Third Workshop on
Parameterization of Lakes in Numerical
Weather Prediction and Climate Modelling
Finnish Meteorological Insitute, Helsinki,
September 18-20 2012

An intercomparison model study of Lake Valkea-Kotinen

(in a framework of LakeMIP)

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Outline

- Study motivation
- Site description
- Measurements
- Models
- Model experiment setup
- Surface temperature
- Surface energy fluxes
- Stratification
- Model sensitivity study
- Outlook

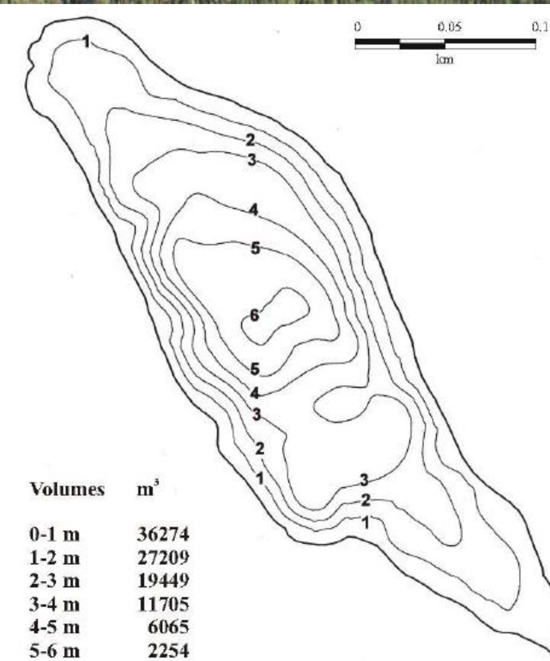
Motivation

- Valkea-Kotinen is a «very small» lake representative of numerous lakes in high latitudes;
- Due to small size (1) “edge-effects” might be important → 1D-assumption may fail and (2) surface flux schemes be inappropriate (inhomogeneity in horizontal);
- The lake is well instrumented (Nordbo et al. 2011)

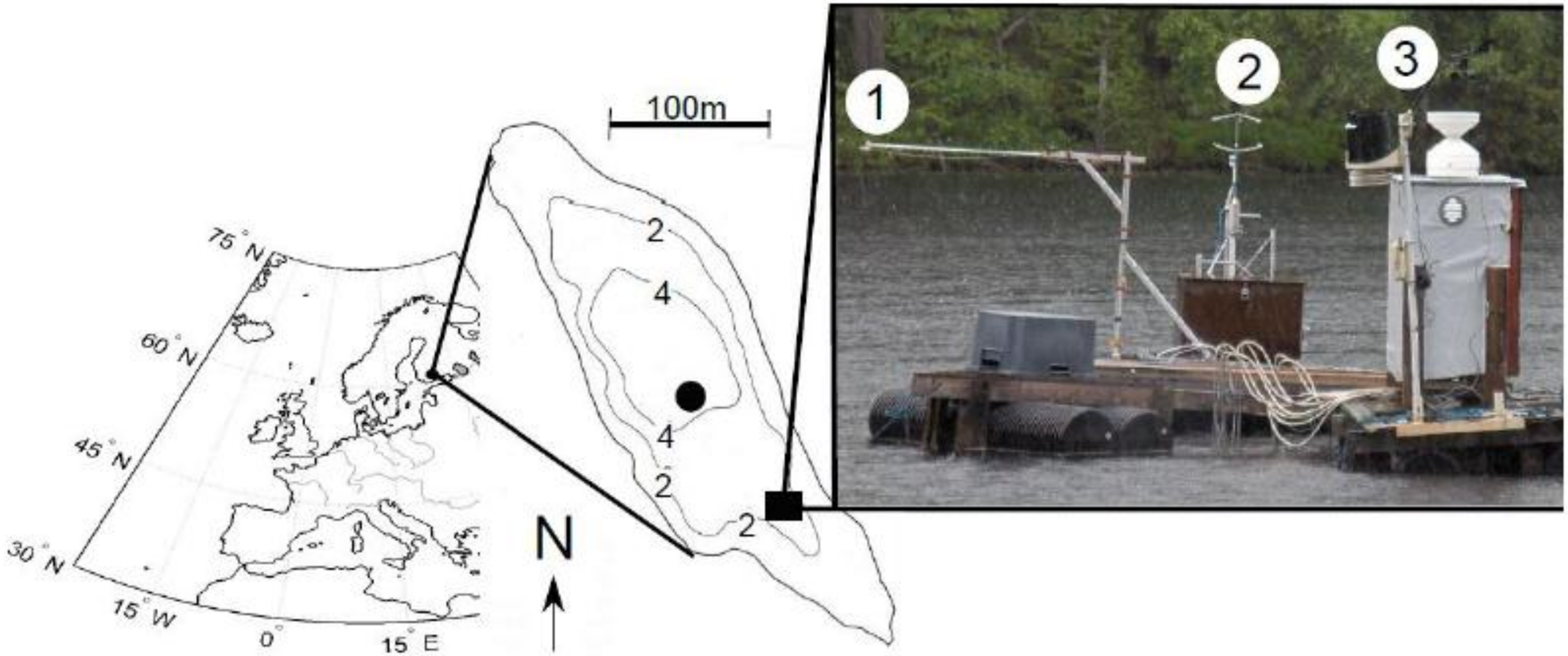
Lake characteristics

Variable	Value
Mean depth	3 m
Maximal depth	6 m
Area	0.041 km^2
Beam attenuation coefficient	6.3 m^{-1}
Diffuse attenuation coefficient	3.1 m^{-1}
Secchi depth	1 m
Altitiude	156 m
Ice-out	2 May
Freeze-up	22 December

Valkea-Kotinen bathymetry - uniform slopes



Measurements
(carried out by University of Helsinki)



- Conventional meteorology: ① Ta, Ts, p, q, wind, precipitation, shortwave radiation, ② net radiation – at 1.5 m
- Eddy covariance: ③ sensible, latent heat and momentum fluxes, ~65% of missing data due to footprint limitations
- Timespan 2 May – 31 December 2006
- Hourly temporal resolution

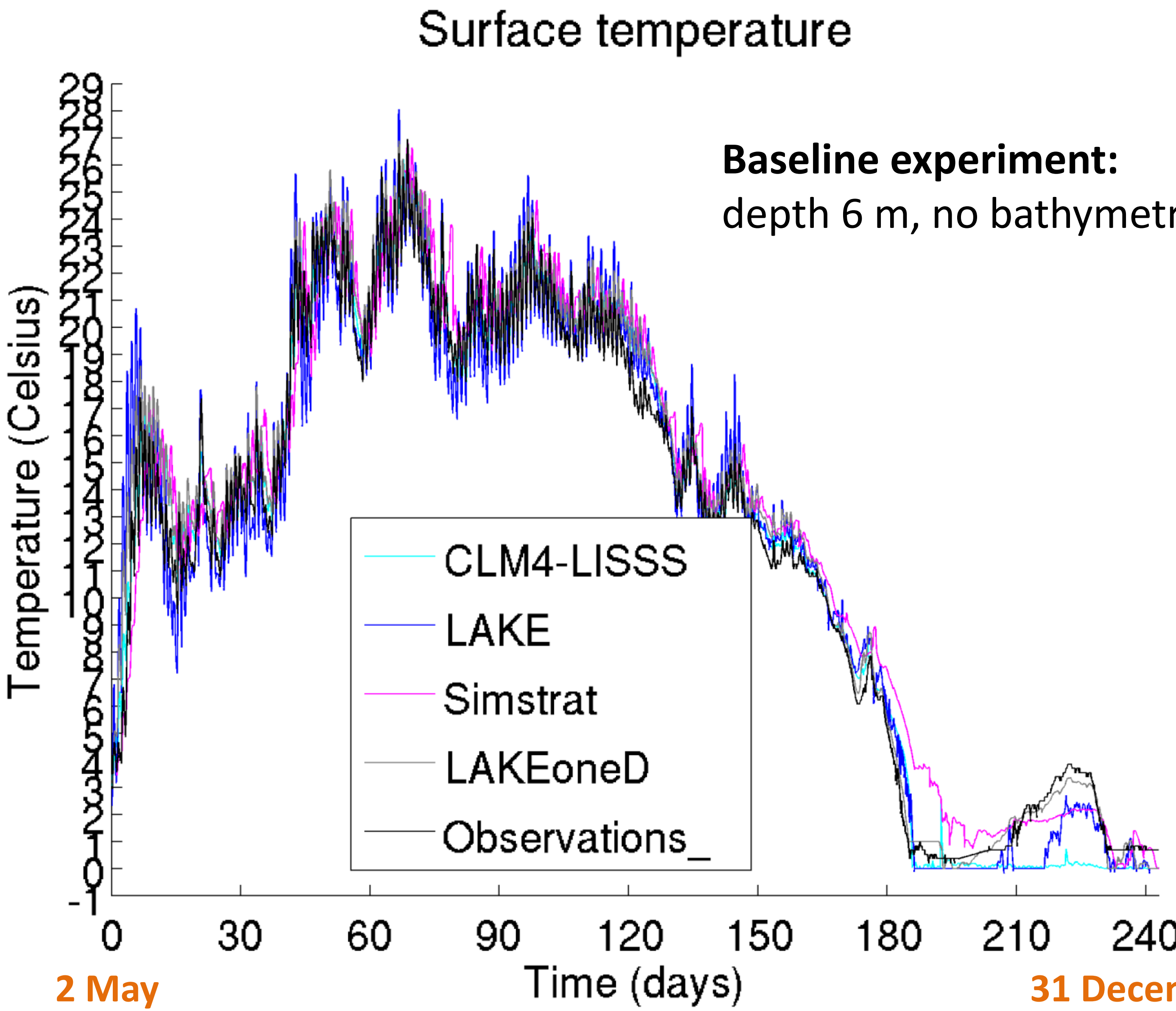
Lake models

Lake model, major publications	Parameterization of turbulent fluxes at the lake-atmosphere interface	Turbulent mixing parameterization	Treatment of bottom heat flux
CLM4-LISSS, *Hostetler and Bartlein 1990, Subin et al. 2011, Oleson et al. 2010*	**An extended scheme from CLM4 model** *(Oleson et al. 2010; Subin et al. 2011)*	**Henderson-Sellers eddy diffusivity, buoyant convection** *(Hostetler and Bartlein 1990)*	**Heat conductance in bottom sediments**
LAKE, *Stepanenko et al. 2011*	**Monin-Oboukhov similarity theory with Businger interpolation formulas** *(Paulson 1970; Beljaars and Holtslag 1991; Large et al. 1994)*	**K-ε with Canuto stability functions**	**Heat conductance in bottom sediments**
SimStrat, *Goudsmit et al. 2002, Perroud et al. 2009*	**Empirical equations** *(Livingston and Imboden 1989; Kuhn 1978; Dingman et al. 1968)*	**K-ε with Galperin stability functions**	**Zero heat flux**
LAKEoneD, *Jöhnk and Umlauf 2001, Jöhnk et al. 2008*	***Rodi, 1993***	**K-ε with standard coefficients**	**Zero heat flux**

Model experiment setup

- **Meteorological forcing**: air temperature, humidity, pressure, wind, total solar radiation, atmospheric radiation, precipitation
- **Bottom heat flux** is set zero for models lacking soil treatment
- **Unified initial temperature profile**
- **Unified lake bathymetry** (no bathymetry and real bathymetry)
- **Unified external parameters**: albedo, emissivity, extinction coefficient, lake depth (maximal and average)
- **Surface flux schemes** are kept «native»
- **Simulation period** 2 May – 31 December 2006

Surface temperature

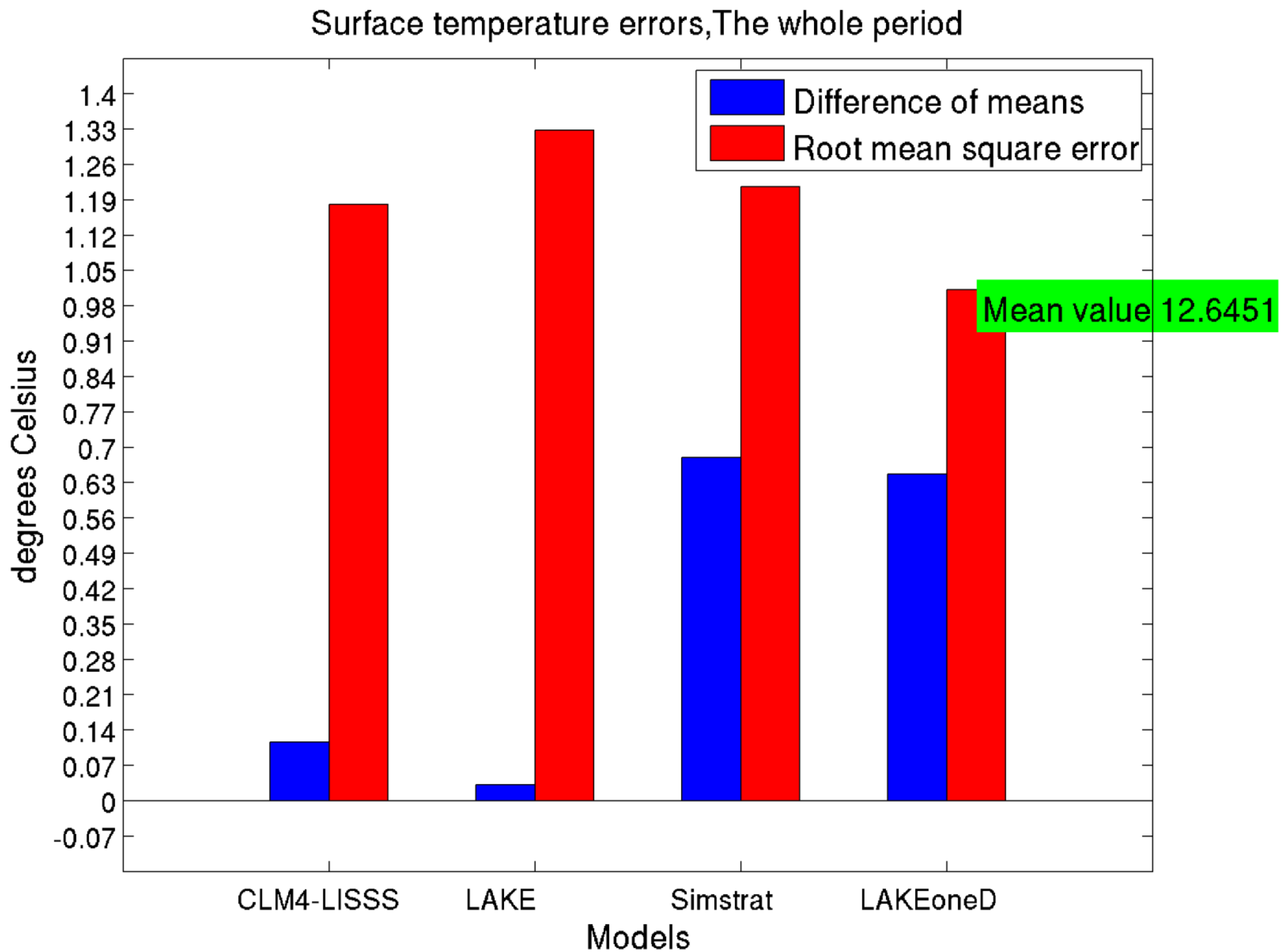


Baseline experiment:
depth 6 m, no bathymetry

2 May

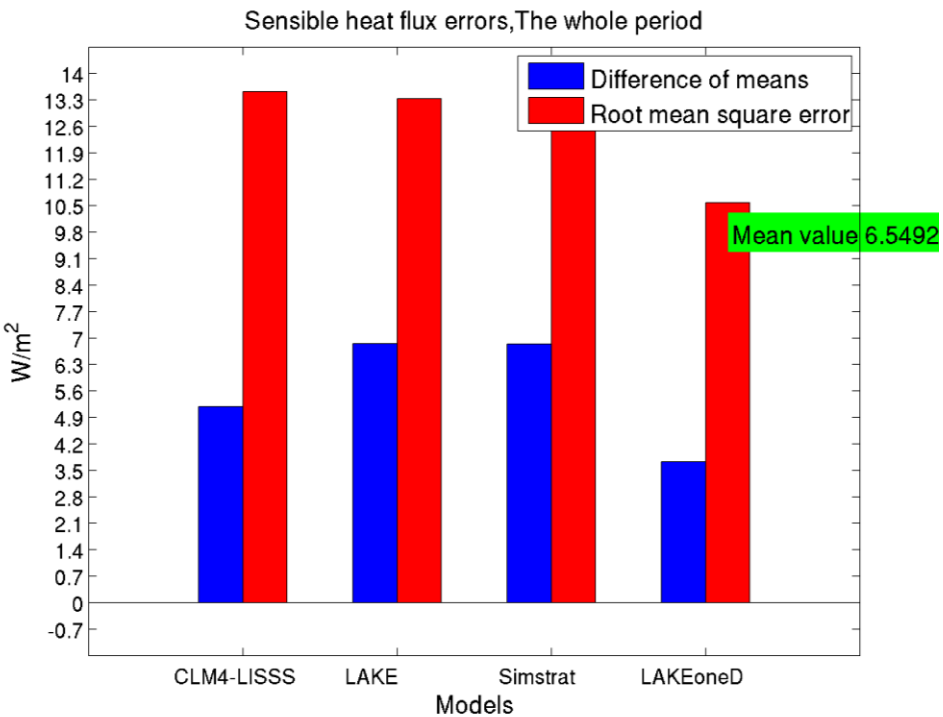
31 December

Surface temperature errors

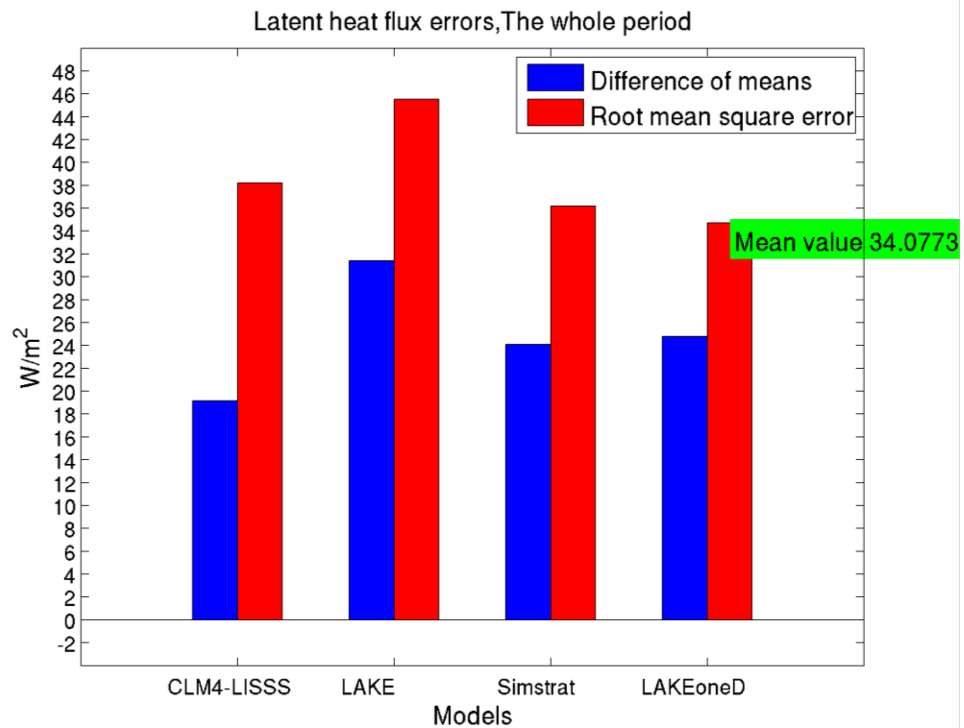


Surface fluxes

Sensible heat flux



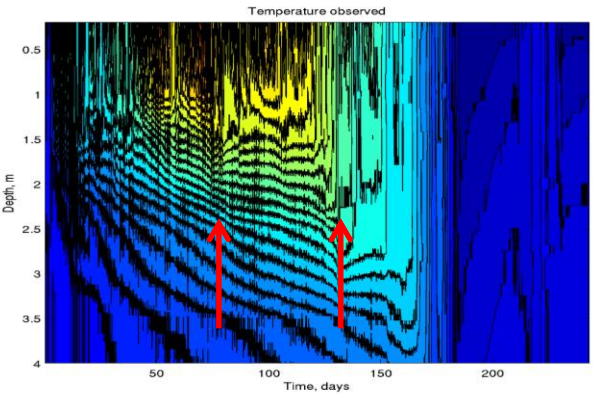
Latent heat flux



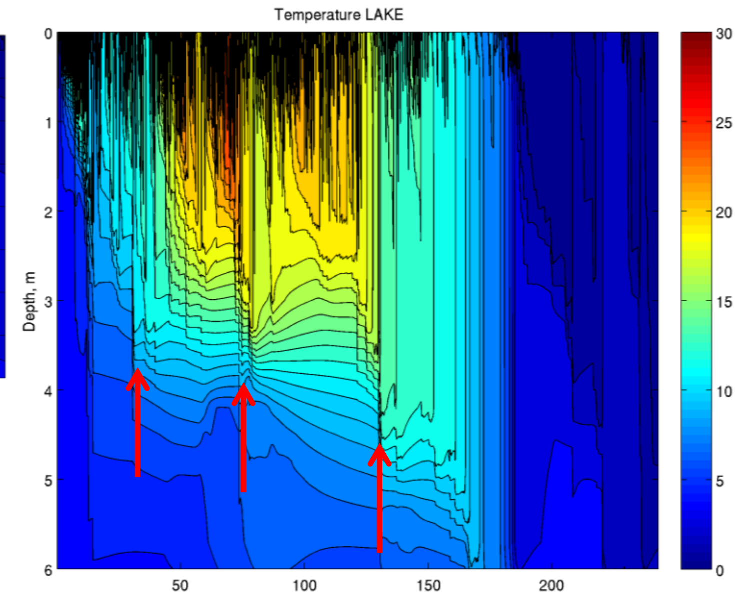
- Both sensible and latent heat fluxes are overestimated by **all models** compared to eddy covariance measurements (the mean difference **up to 100%** of the flux)
- Similar overestimation for **all models** was obtained in the previous LakeMIP study for Kossenblatter Lake (Germany)
- This is consistent with observational study (Nordbo et al. 2011) where EC fluxes did not allow to close the heat balance of Valkea-Kotinen

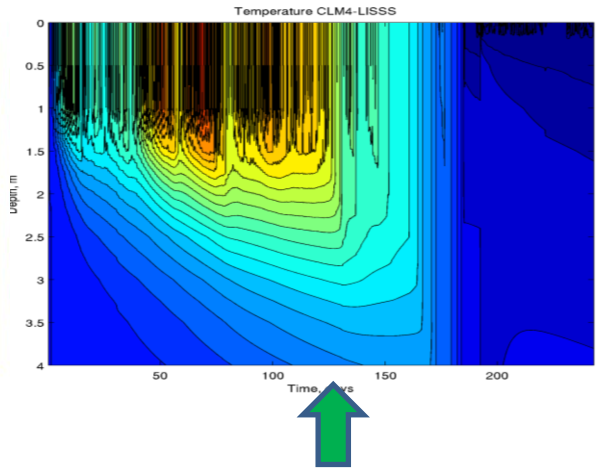
Stratification

Observed



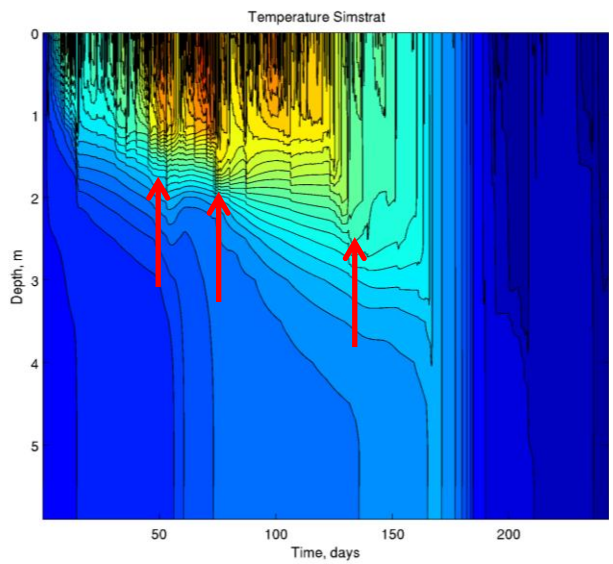
LAKE



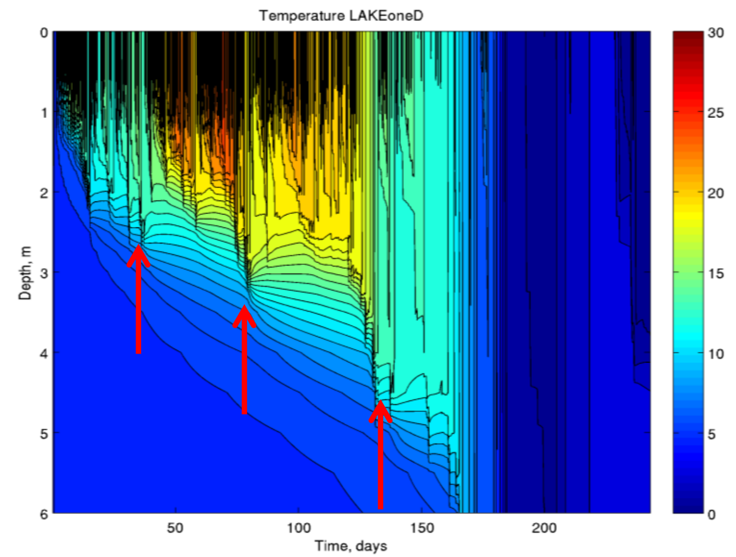


CLM4-LISSS

Simstrat



LAKEoneD

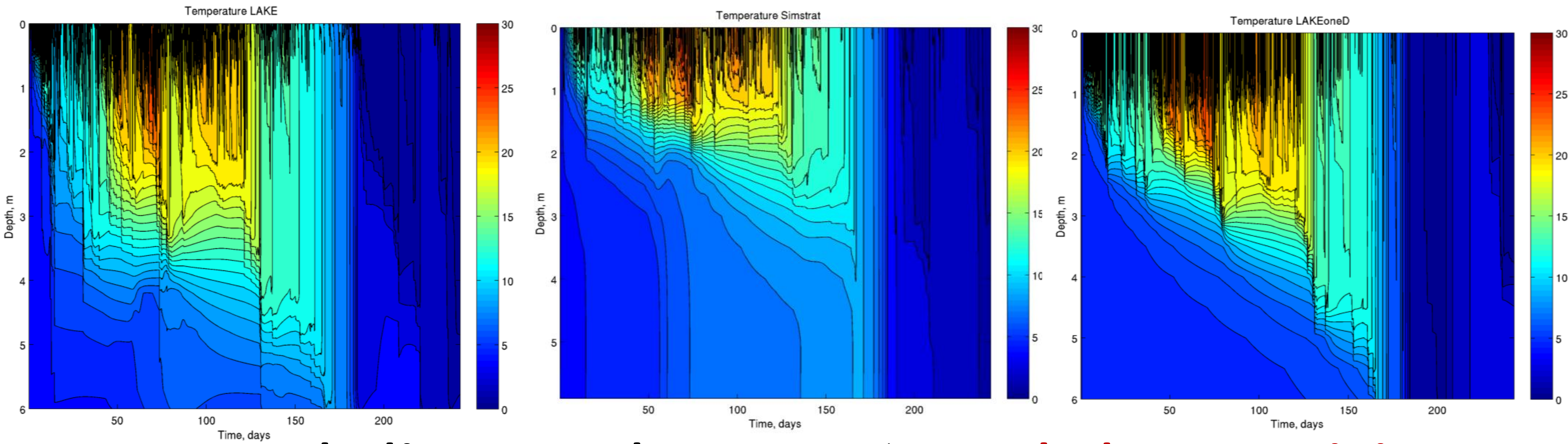


- Seasonal course of thermocline stratification is qualitatively well simulated by all models
- CLM4-LISSS produces more smooth temporal variability
- K-epsilon models produce similar temperature pattern, but LAKE and LAKEoneD overestimate thermocline depth

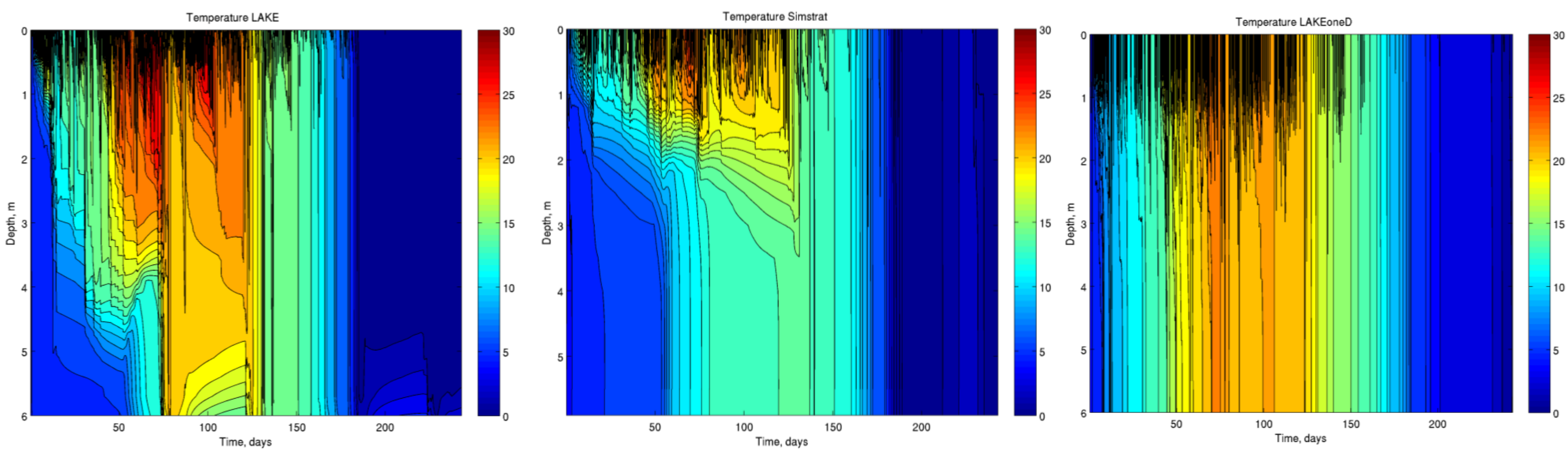
Stratification – effect of morphometry

LAKE **Simstrat** **LAKEoneD**

Single-column mode



Including morphometry → much deeper mixing



Morphometry effect

Averaging 3D temperature equation over horizontal cross-section yields 1D equation for

$$\tilde{T} = \frac{1}{A}\iint_A T dA$$

Temperature equation with morphometry

$$\frac{\partial \tilde{T}}{\partial t} = \frac{1}{A}\frac{\partial}{\partial z} A k_T \frac{\partial \tilde{T}}{\partial z} + F_{T_z}^b \frac{dA}{dz} - \frac{1}{\rho_0 c_p}\frac{\partial \tilde{S}}{\partial z}$$

Heat exchange with soil neglected in all models

$$\frac{\partial \tilde{T}}{\partial t} = \frac{\partial}{\partial z} k_T \frac{\partial \tilde{T}}{\partial z} + \frac{1}{A}\frac{dA}{dz} k_T \frac{\partial \tilde{T}}{\partial z} - \frac{1}{\rho_0 c_p}\frac{\partial \tilde{S}}{\partial z}$$

> 0 below well-mixed layer in summer!

Temperature equation in single-column mode

$$\frac{\partial \tilde{T}}{\partial t} = \frac{\partial}{\partial z} k_T \frac{\partial \tilde{T}}{\partial z} - \frac{1}{\rho_0 c_p}\frac{\partial \tilde{S}}{\partial z}$$

I. Including morphometry without heat exchange with soil results in extra heating below the well-mixed layer.

II. The measurement point is located in a deep part of lake where the waters are colder than horizontal average

Models tuning

↓

to fit the observed surface temperature

- In Simstrat surface exchange coefficient was tuned
- In LAKE "the best" surface flux scheme was chosen and further tuned

↓

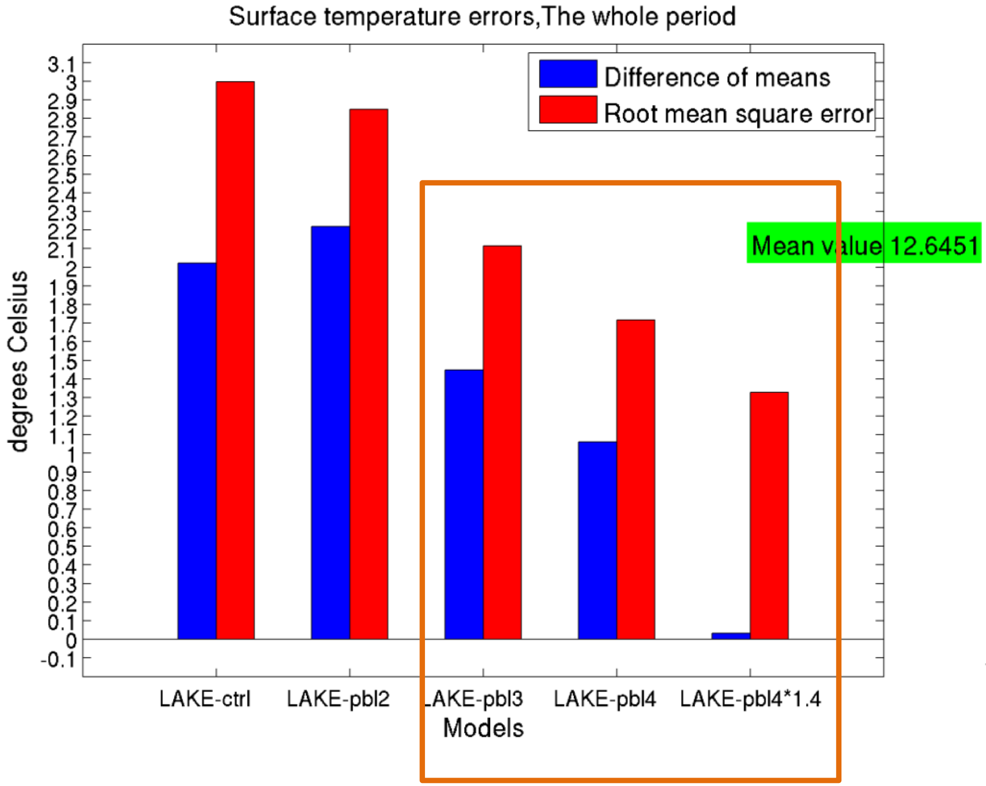
The information on **sensitivity of surface temperature and surface fluxes'** errors to different model parameters and parameterizations is important to identify **model features deserving further development and to provide guidance for model tuning**

Sensitivity study
(carried out with LAKE model as representative of k-epsilon 'family')

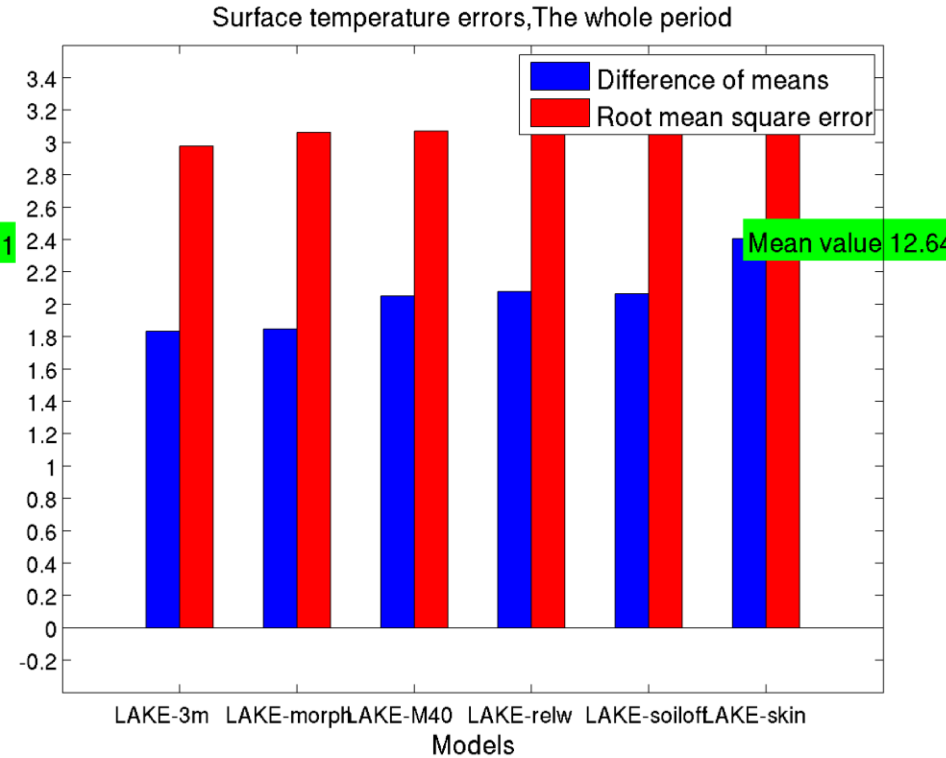
Parameter/parameterization	Control values	Alternative values
Lake depth	6 m (maximal depth)	3 m (mean depth)
Wind treated as relative to currents	OFF	ON
Cool skin parameterization	OFF	ON
Soil model	ON	OFF
Fetch-dependent roughness	OFF	ON
Surface flux schemes	Businger-Dyer	(1)Louis, (2)FLake, (3)Grachev
Morphometry	OFF	ON
Vertical resolution	20 layers	(1)10 layers, (2)40 layers
Stability functions in k-epsilon model	Canuto functions	(1)Galperin, (2)standard k-epsilon

Surface temperature sensitivity

Different surface schemes



Other parameterizations



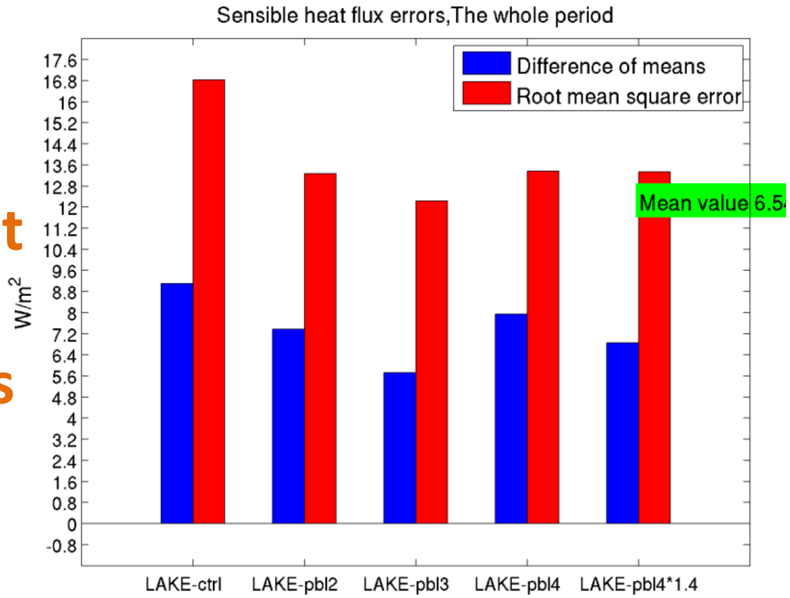
The largest sensitivity of surface temperature in terms of mean difference and RMSE is when using different surface flux schemes

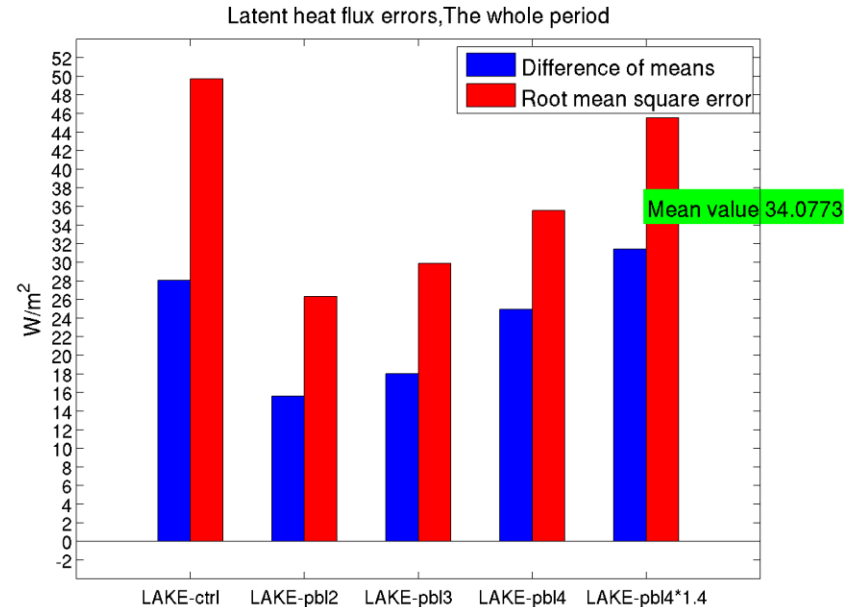
Heat fluxes sensitivity

Sensible heat flux

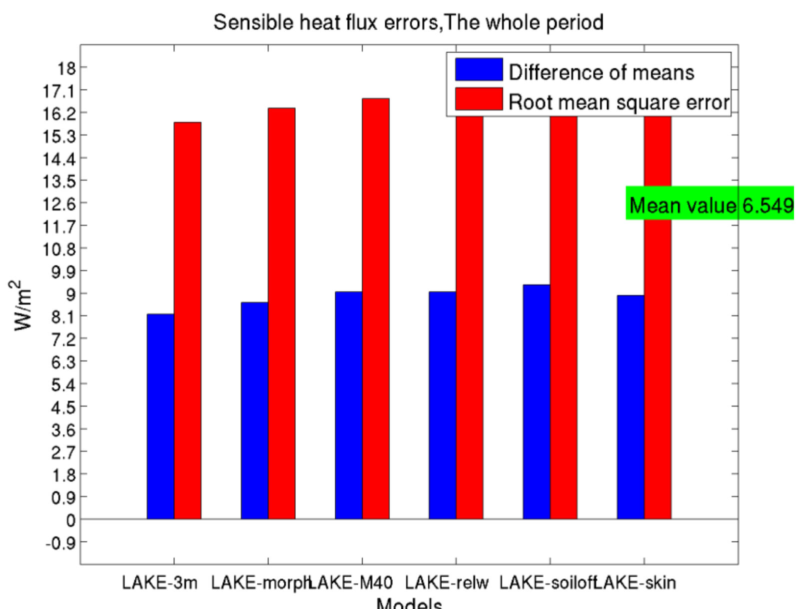
Latent heat flux

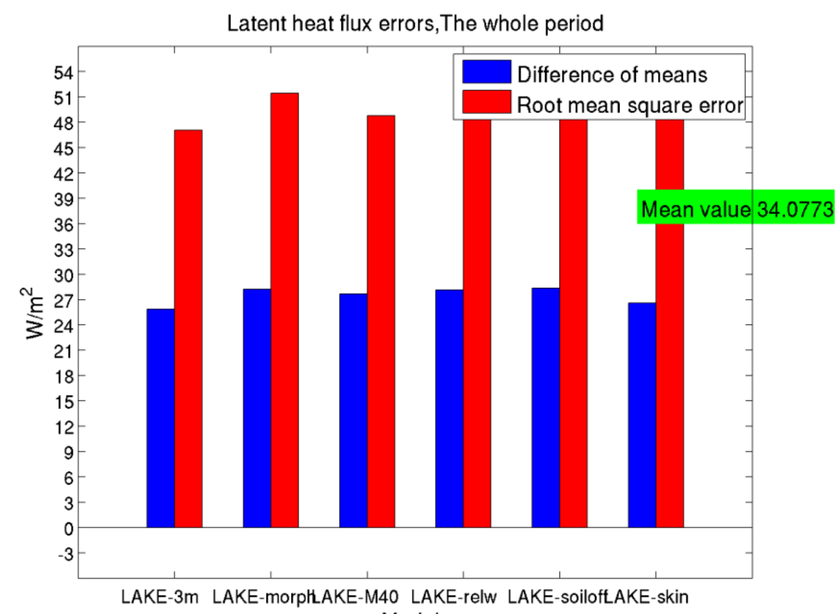
Different surface schemes





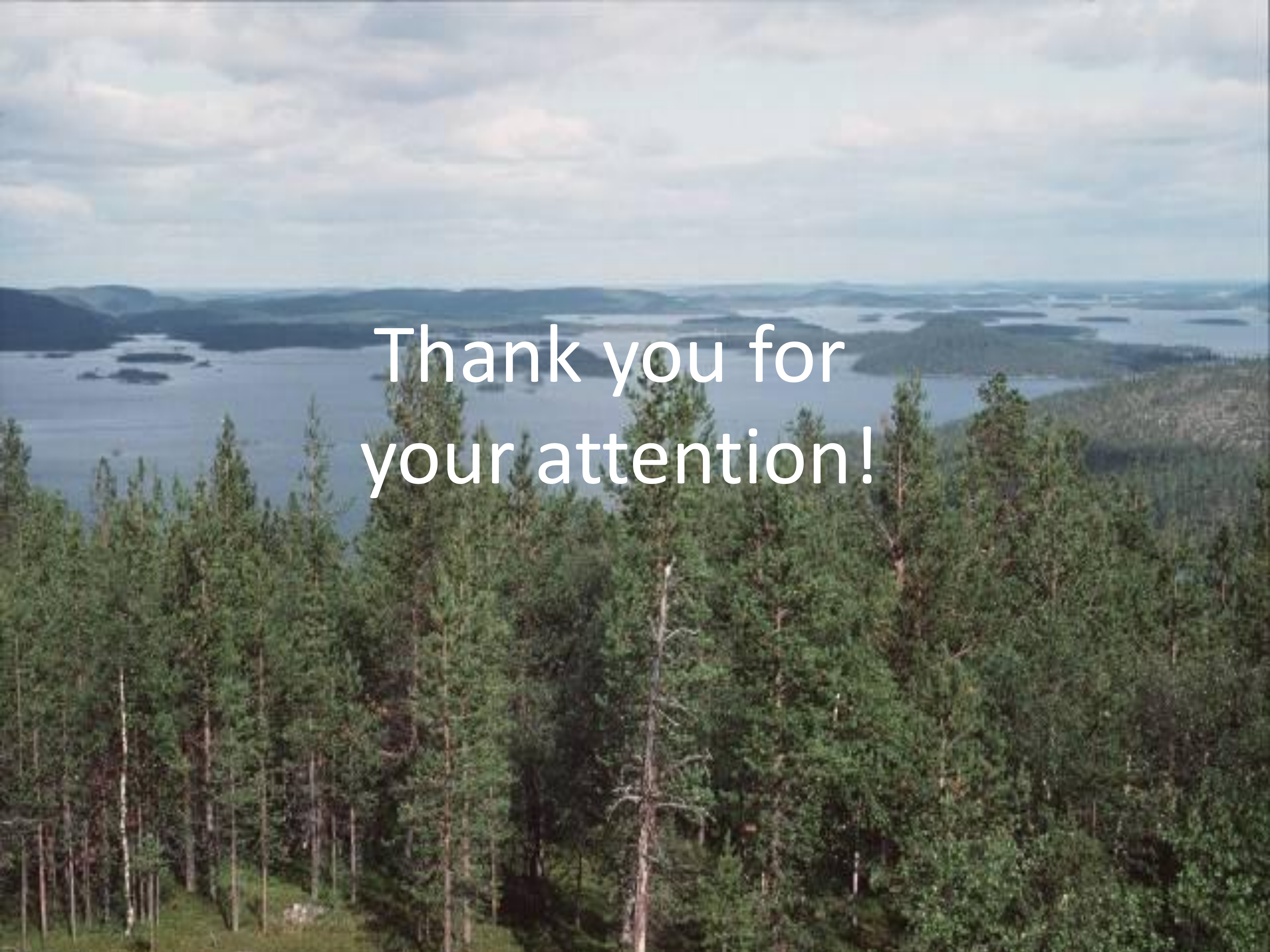
Other parameterizations





Conclusions and Outlook

- Models successfully simulated surface temperature, but in at least two models surface flux schemes were tuned, pointing at possible problems with surface layer parameterization;
- Models considerably overestimated eddy covariance sensible and heat fluxes and underestimated the momentum flux (not shown), consistent with other studies;
- Including morphometry in 1D lake models results in extra mixing below thermocline that is likely due to omitting edge heat exchange effects and is not representative for lake's deep part;
- Surface flux scheme is the main factor of surface temperature model error (if radiation fluxes and optical properties are known)


Thank you for
your attention!