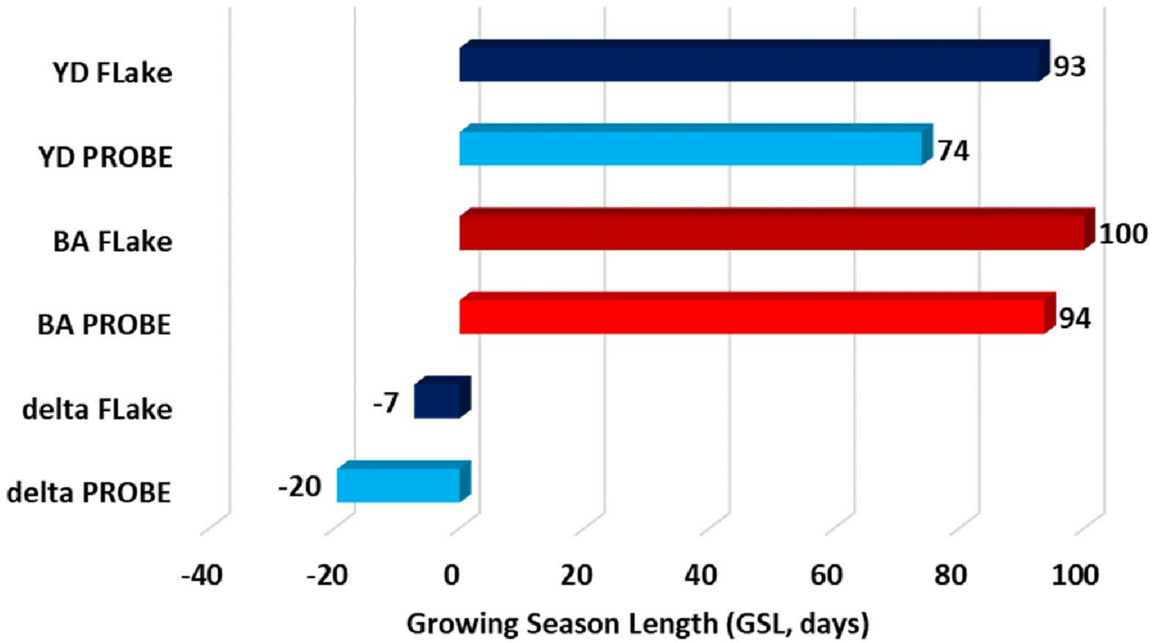
Implications for Δlake conditions

- PROBE: longer ice season, rapid warming, 3-5 K warmer
  → very short growing seasons but warmer summers
- FLake: ~2 weeks longer ice cover, small ΔT_{summer}
  → no stratification yields better agreement with proxies



Conclusion

- **H_0**: Younger Dryas consistent with **ΔAMOC-only** ☺

- **Lake model confirms: proxy data from lakes for T_{July}**
  - cold anomalies (chironomids) = cold spring / Δseasonality
  - warm summers (plant indicators) ~ CESM1 = air temperature

- **Large uncertainties → lake model dependent**
  - stratification/depth sensitivity
  - ice season length
  - meta information for paleo lakes needed
  - **multi-model ensemble needed**