Lake response to climate variability: modelling aspects

Georgiy Kirillin, Sergey Golosov

Institute for Freshwater Ecology and
Inland Fisheries, Berlin

IGB

Lake response to climate variability:

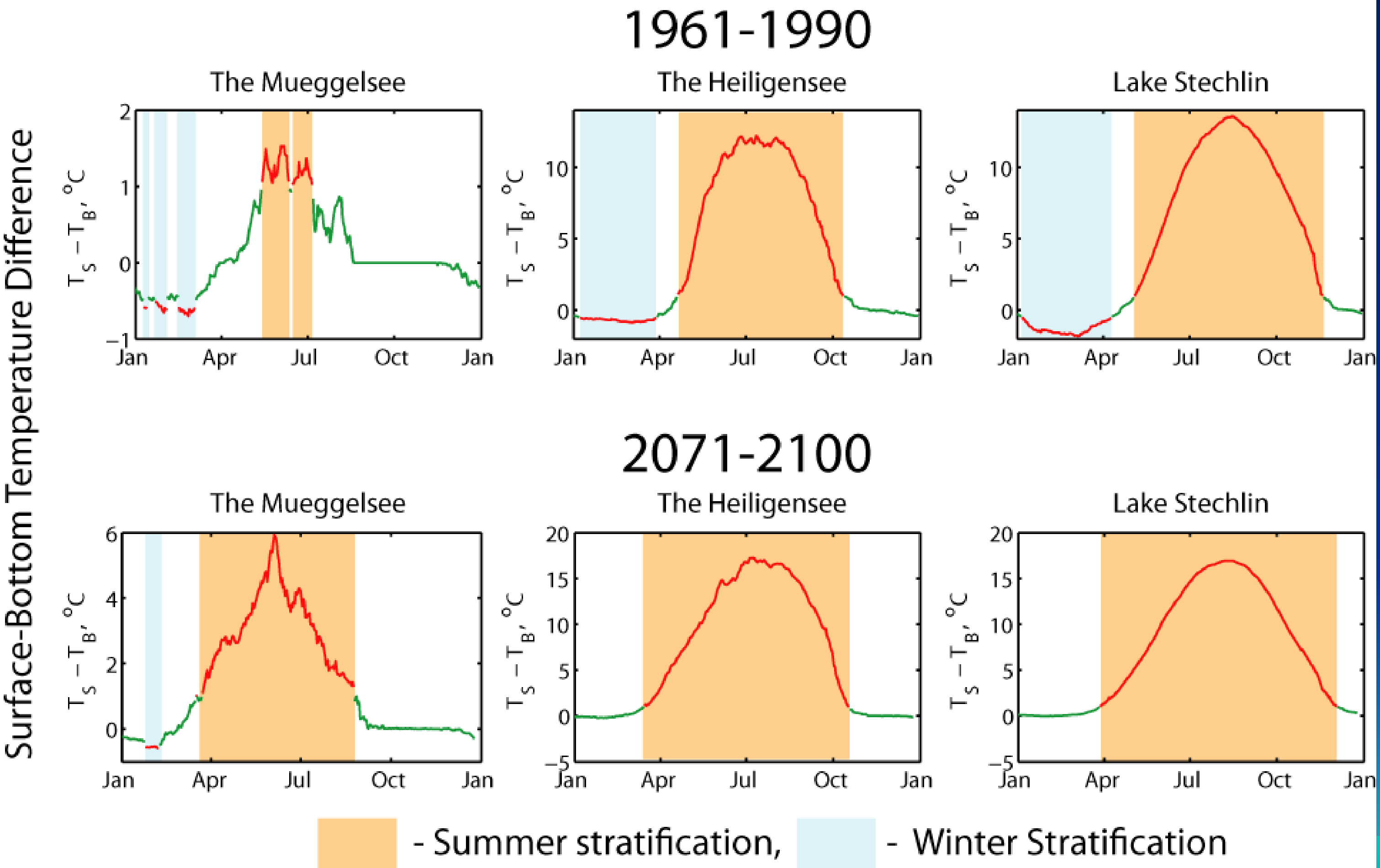
the role of the heat storage by sediments

Outline

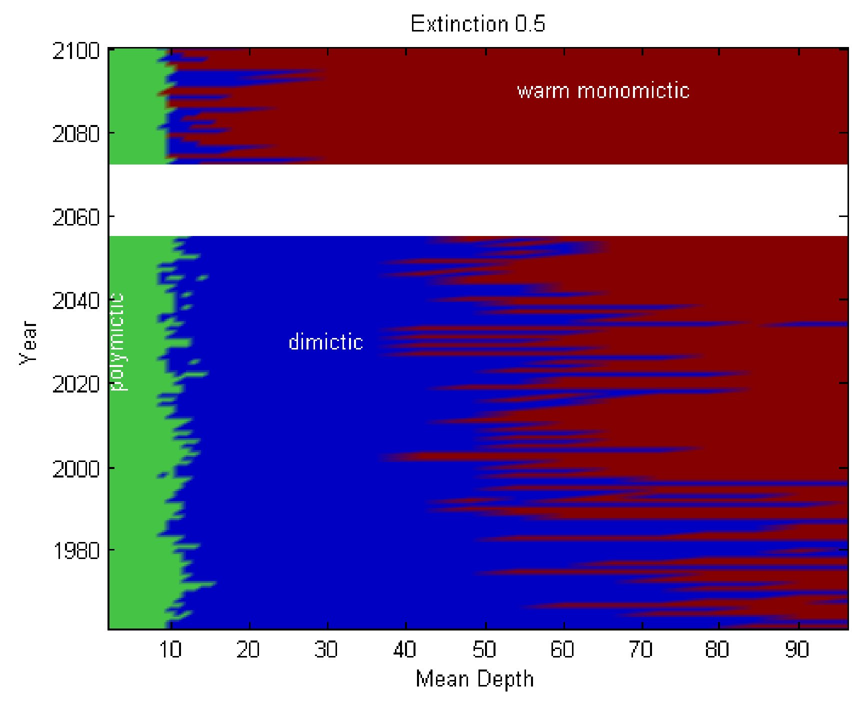
- Modeling global warming effect on German lakes
- Sediments submodel of FLake: parameterizations and external parameters
- Effect of heat storage by the sediments on the climatic scales
- FLake online

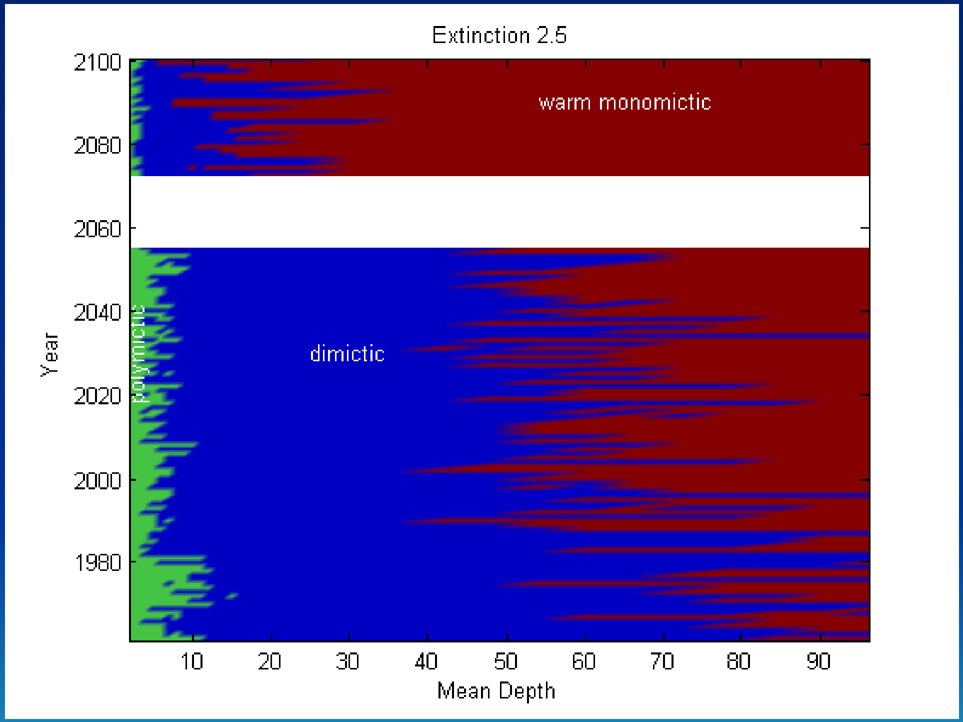
- For lake ecology, in contrast to lake parameterization in atmospheric models, the strength of stratification and the bottom temperature are much more important than the surface temperature

Future scenarios: changing of the mixing regime in many lakes



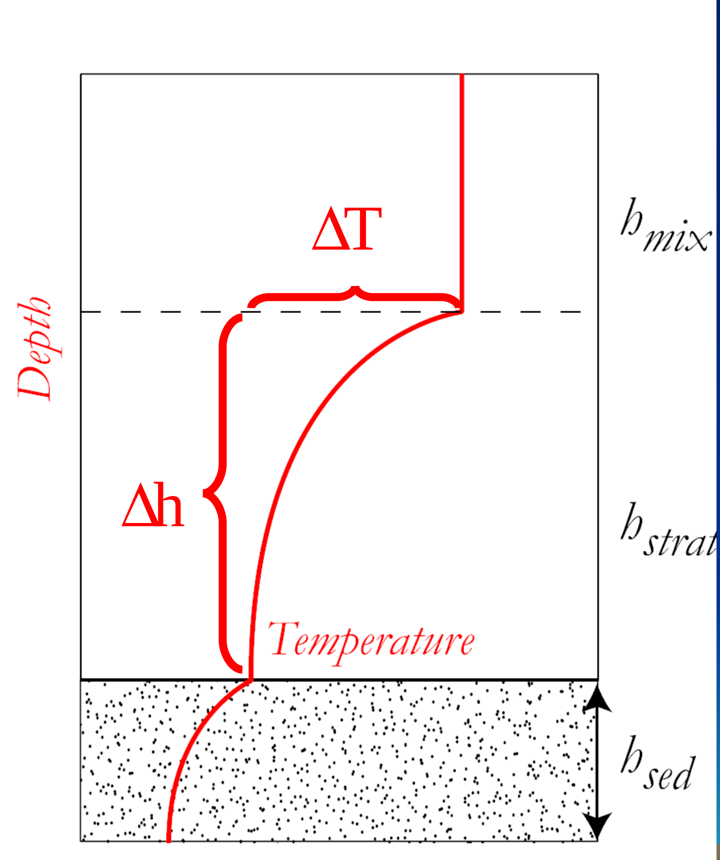
Future transition of lake mixing regimes (Eastern Germany)


Extinction 0.5


Extinction 2.5

FLake model: do we need sediments block?

Temperature profile parameterization in FLake model



Sediments layer can redistribute additional heat input over the year affecting potentially modeling results on climatic scales

Seasonal heat exchange with sediments: general concept

Birge, Juday, March:
The temperature of the bottom deposits of Lake Mendota,
Trans. Wisc. Acad. Sci. 1927

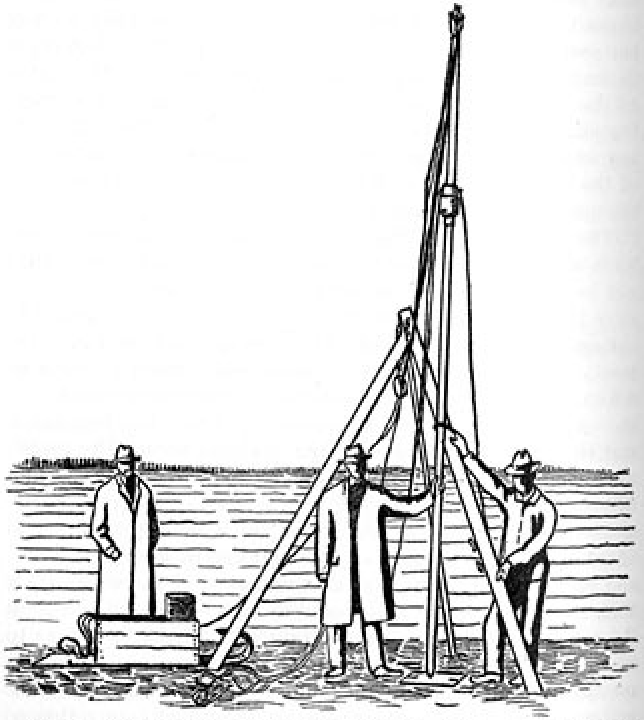
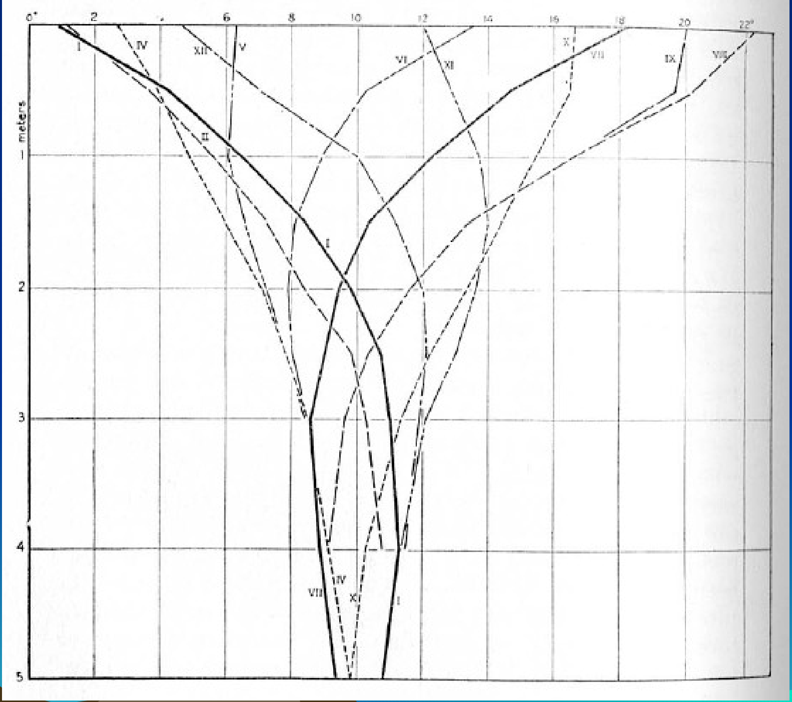
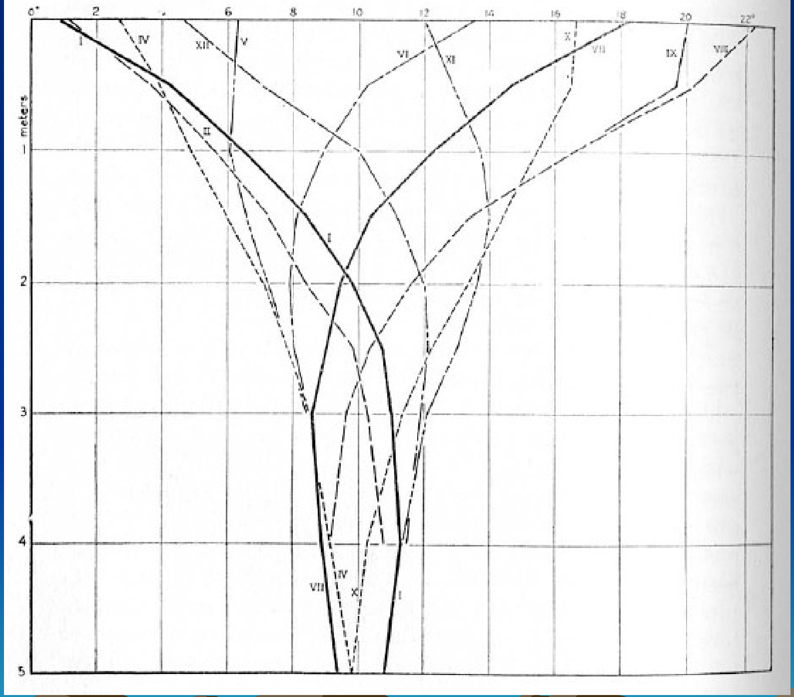


Fig. 1. The mud thermometer on the ice. This is the first one made, the 3.5 m. instrument, with hammer permanently attached to it. The insulated wires and rope are seen attached to the top; also the hammer with its two lines. The thermometer is driven into the mud as far as the point where the hammer rests. From Trans. Wis. Acad.; 20, 534, Madison, 1922.

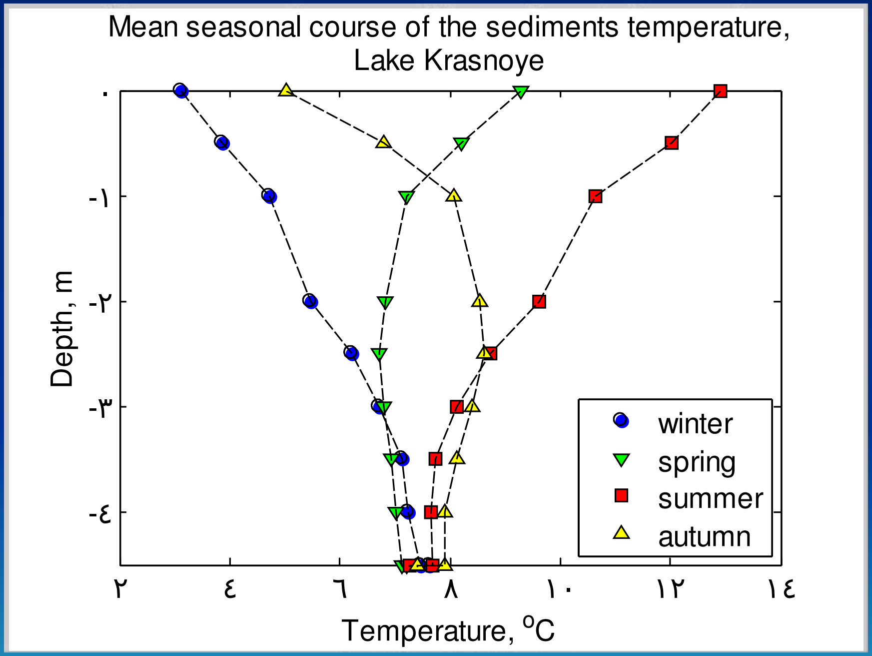


Temperature evolution in sediments: Seasonal thermal wave

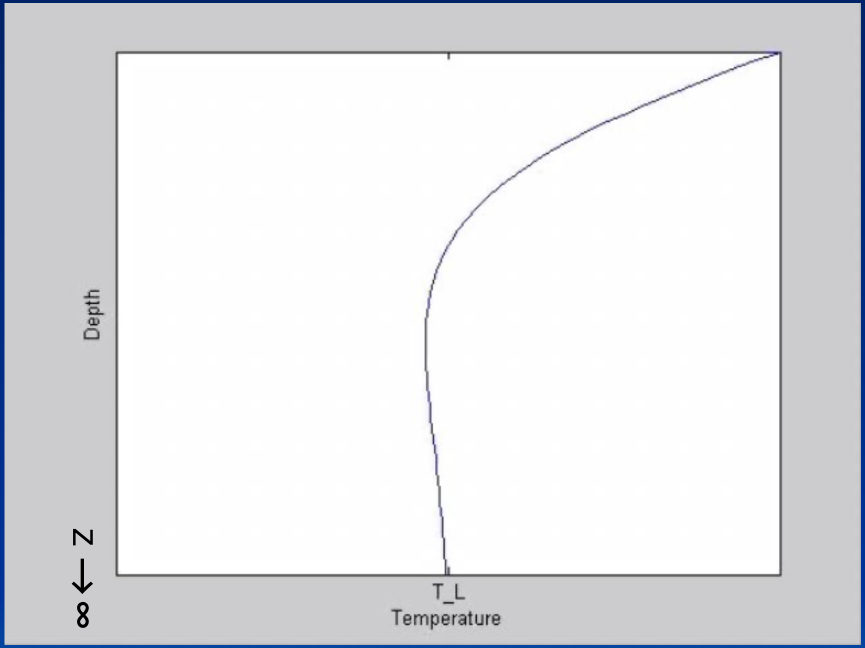
First measurements in sediments.
Lake Mendota 1925 (Birge 1927)



Mean temperature profiles in sediments.
Lake Krasnoye, 1971-1987



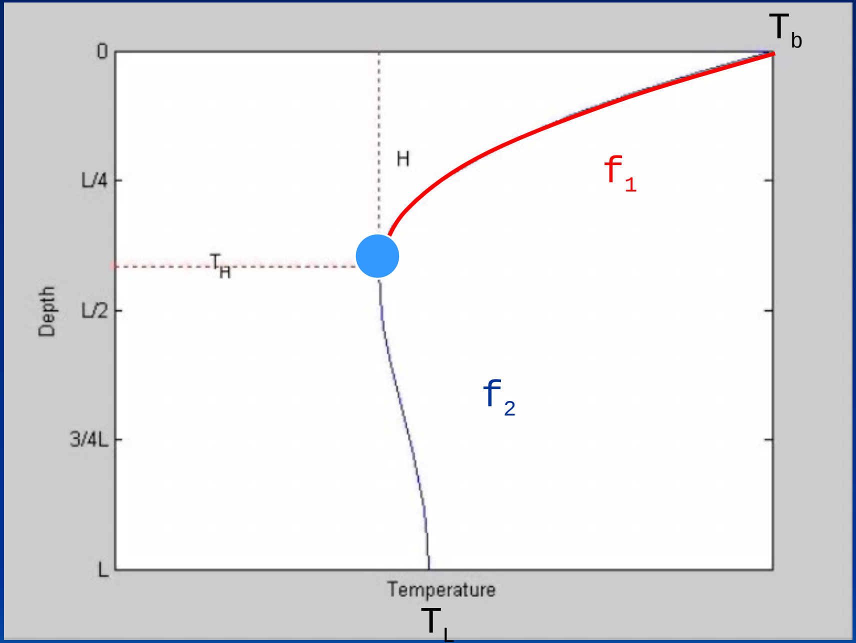
Temperature evolution in sediments: Seasonal thermal wave



Periodical forcing at the water-sediments interface

$$\theta(z,t) = \theta_\infty + \theta_A \exp\left(-z\sqrt{\frac{\omega}{2K}}\right) \sin\left(\omega t - z\sqrt{\frac{\omega}{2K}}\right),$$

Sediments temperature model: parameterized



Polynomial approximations of functions *f1* and *f2*:

$$f_1(x_1) = 2x_1 - x_1^2, \qquad x_1 = \frac{z - D}{H - D}$$

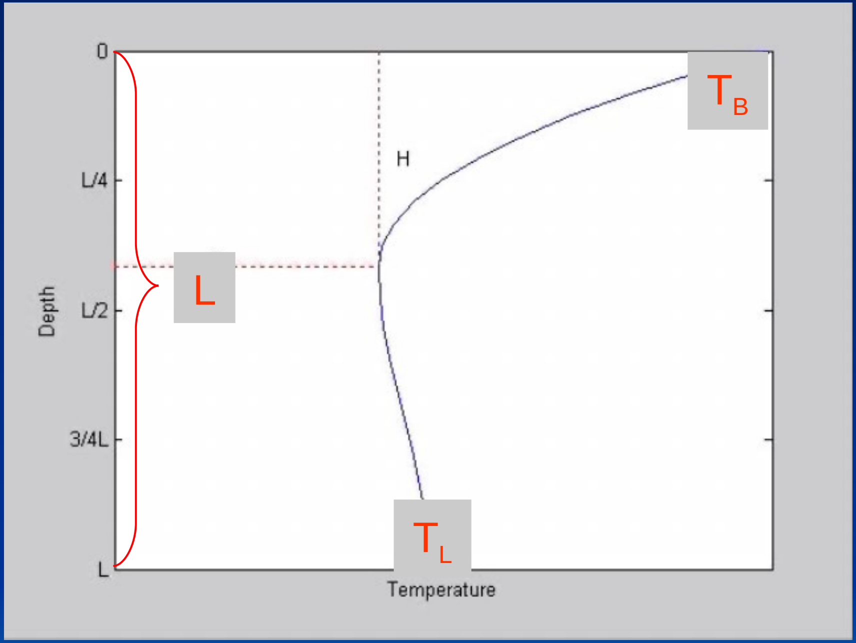
$$f_2(x_2) = 3x_2^2 - 2x_2^3, \qquad x_2 = \frac{z - H}{L - H}$$

$$\frac{\mathrm{d}T_D}{\mathrm{d}t}(H - D)(1 - \mu) + \frac{\mathrm{d}T_H}{\mathrm{d}t}(H - D)\mu + \frac{\mathrm{d}H}{\mathrm{d}t}(T_D - T_H)(1 - \mu) = Q_D,$$

$$\frac{dH}{dt}(T_L - T_H)(1 - \eta) = \frac{dT_H}{dt}(L - H)\eta,$$

where μ and η are integral constants:

External model parameters

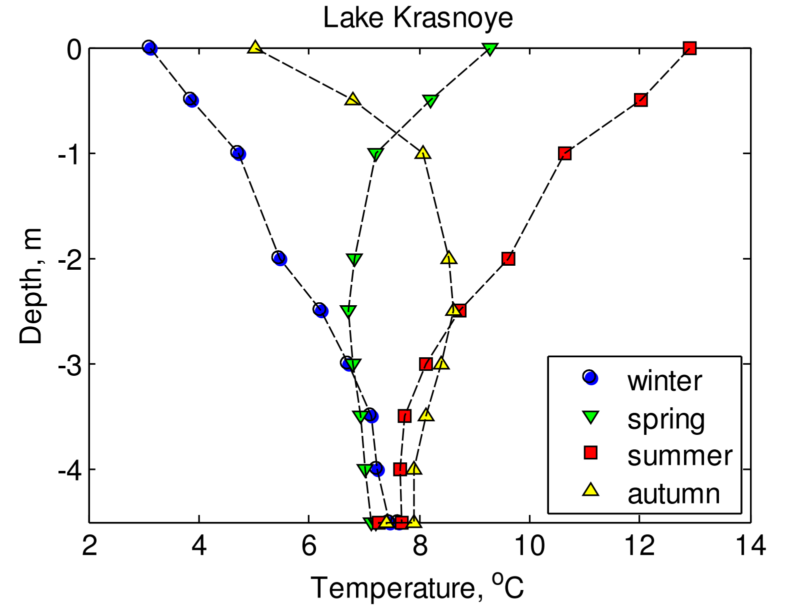


T_B – variable temperature at the water-sediments interface. Input parameter (measured or from a water column temperature model)

T_L – “constant” temperature of deep sediments. Can be determined as long-term average of T_B (seasonal variations removed)

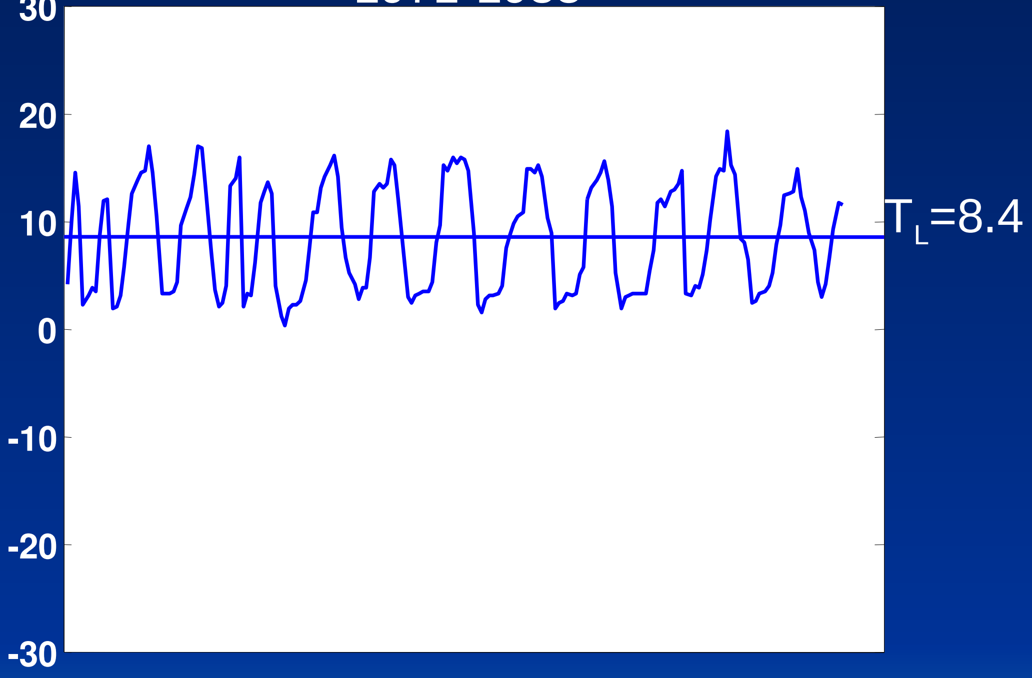
L – thickness of the “*thermally active sediments layer*” with seasonal T variations. The most uncertain parameter.

T_L Estimation


Mean seasonal course of the sediments temperature, Lake Krasnoye

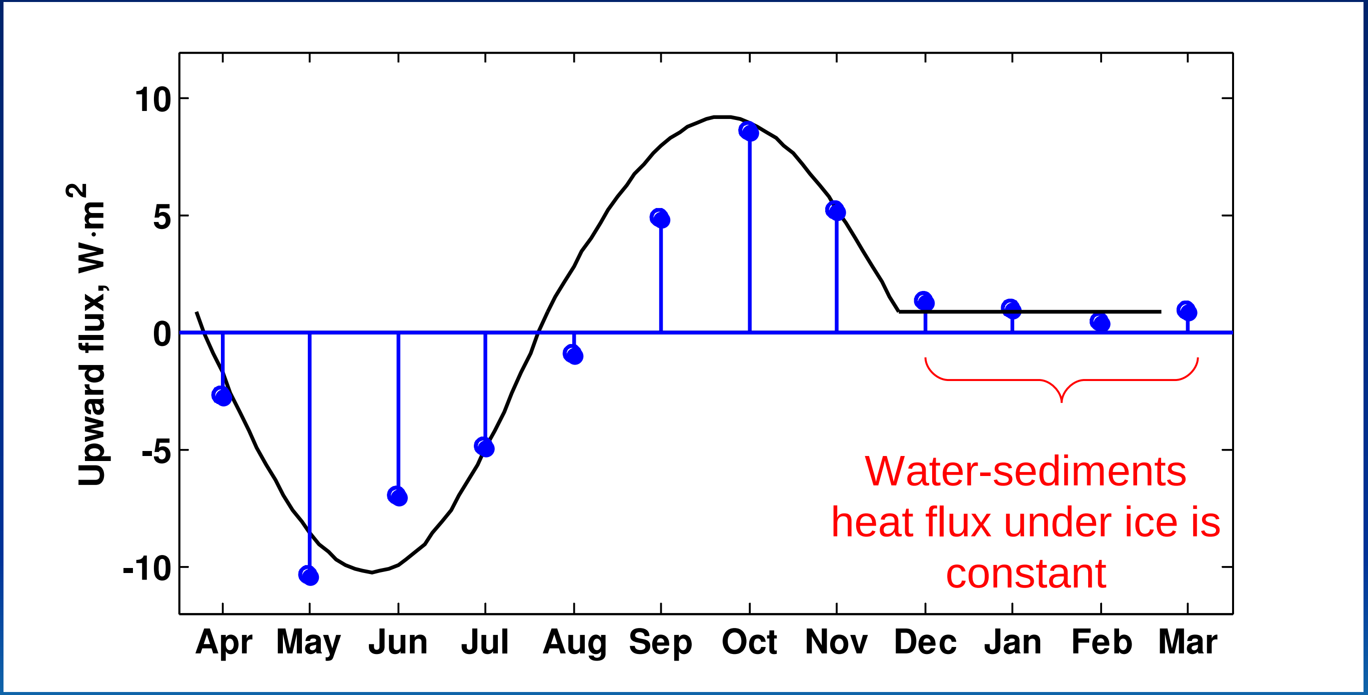
$T_L ≈ 8^oC$

Near-bottom temperature, Lake Krasnoye 1971-1988



How to estimate thickness *L* of the thermally active sediments layer?

15 years mean heat flux at the water-sediments interface,
Lake Krasnoye



Water-sediments heat flux under ice is constant

Water-sediments heat flux under ice is nearly ***constant***

$Q_b = \text{const} \rightarrow T_b \propto t^{1/2}$

ODE system

$$\frac{dT_D}{dt}(H-D)(1-\mu)+\frac{dT_H}{dt}(H-D)\mu+\frac{dH}{dt}(T_D-T_H)(1-\mu)=Q_D,$$

$$\frac{dH}{dt}(T_L-T_H)(1-\eta)=\frac{dT_H}{dt}(L-H)\eta,$$

where μ and η are integral constants:

If value of *Q* is known,
L can be also determined

$$L=\chi(T_L-T_0)/Q_b$$

Solution at Q=const

$$T_b(t)=T_0+Q_b\left(\frac{1}{2\varkappa}+\frac{1}{\chi}\right)\sqrt{H_0^2+\frac{2\varkappa t}{\varkappa/\chi+1/3}}$$

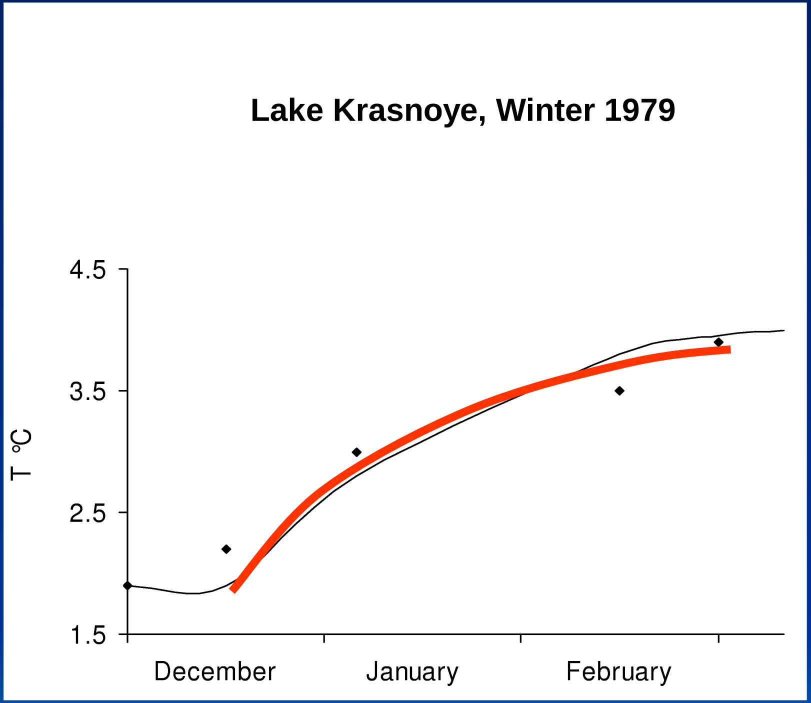
$$\chi=Q_bL/(T_L-T_0)$$

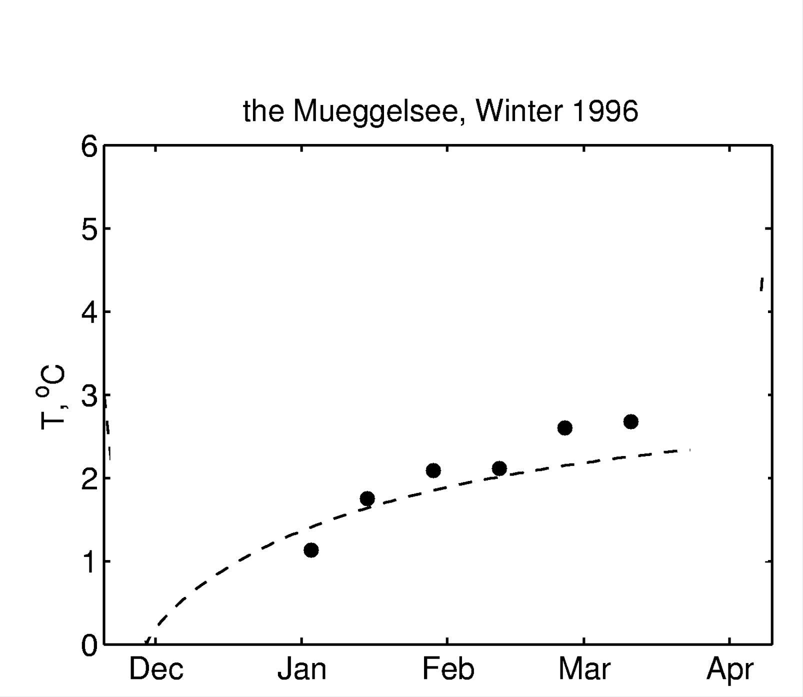
If we assume $H_0=0$ and $\chi=\varkappa$, then

$$T_b(t)=T_0+\frac{Q_bL_t}{\varkappa}\left(\frac{8}{3}\right)^{-1/2} \quad \text{where } L_t = 2\sqrt{\varkappa t}.$$

cf. $T_b(t)=T_0+\frac{Q_bL_t}{\varkappa}\pi^{-1/2}$ (from analytical solution of HTE).

Near-bottom temperatures under ice


Lake Krasnoye, Winter 1979


the Mueggelsee, Winter 1996

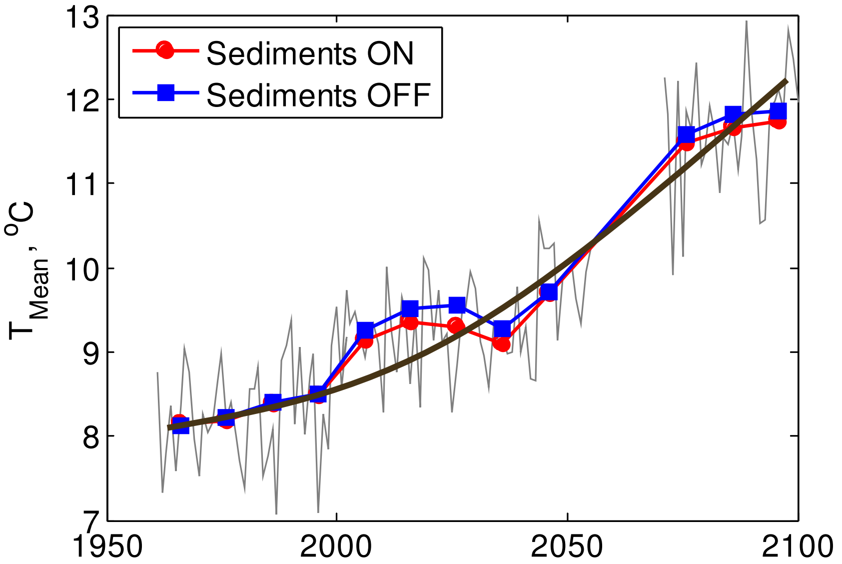
$$T_b(t) = T_0 + \frac{Q_b L_t}{\varkappa}\left(\frac{8}{3}\right)^{-1/2}$$

where $L_t = 2\sqrt{\varkappa t}$.

$$L = \chi(T_L - T_0)/Q_b$$

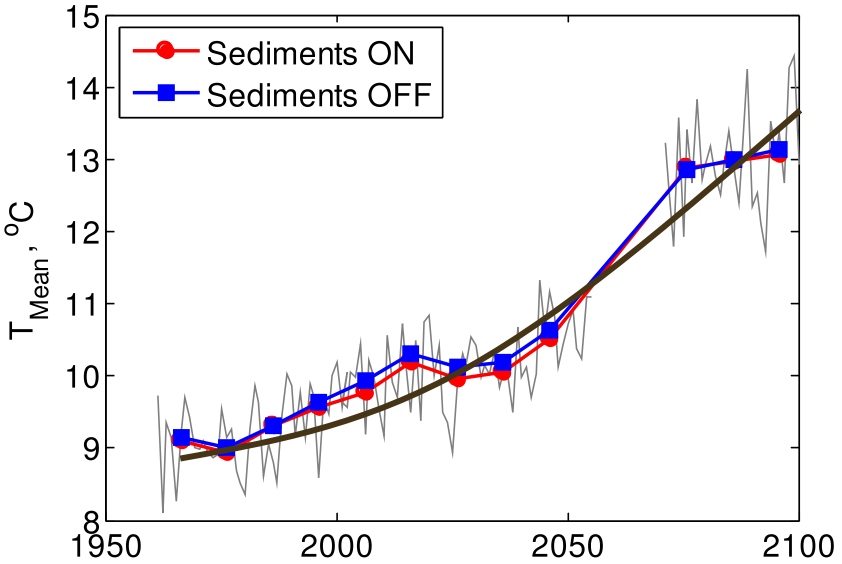
Climatic trends in **annual mean** lake temperatures

dimictic



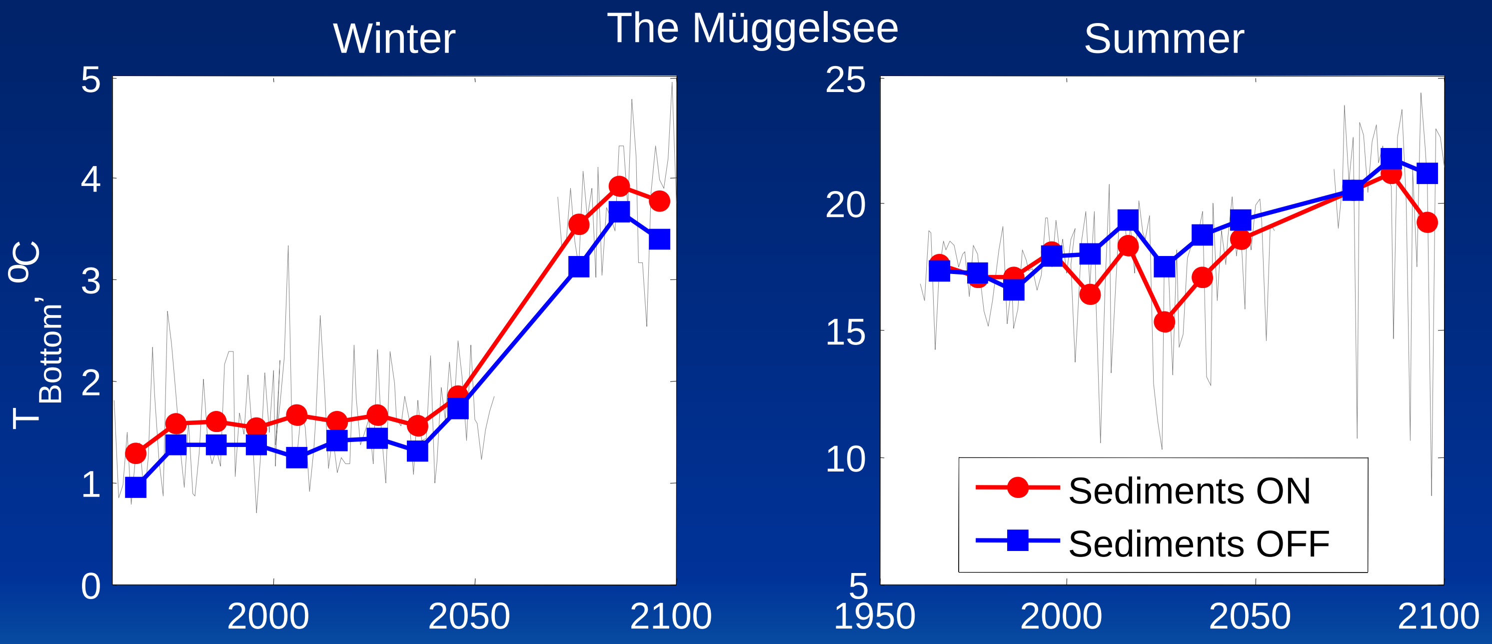
Mean temperature trend, 1961-2100, Lake Heiligensee

polymictic

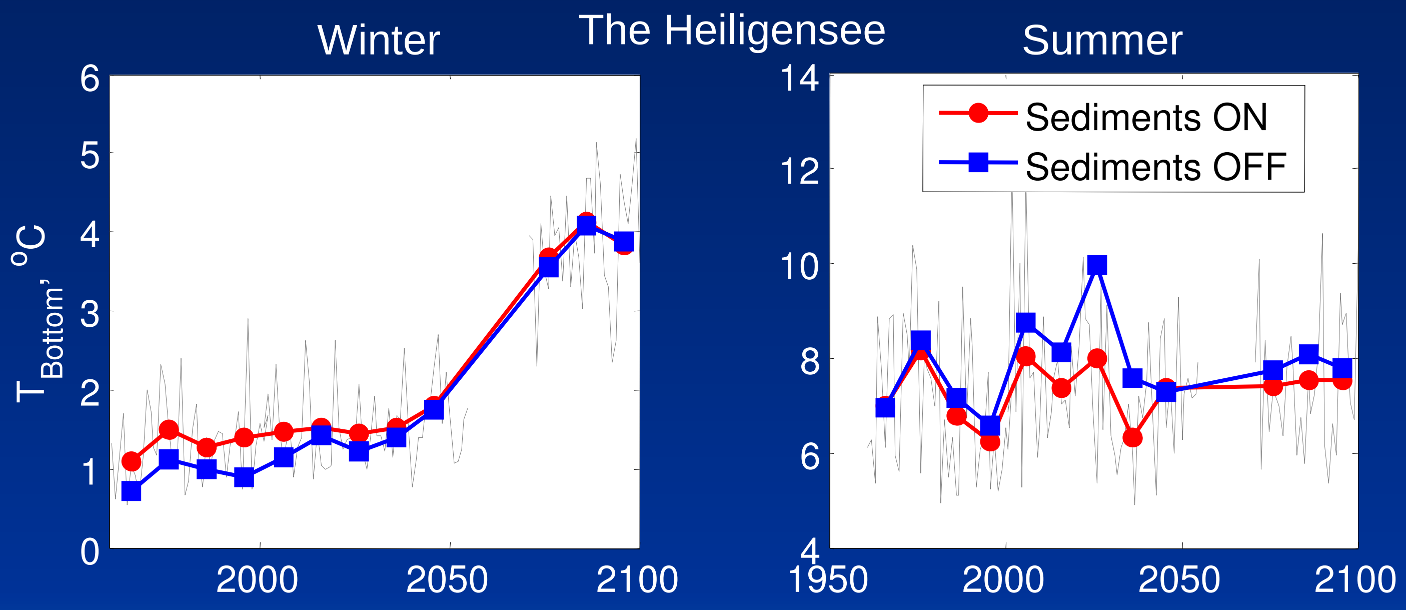


Mean temperature trend, 1961-2100, Lake Mueggelsee

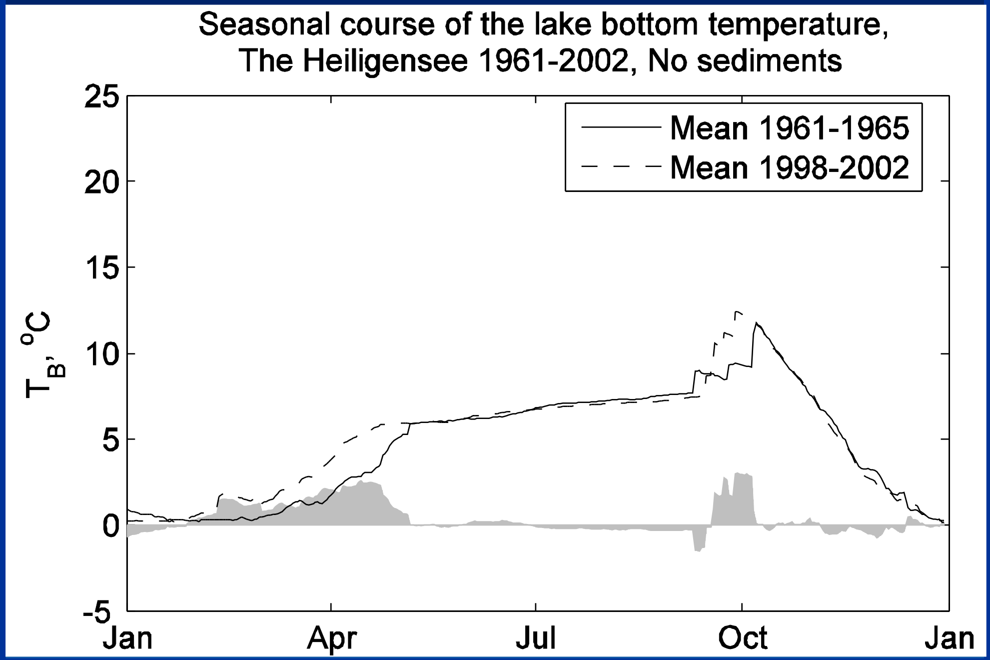
Seasonal trends in a **polymictic** lake



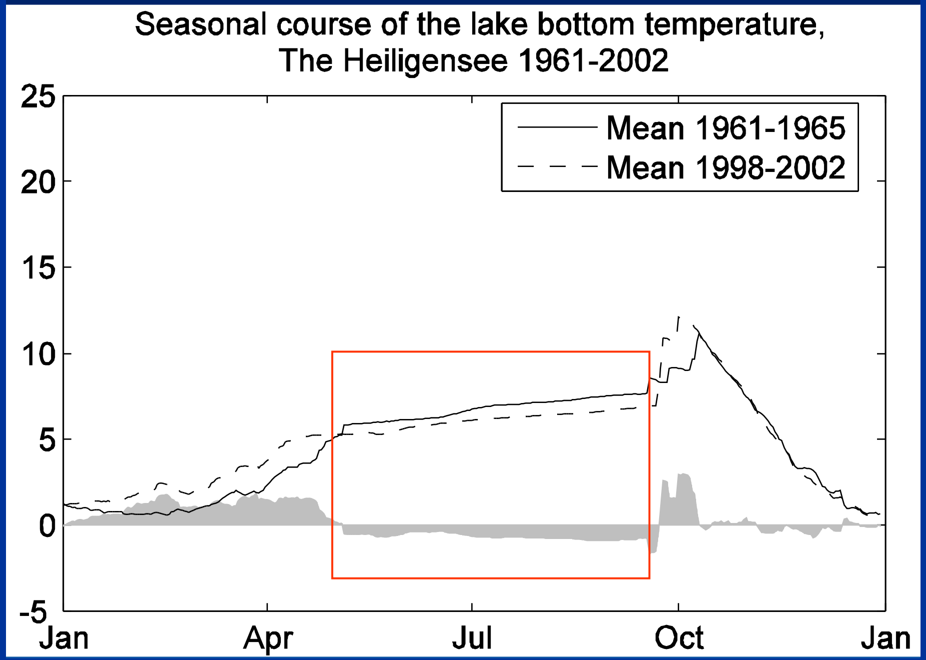
Seasonal trends in a **dimictic** lake



Decrease of summer bottom temperatures



Seasonal course of the lake bottom temperature,
The Heiligensee 1961-2002, No sediments



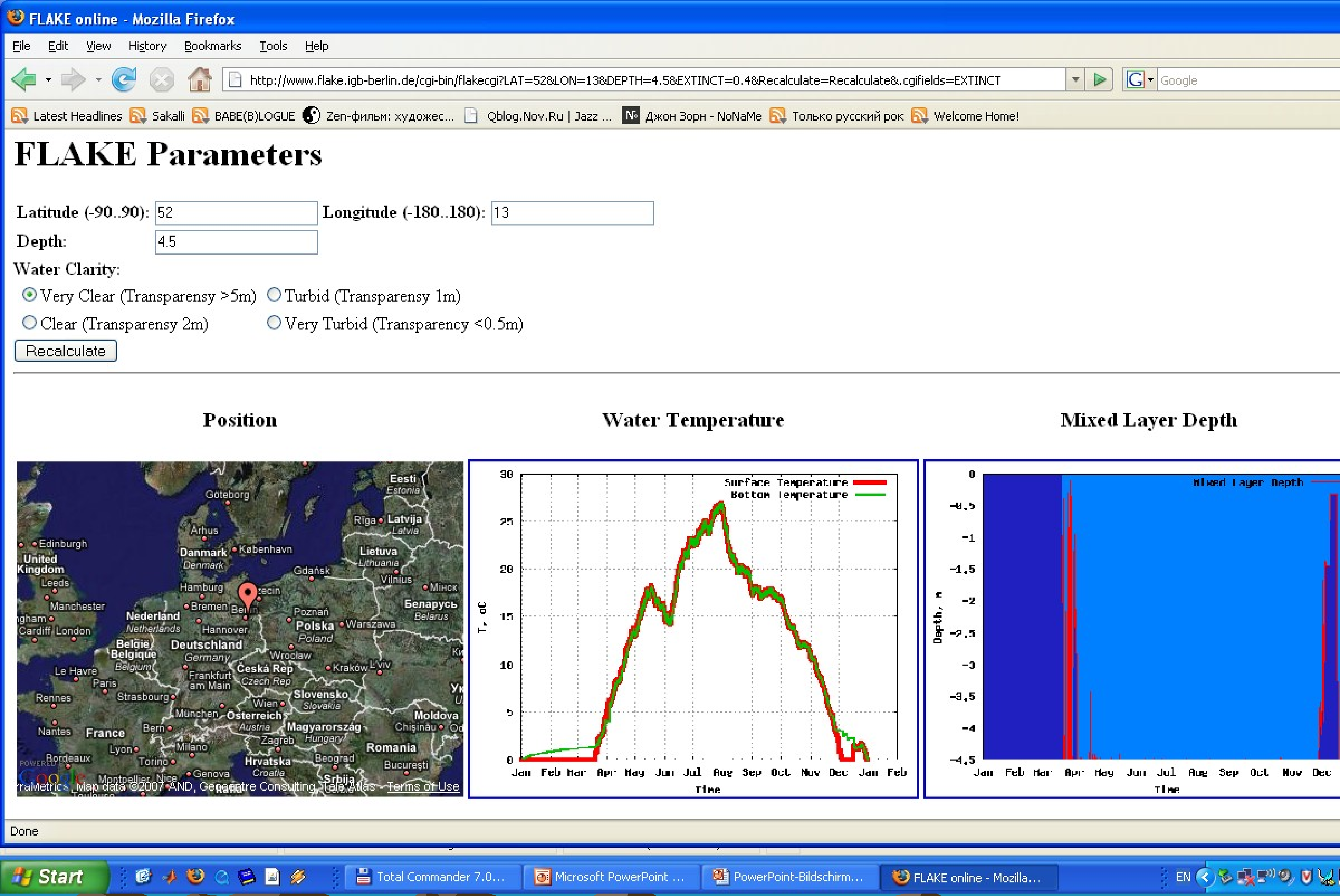
Seasonal course of the lake bottom temperature,
The Heiligensee 1961-2002

Summary

- (a) The *increase* in *winter bottom* temperatures is higher, when sediments are accounted for. This effect is stronger in *polymictic* lakes.

- (b) The *summer bottom* temperatures are *decreasing*: The stratification effect in couple with the heat sink to sediments. This summer effect is more pronounced in *dimictic* lakes.

- Thus, the **sediments heat storage shifts the overall temperature increase in lakes to the winter hypolimnion heating**.



FLAKE Parameters

Latitude (-90..90): 52 **Longitude (-180..180):** 13

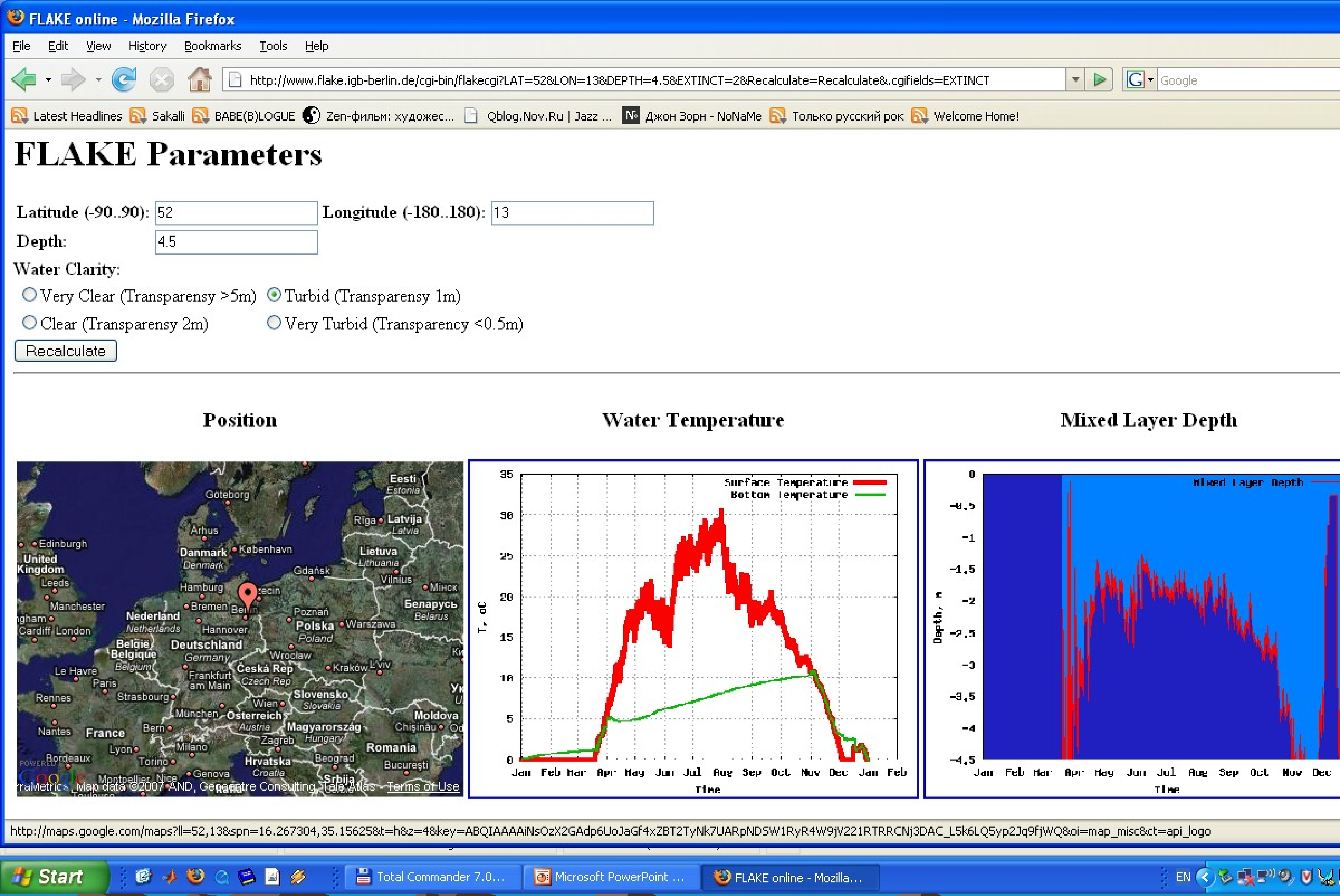
Depth: 4.5

Water Clarity:

● Very Clear (Transparensy >5m) ○ Turbid (Transparensy 1m)

○ Clear (Transparensy 2m) ○ Very Turbid (Transparency <0.5m)

Position **Water Temperature** **Mixed Layer Depth**



FLAKE Parameters

Latitude (-90..90): 52 **Longitude (-180..180):** 13

Depth: 4.5

Water Clarity:

○ Very Clear (Transparensy >5m) ● Turbid (Transparensy 1m)

○ Clear (Transparensy 2m) ○ Very Turbid (Transparency <0.5m)

Position **Water Temperature** **Mixed Layer Depth**

FLake online

North Pole

Lake Vättern (SE)

Siberia

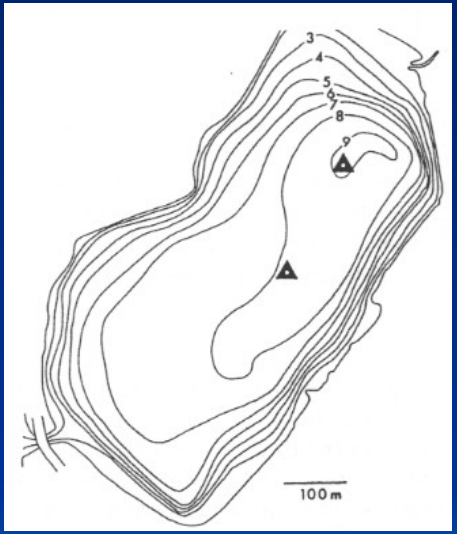
Lake Victoria

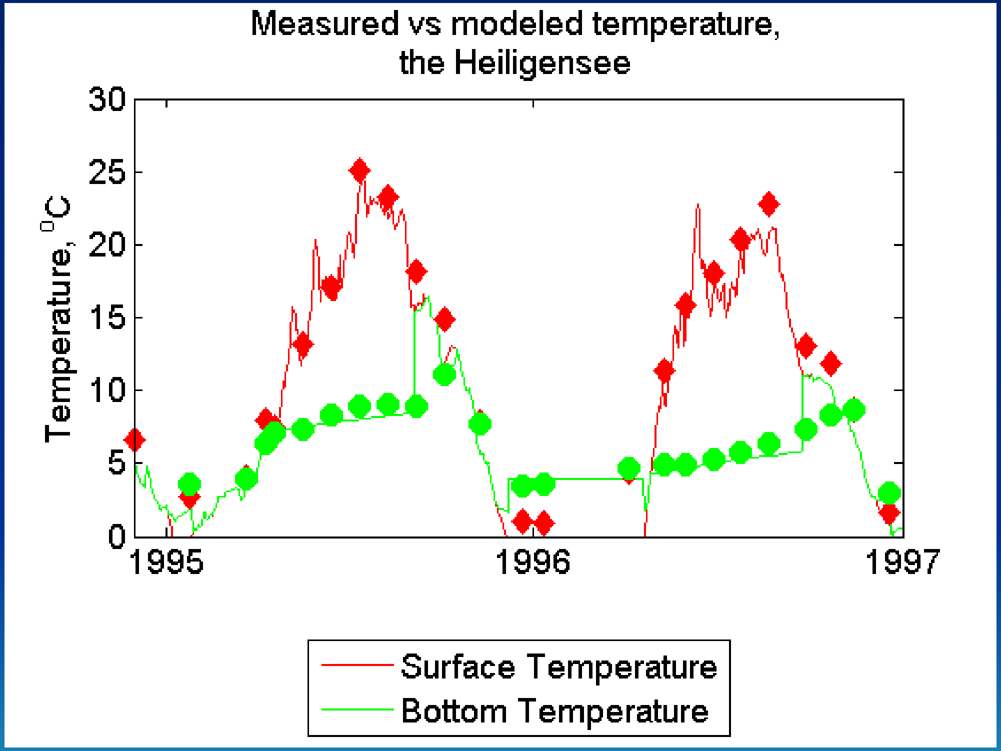
Three Gorges Dam (China)

South Pole

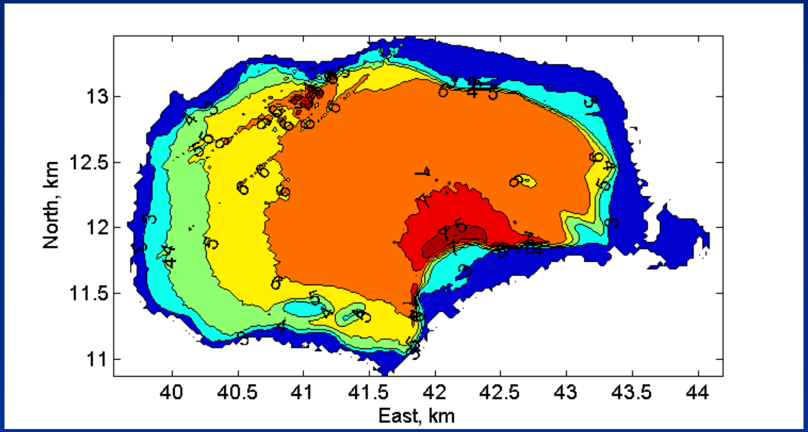
Thank You!

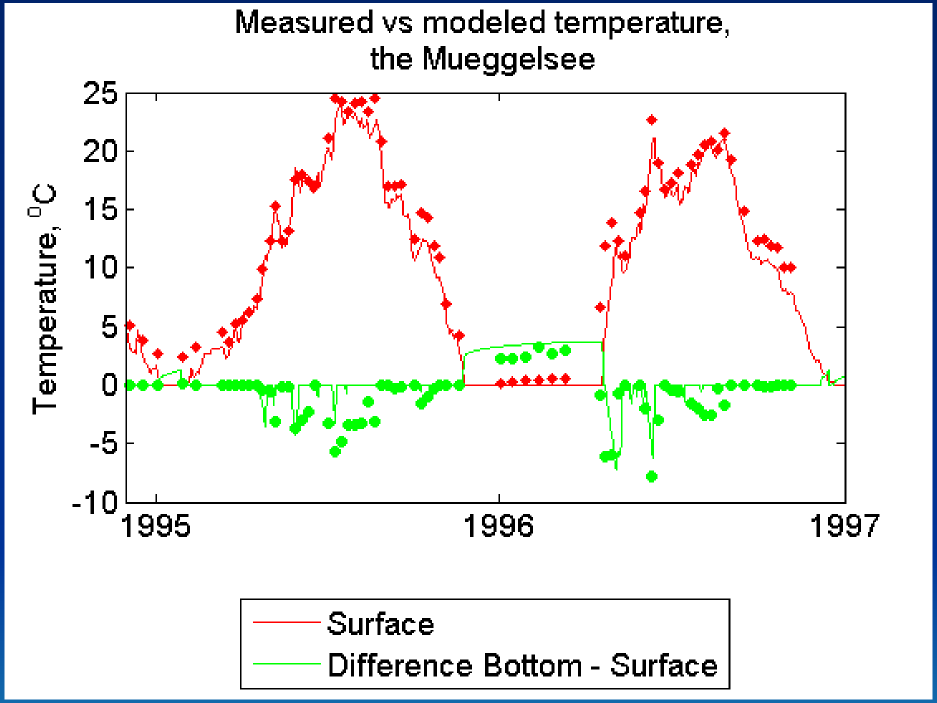
Lake Heiligensee:
Depth 5.1m, eutrophic, dimictic



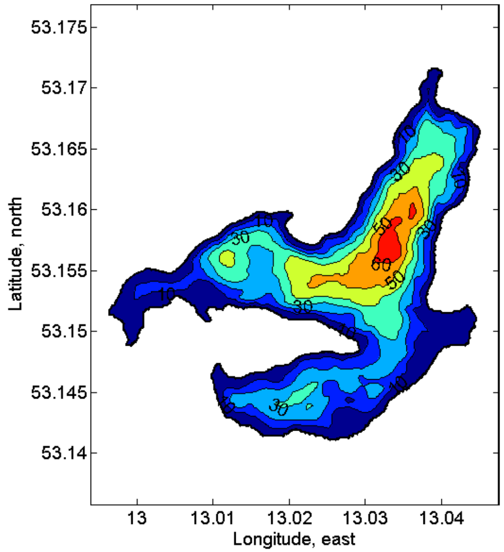


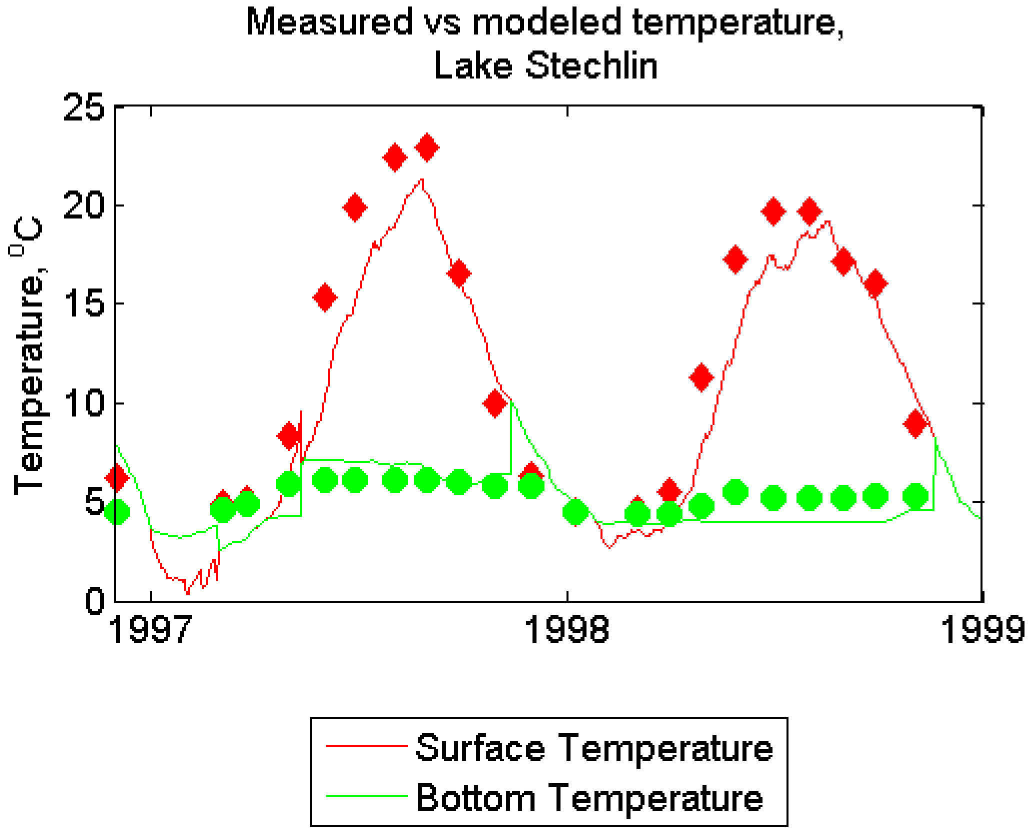
Lake Müggelsee:
Depth 4.9m, eutrophic, polymictic





Lake Stechlin:
Depth: 23m, oligotrophic, dimictic




Measured vs modeled temperature, Lake Stechlin