Variance based sensitivity analysis of FLake lake model for global land surface modeling

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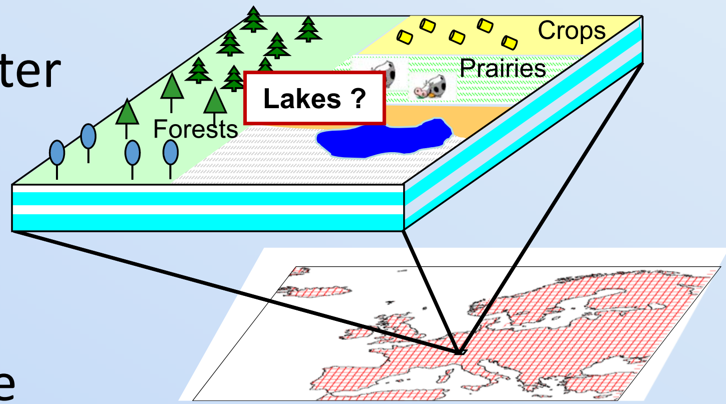
Motivation:



Representation of lakes in ORCHIDEE-LMDZ climate model to better understand/predict the interactions lakes/climate

New processes require separate energy/water budgets

→ implementation of a lake tile in ORCHIDEE grid

→ use of FLake model (Mironov, 2008) to calculate energy balance (surface temperature and fluxes)

<u>Questions relative to the representation at global scale</u>:

How to characterize lake fraction in a grid cell (size ranging between 20 and 200 km) ?

What is the spatial variability of lake parameters and how it influences energy budgets?

What could be the contribution of SWOT and how should we assimilate the data?

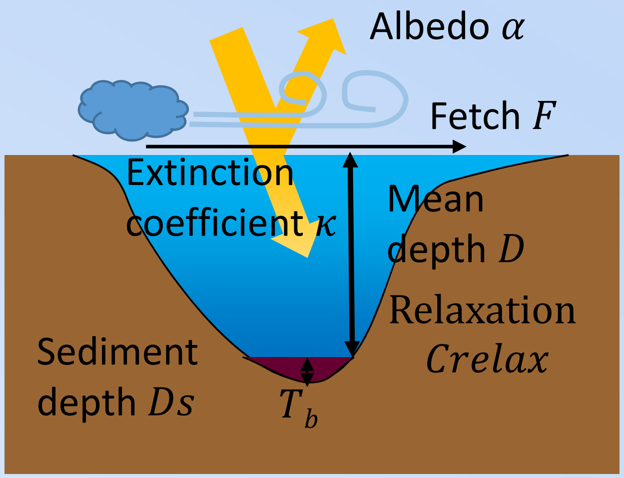
Method:

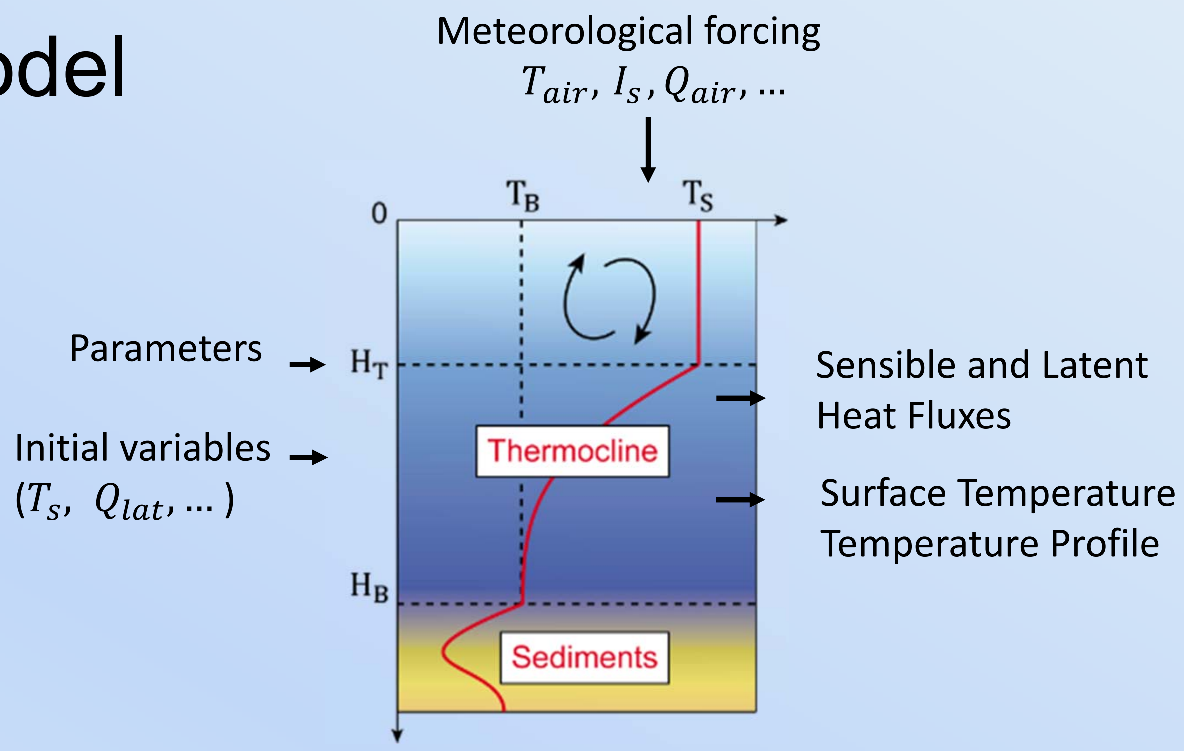
- Characterisation of spatial/temporal variability of lake features and related model parameters
- Sensitivity analysis of the lake model given these variabilities (parameter ranges of variation) for the dominant lake types/climates at global scale

Tools:

- Lake databases of area, depth, water level, radiative properties
- Variance-based methodology to analyze and rank the model parameter sensitivities

Flake model





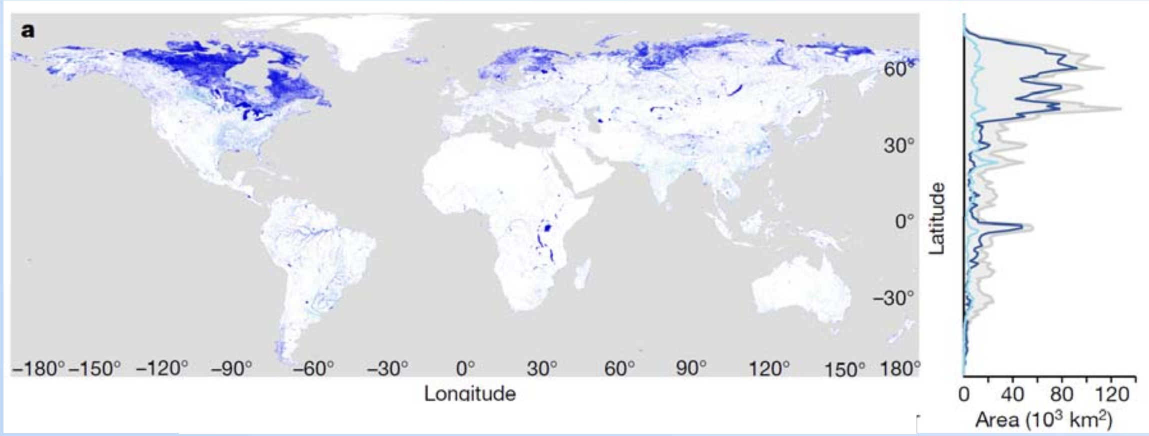
7 parameters: depth, albedo, extinction coeff., fetch, relaxation coeff., sediment layer depth and bottom temperature

- Constant in standard configuration
- Estimation of sources of uncertainties partly linked to seasonal variations

Dominant lake features at global scale

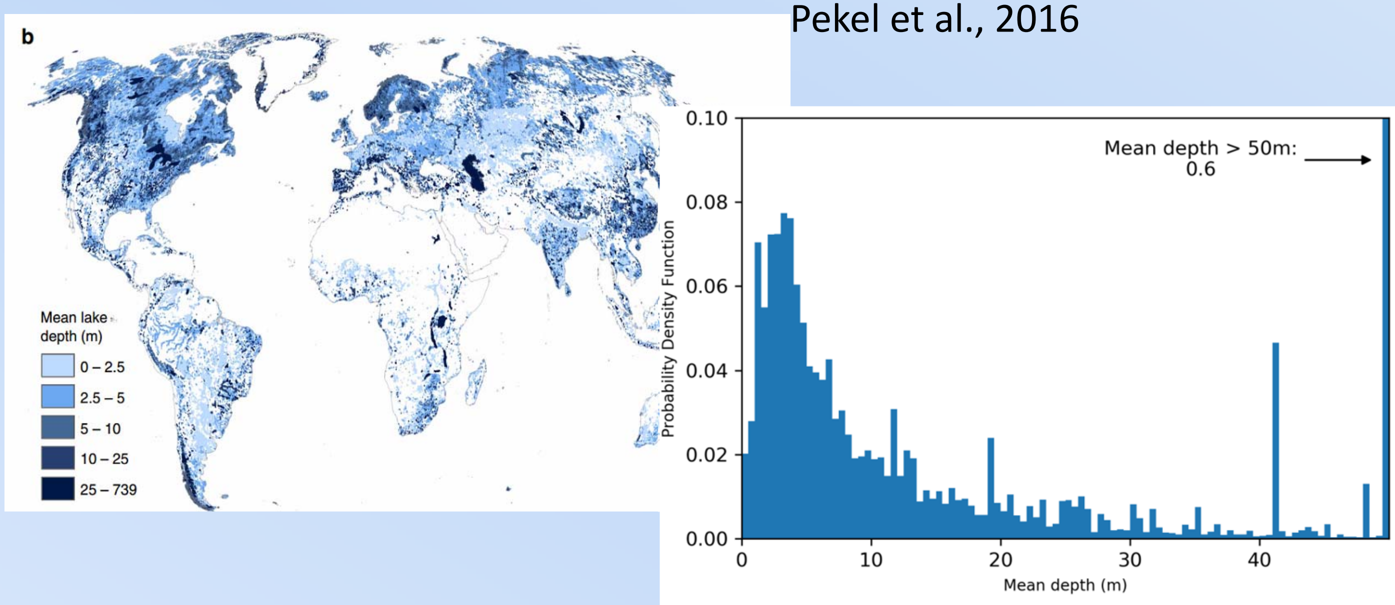
- Identification of 3 main types:
  Shallow (5m), Deep (50m) ,
  Intermediate (20m)

and 3 climates: Boreal, Temperate,
  Tropical



Pekel et al., 2016

Hydroweb, Crétaux et al., 2011



HydroLakes, Messager et al., 2016

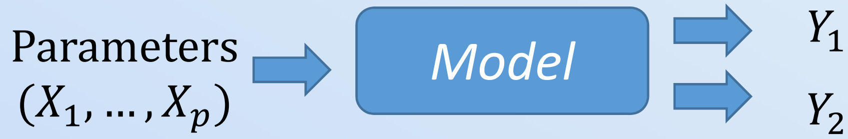
Parameter ranges of variation

- 4 lake configurations: shallow (with ou without sediments), deep and intermediate
- 3 climates (meteo extracted from WFDEI reanalysis): Boreal, Temperate, Tropical

Parameter	Range of variation				Source
	Sediment	Shallow	Intermediate	Deep	
Depth (m)	0.5 - 5.5	0.5 - 5.5	22.5 - 27.5	47.5 - 52.5	Hydroweb
Fetch (m)	0 - 1300	0 - 1300	0 - 10600	0 - 26600	HydroLakes
Albedo α	0.025 - 0.175				*McMahon, Moore (2017)*
Extinction κ	0.225 - 2.435				ILEC *(2005)*
C_{relax}	10^{-2} - 10^{-5}				*Mironov (2019), Layden (2016)*
Sediment T_b (K)	Boreal: 271.2 - 273.2				WFDEI, *Weedon (2014)*
	Temperate: 282.7 - 284.1				
	Tropical: 295 - 296.8				
D_s (m)	3 - 10				*www.igb-berlin.de*

Model parameters Sensitivity Analysis

- Based on Variance decomposition



$$Y_1 = f(X_1, \dots, X_p)$$

$$Y_2 = g(X_1, \dots, X_p)$$

Total variances of output variables are decomposed into component variances caused by each parameter and its interactions with the others

Sobol indices:

First order: Fraction of the variance explained by parameter *i*

$$\boldsymbol{S_i = \frac{V_i}{Var(Y_1)}}$$

Total effect: Fraction of the variance explained by parameter *i* and all the interactions with the other parameters

$$\boldsymbol{S_{T_i} = 1 - \frac{Var\big(E(Y_1|X_{\sim i})\big)}{Var(Y_1)}}$$

$S_i \sim 1$: Very influential parameter

$S_i \sim 0$: Not influential

$S_i \sim S_{T_i}$: Independant parameter

Model Sensitivity Analysis

- Sobol indices calculated at daily timescale: allow to identify the time variability of parameter sensitivities and dependencies linked to variability of dominant processes

- Generalized Sobol indices calculated on temporal series (annual time scale)

$$GS_i = \sum_t \frac{Var(Y_1(t))}{\sum_{t_1} Var(Y_1(t_1))} S_i(t)$$

$$GST_i = \sum_t \frac{Var(Y_1(t))}{\sum_{t_1} Var(Y_1(t_1))} S_{T_i}(t)$$

- Application on Flake model: Experimental design
  - 12 cases (4 lake types, 3 climates, 5 years time series)
  - Pseudo Monte Carlo sampling of the parameter space: 4000 simulations/case
  - Sobol analysis on surface temperature and turbulent fluxes (heat and water)

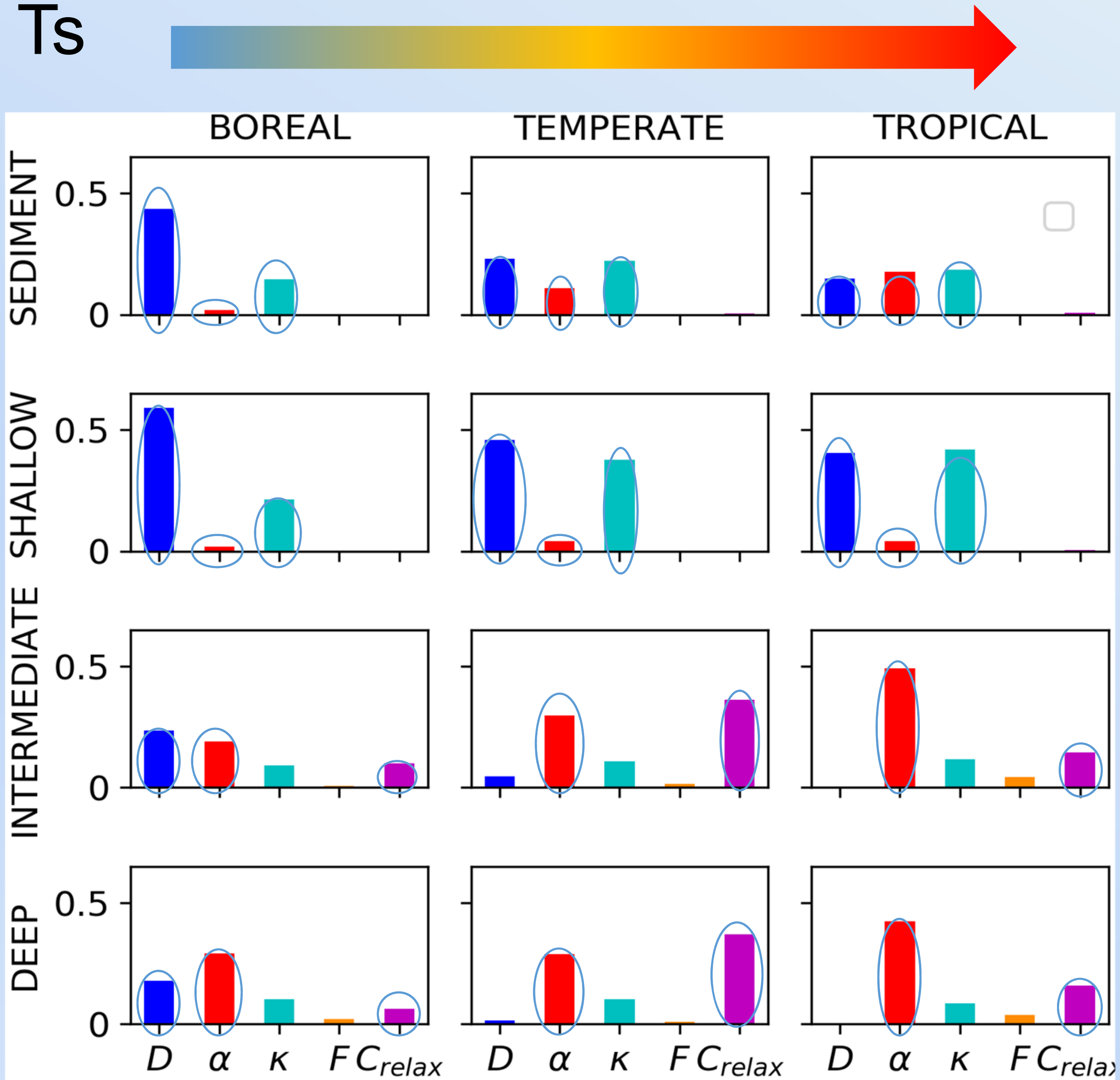
Generalized Sobol indices on Ts (annual scale)

- Few differences between 1st order and Total order indices : few parameter interactions

- Two different responses from shallow and deep lakes:
  - Shallow: T_s sensitive to D and κ
  - Deep: T_s sensitive to α and C_{relax}

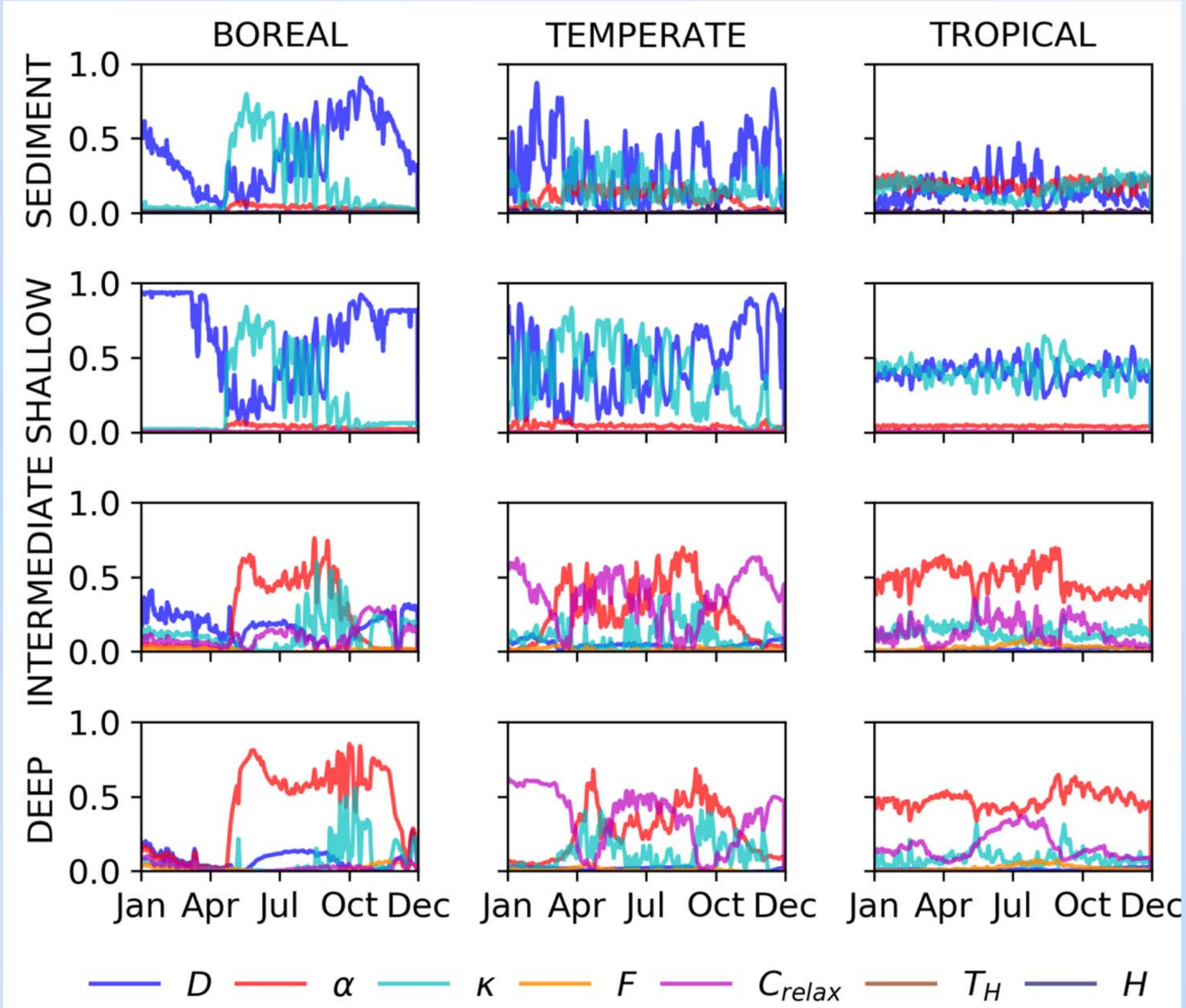
- Sensitivity to surface albedo α increase with depth and incoming radiation

- Activation sediment layer
  => α more sensitive



Generalized Sobol first order indices measure T_s sensitivity to each parameter during one year

Sobol first order indices on Ts (daily timestep)



- Larger influence of radiative properties (extinction or albedo)/depth in summer/winter
- Impact of the relaxation coefficient in temperature stratification periods, larger for temperate lakes
- Very low influence of Fetch and sediment parameters

Conclusions

Results of Flake sensitivity analysis on surface temperature and fluxes:

- **Depth** D and **Extinction coefficient** κ are dominant parameters for **shallow lakes**
- **Albedo** α and **Relaxation coefficient** C_{relax} dominant for **deeper lakes**
- Relative **importance of depth/radiative** parameters vary with incoming radiative forcing (the larger the radiation, the larger the weight of albedo/extinction coefficient parameters)
- Relative **importance of albedo/extinction** coefficients, vary with degree of lake stratification
- **Shallow lakes** in **cold climates/seasons** will benefit from **frequent depth control**

  - ✓ **SA results** will help in the future works:
    - ✓ **Lake representation** in the grid cell (**differentiation** of **shallow and deep lakes**)
    - ✓ **DA strategy (parameter choice and time periods** used in the **optimization process)**

  - ✓ **Limits:** results **concerned only lake energy budget** monitoring

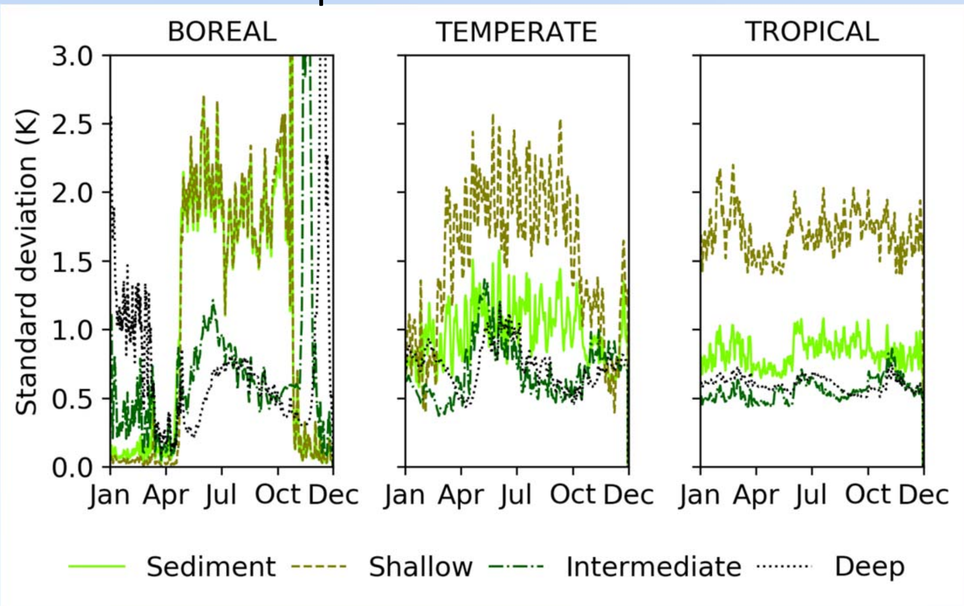
Perspectives:

- Work in progress on the **modeling of mass balance**
- New model **sensitivity analysis** needed to drive the use of **SWOT** for calibration of **lake depth and evaporation/inflow/outflow** processes.

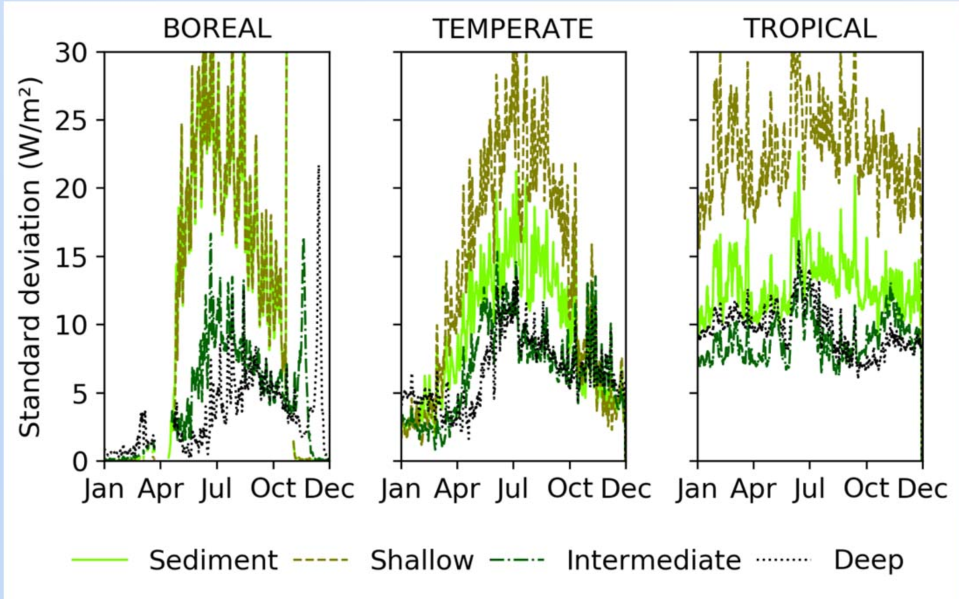
Thanks for your attention !

Results: Temperature and Latent Heat variances

Temperature Total Variance



Latent Heat Flux Total Variance



Same features for both variables: variances larger for shallow lakes/deeper ones:

- larger in summer/winter

- Around 2K for Ts , up to 30W/m^2 for LE