РОССИЙСКАЯ АКАДЕМИЯ НАУК
СИБИРСКОЕ ОТДЕЛЕНИЕ
ИНСТИТУТ МОНИТОРИНГА КЛИМАТИЧЕСКИХ И ЭКОЛОГИЧЕСКИХ СИСТЕМ

Modeling of thermal properties of peat soil

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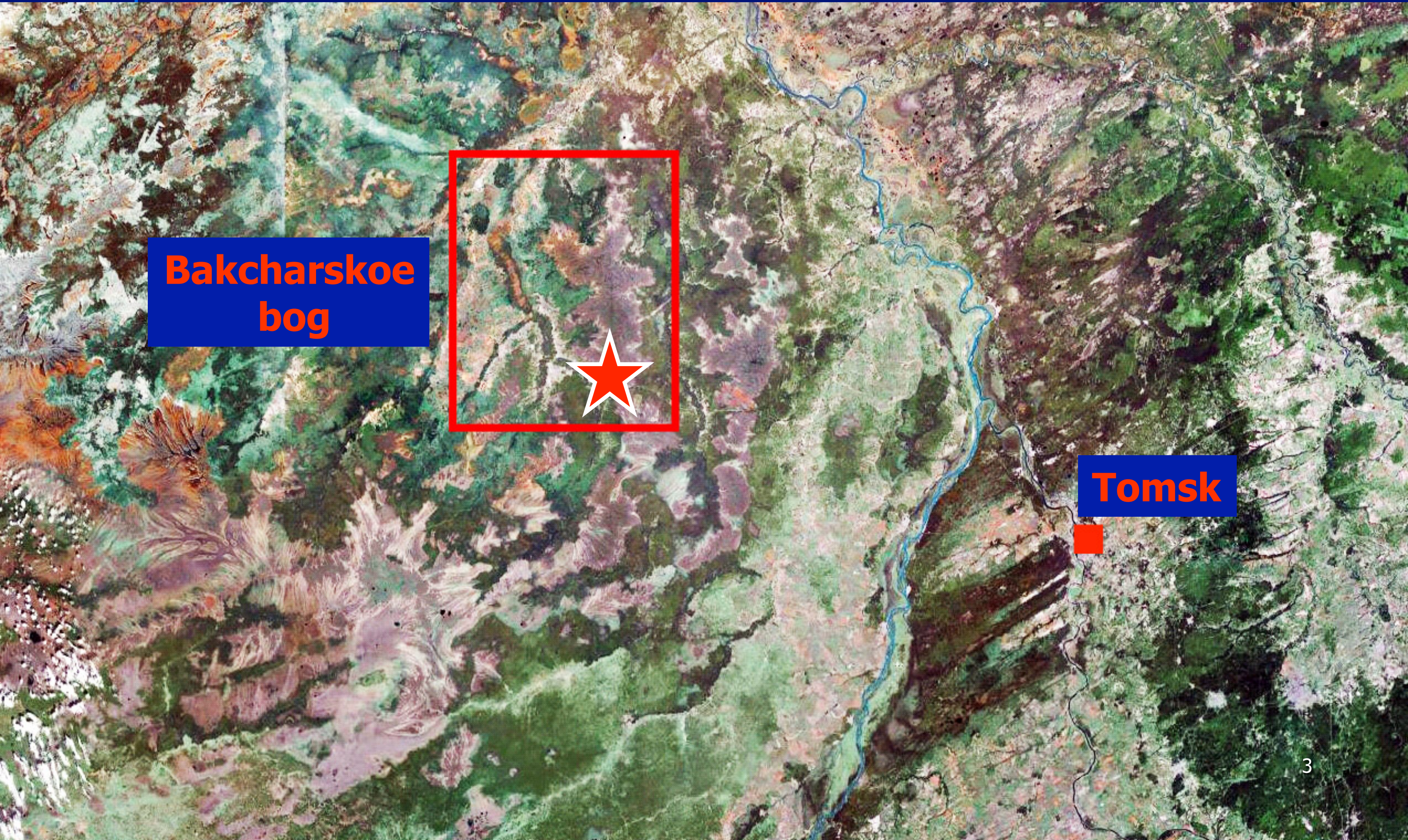
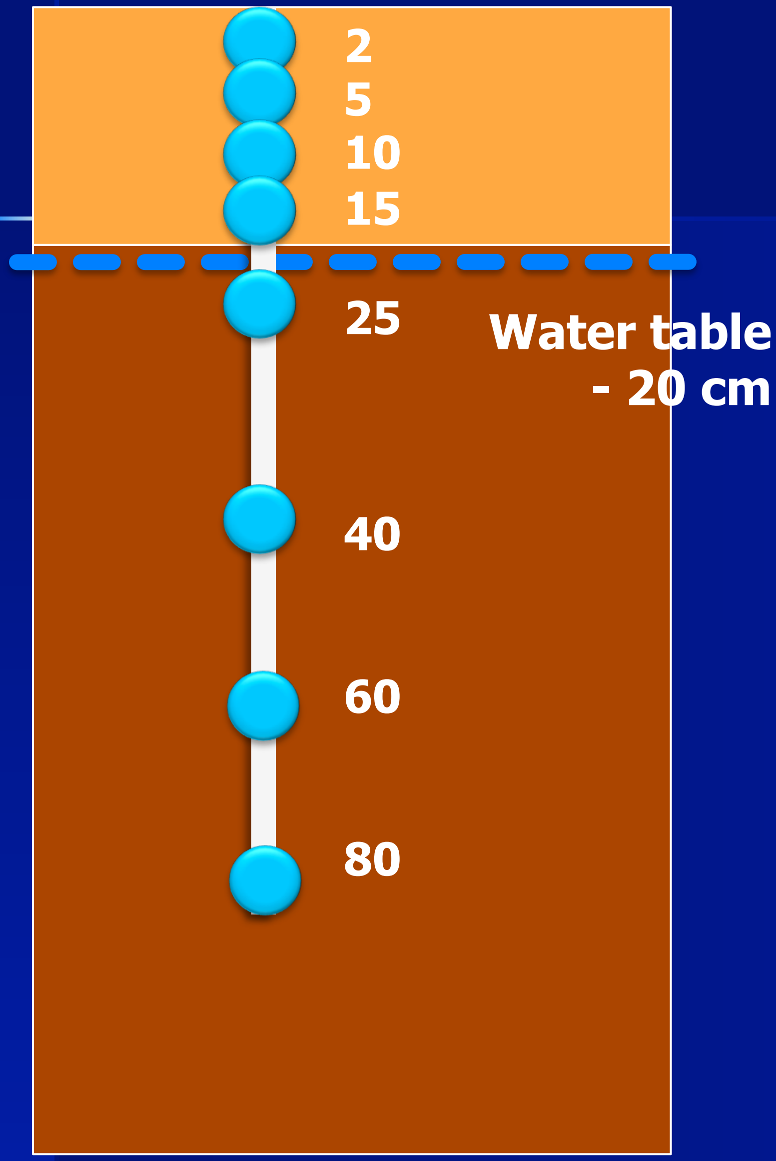
- Peat deposit is a complex organic-mineral system with specific properties. Peat layers has high porosity, and contains large amount of weakly decomposed water saturated organic matter. Thermal regimes of peat deposit and mineral soil are essentially differs. Temperature of peat influences on course and rate of physical, chemical, and microbiological processes in the peat deposit. Studying of temperature regime allows to reveal features of heat, water and gas regimes of peatland ecosystems.

Study area



Pine-shrub-sphagnum community (Low ryam)

Observation data



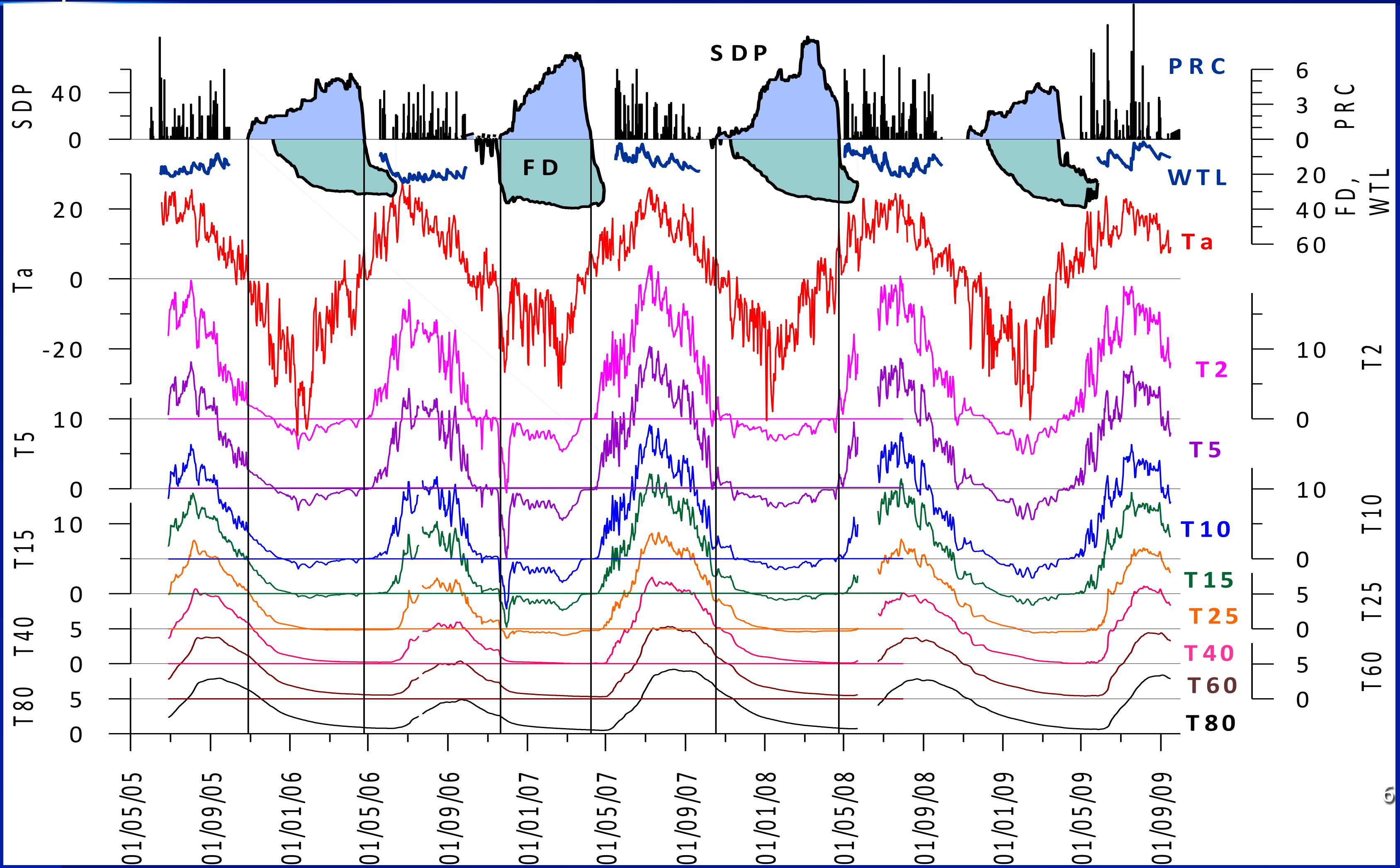
Peat depth – 2 m

Soil temperature at
2,5,10,15,25,40,60,80 cm

from 28 june 2005
to 7 september 2010

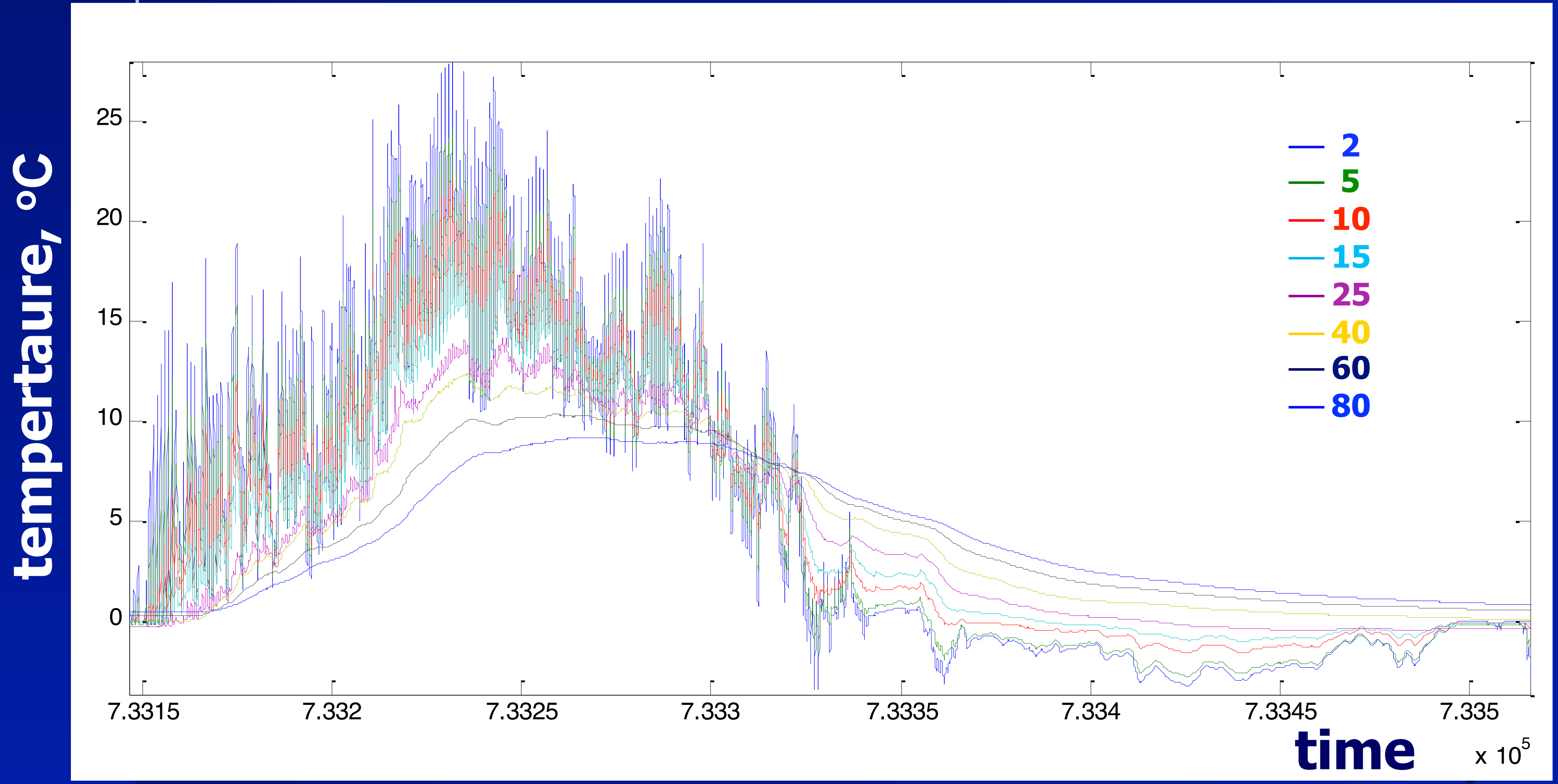
Time step:
15 min (summer)
60 min (winter)

Daily air temperature (Ta), soil temperature at 2 – 80 cm (T2, T5, T10, T15, T25, T40, T60, T80), snow depth (SDP, cm), soil freeze depth (FD, cm), water table level (WTL, см) and daily precipitation (PRC, mm).

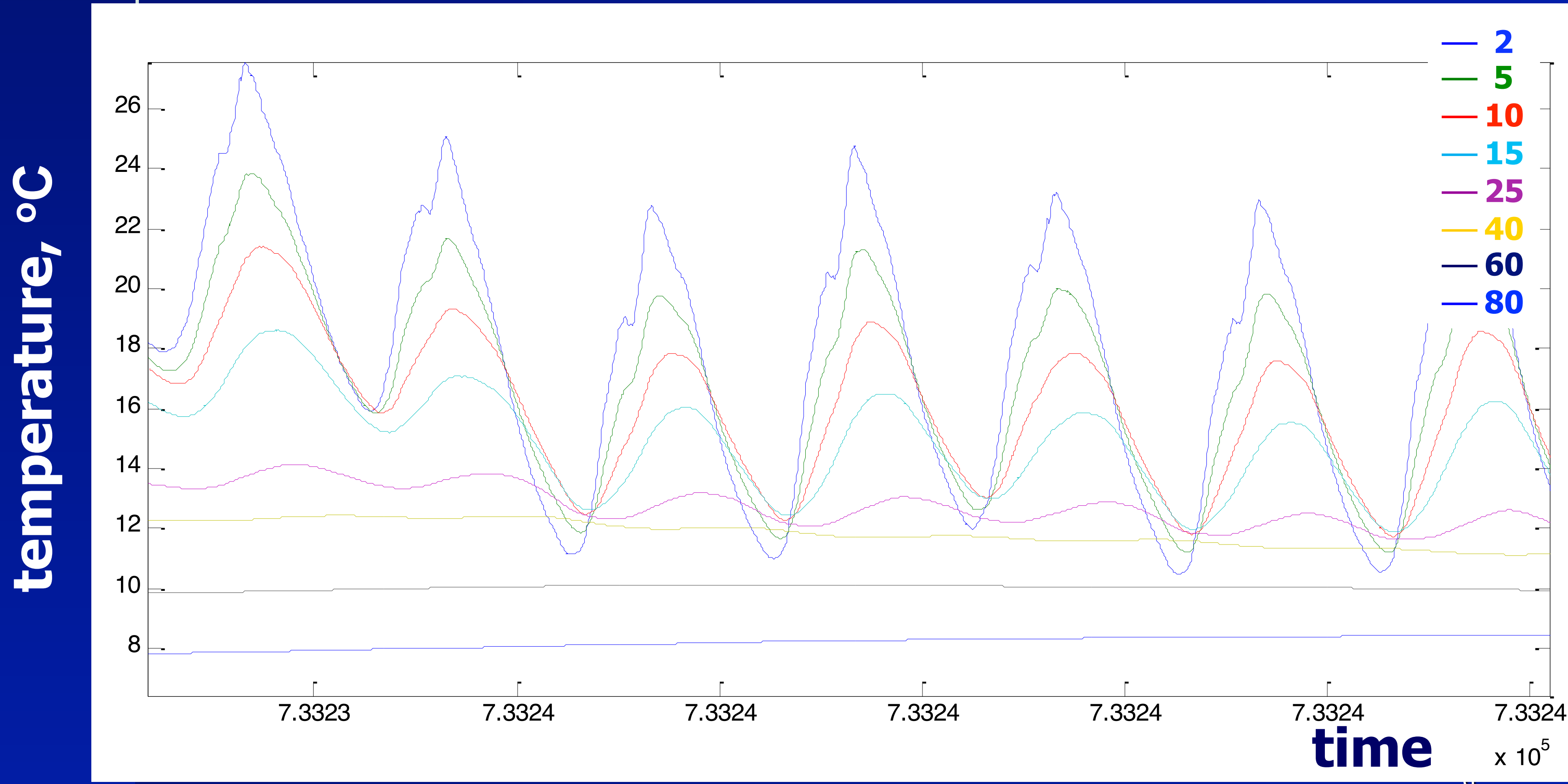


Data examples

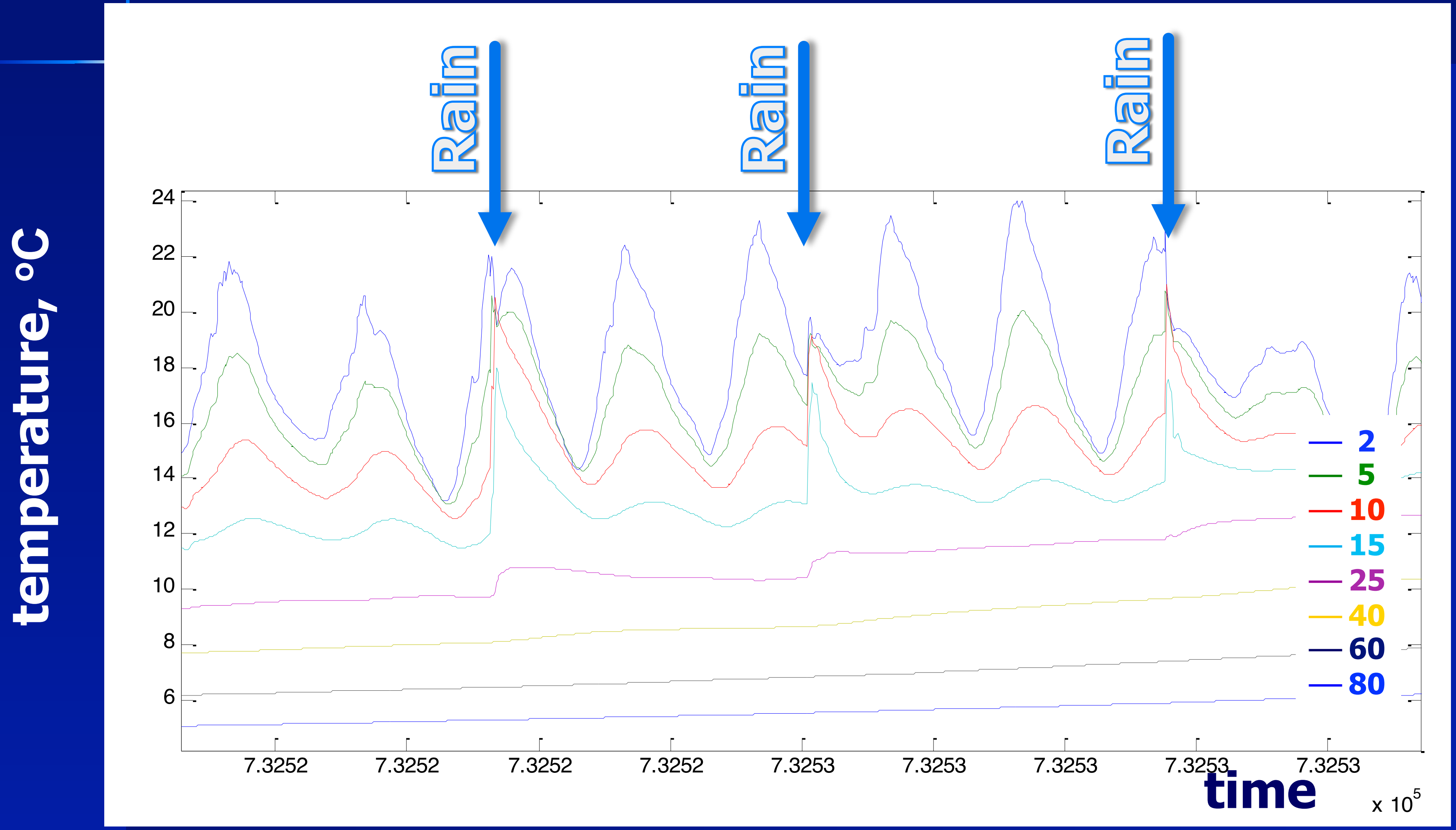
Annual course of soil temperature



Diurnal temperature variations

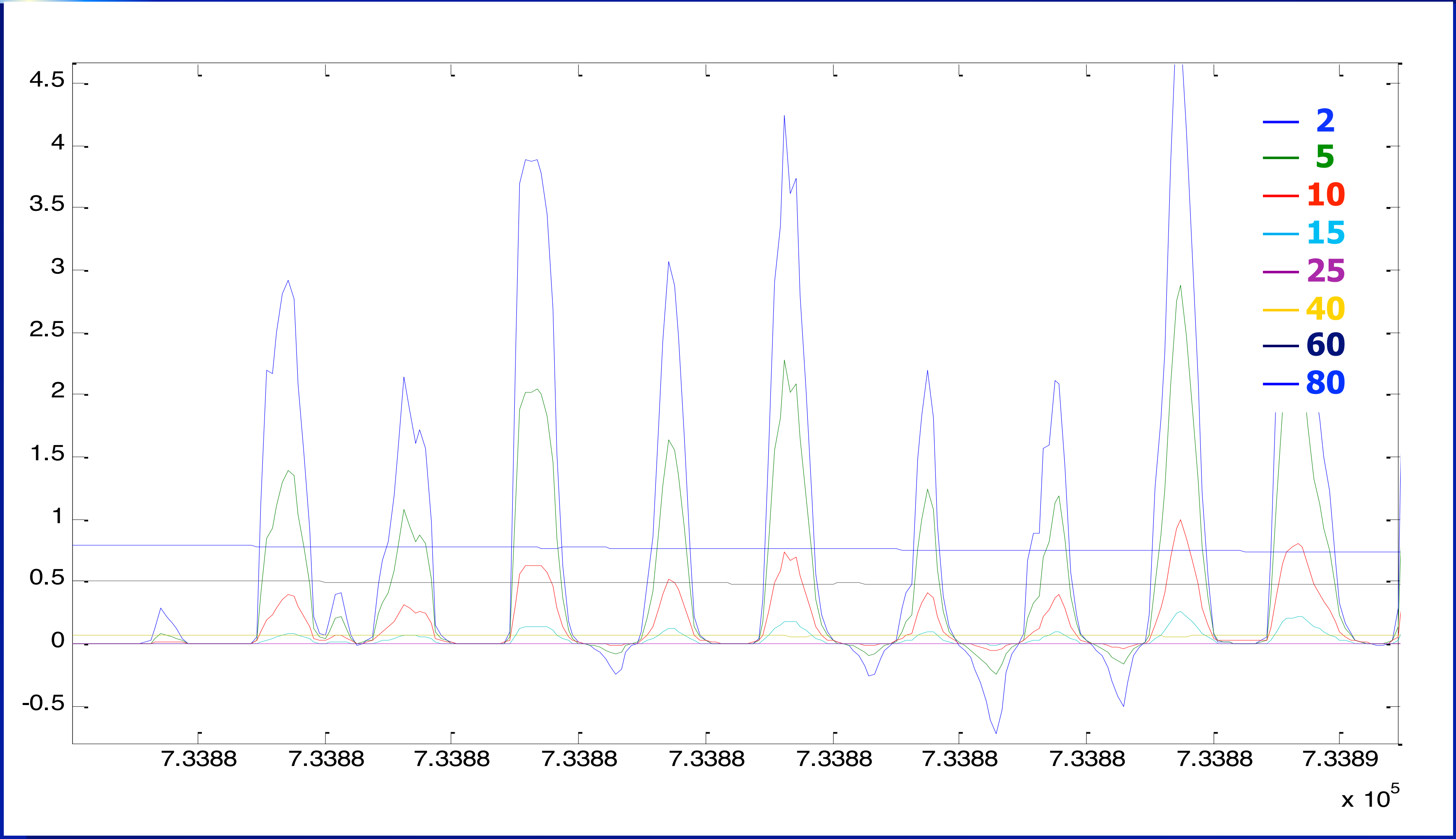


Peat warming at water infiltration

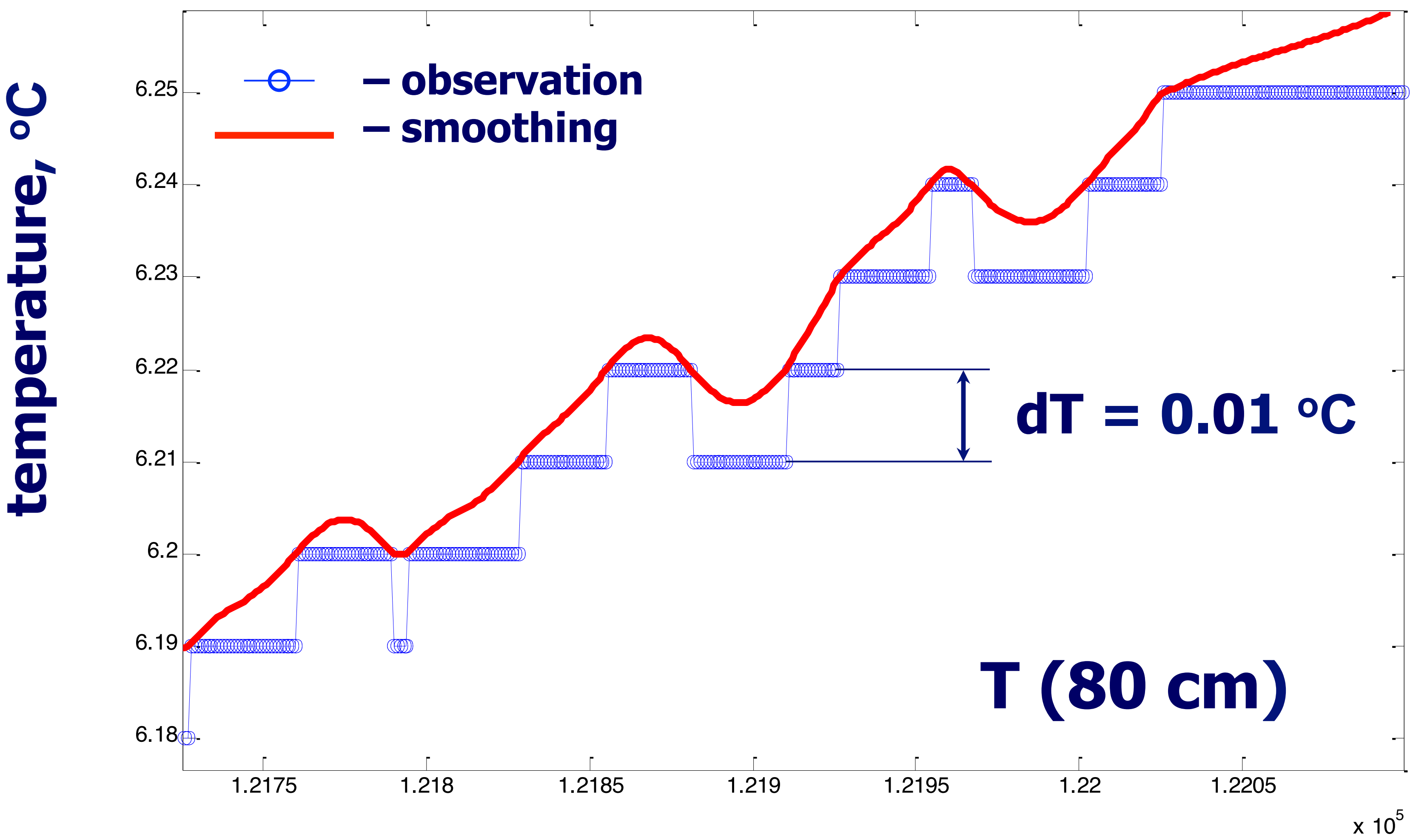


Data pre-processing

In-situ data calibration using "zero curtain"



Removing data quantification



Soil thermal properties

a - apparent heat diffusivity

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(a(z)\frac{\partial T}{\partial z} \right)$$

Methods of determination of soil thermal properties

- Experimental methods
  - Field
  - Laboratory
- Computation using soil mechanical properties and composition
- Computation using temperature data
  - Amplitude method
  - Phase method
  - Direct numerical method
  - Inverse problem

Amplitude method of apparent heat diffusivity calculation

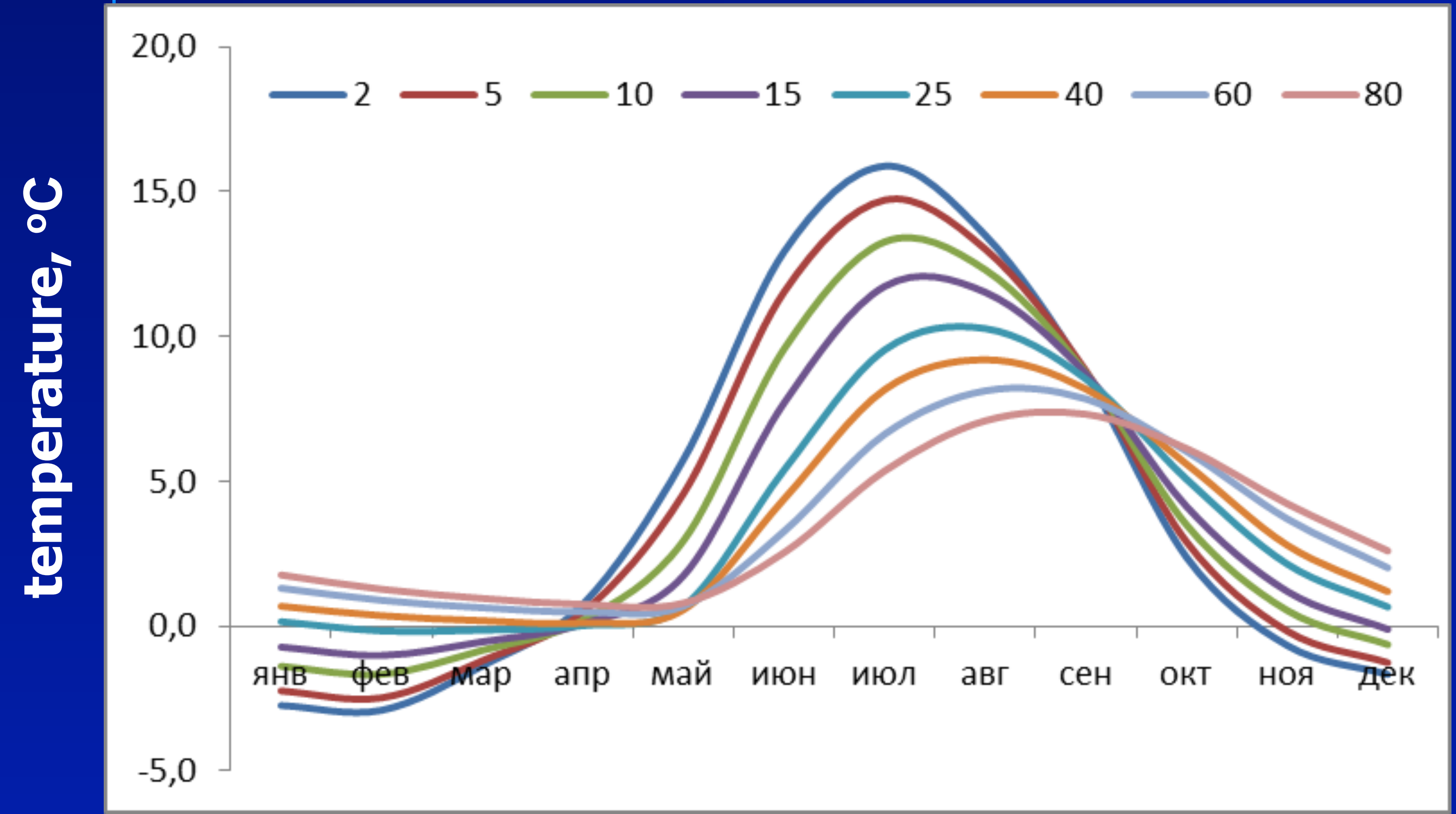
$$\frac{\partial T}{\partial t} = a\frac{\partial^2 T}{\partial z^2}$$

$$T(0,t) = T_0 + A_0 \sin(\omega t)$$

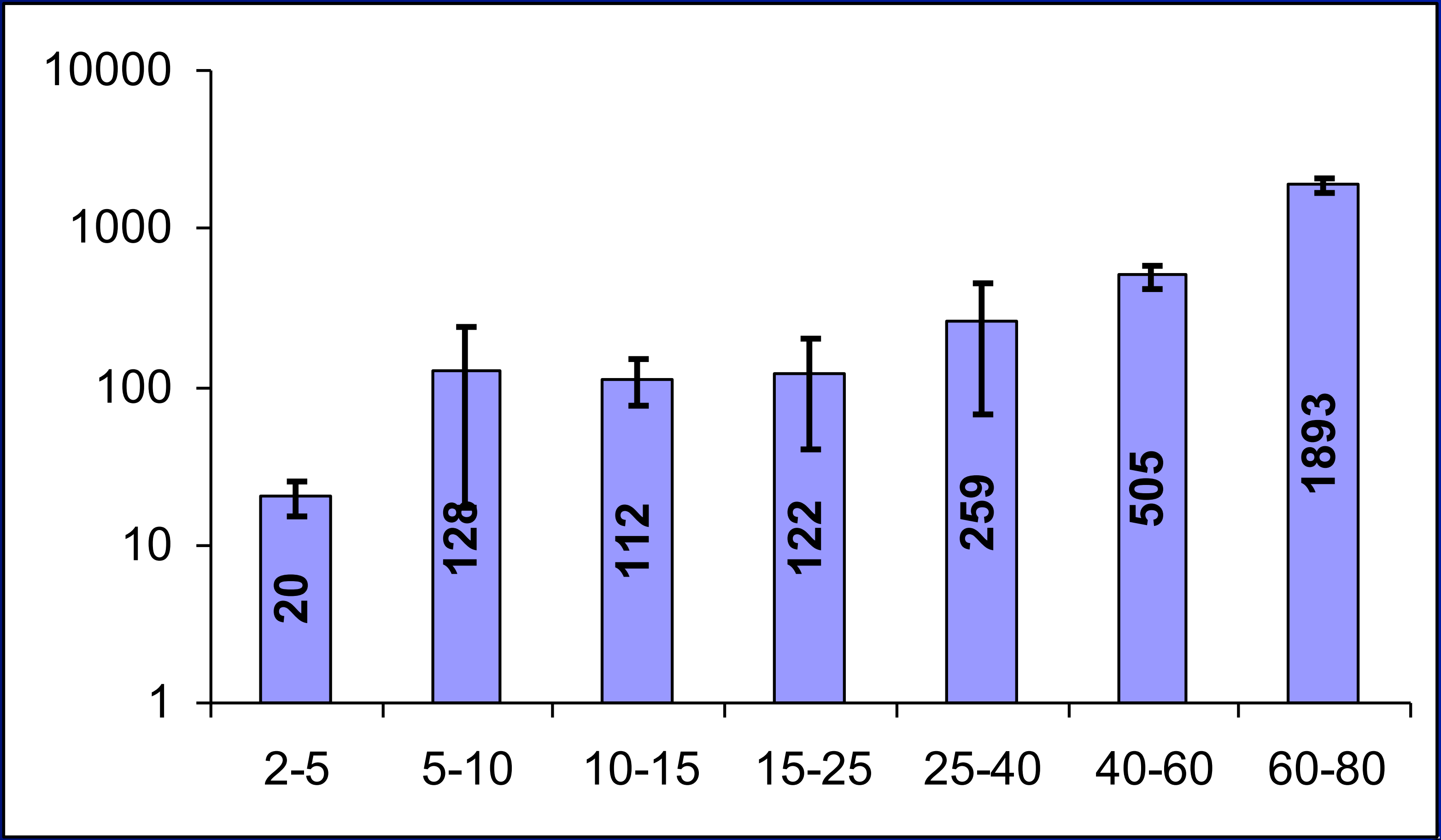
$$T(z,t) = T_0 + A_0 \exp\left(-z\sqrt{\frac{\omega}{2a}}\right)\sin\left(\omega t - z\sqrt{\frac{\omega}{2a}}\right)$$

$$a = \frac{\omega}{2}\left(\frac{z_1 - z_2}{\ln(A_1 / A_2)}\right)^2$$

Monthly soil temperature. 2005-2010 averaged.

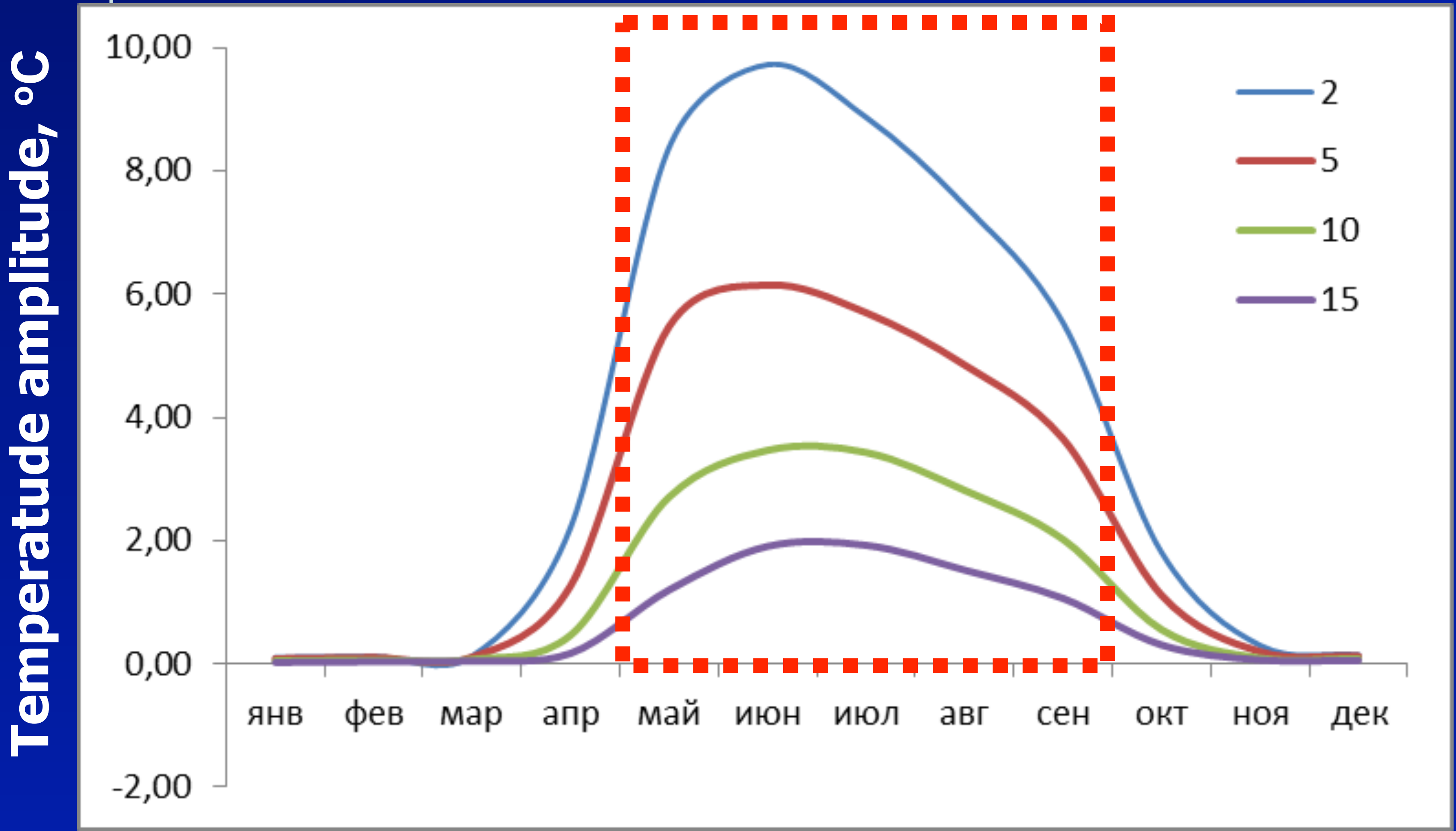


Heat diffusivity, cm^2/day. Amplitude method. Annual oscillation.

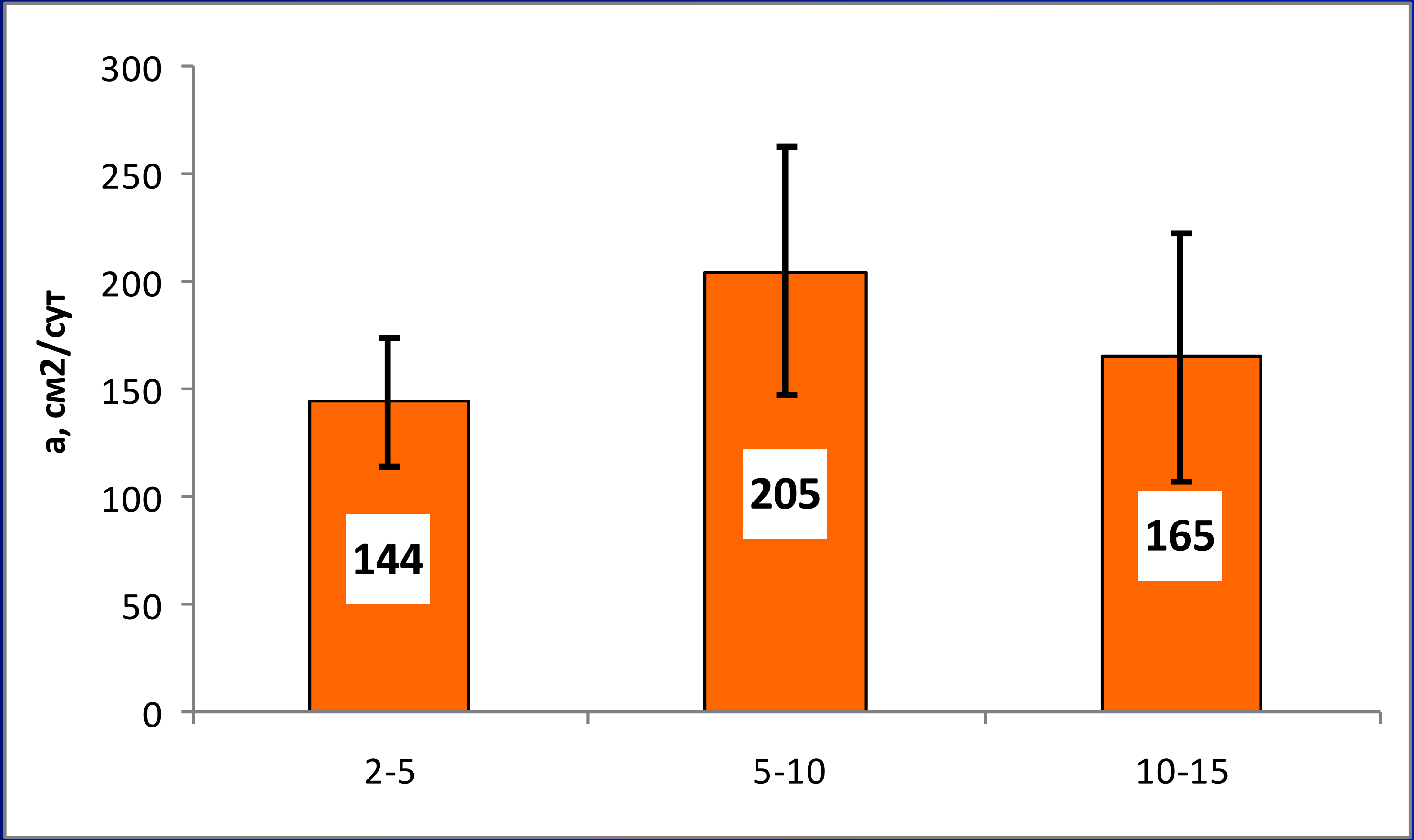


layer

Monthly amplitudes of diurnal temperature, 2005-2010 averaged.

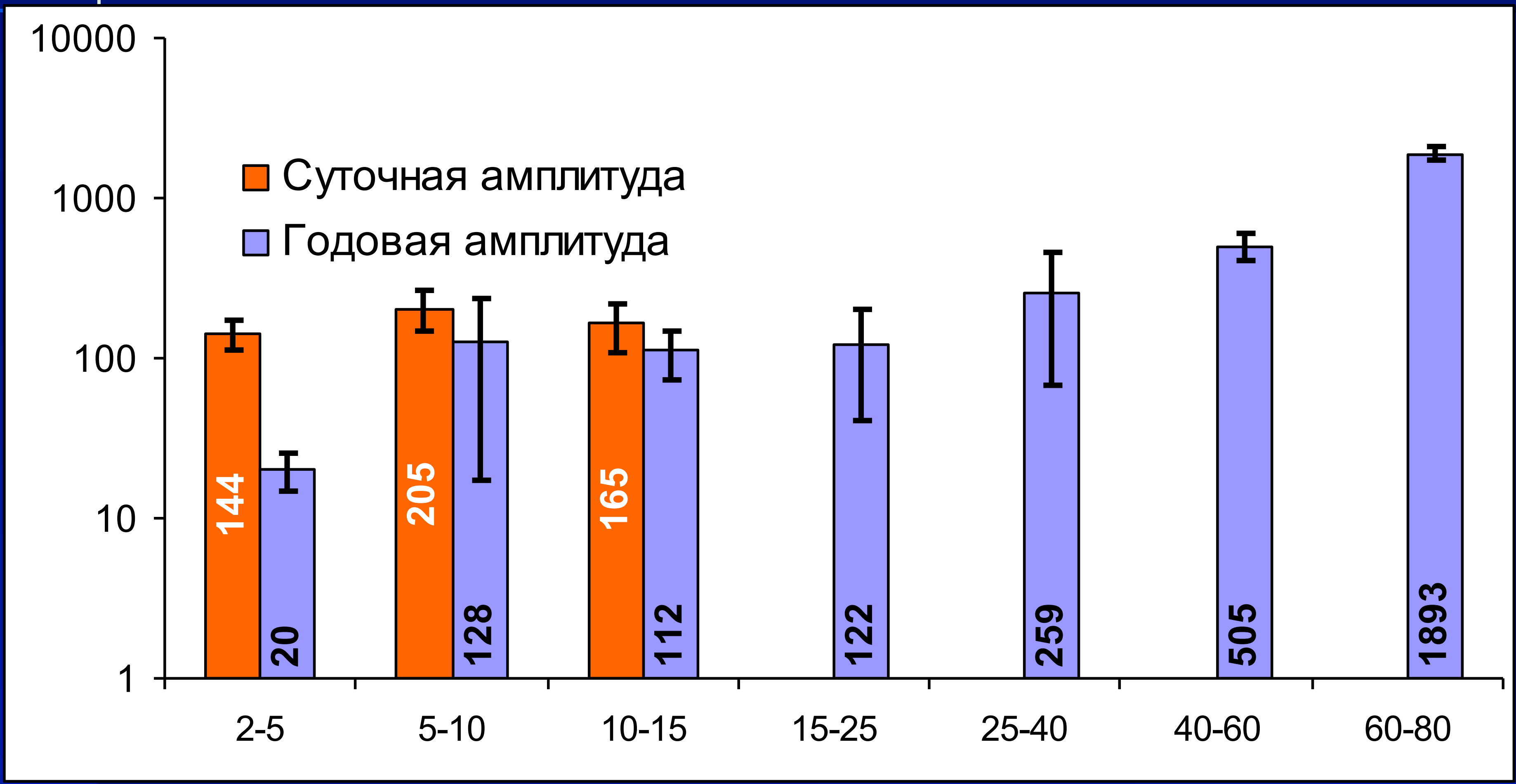


Heat diffusivity, cm²/day. Amplitude method. Daily oscillation.



layer

Heat diffusivity, cm^2/day. Annual and daily oscillations.



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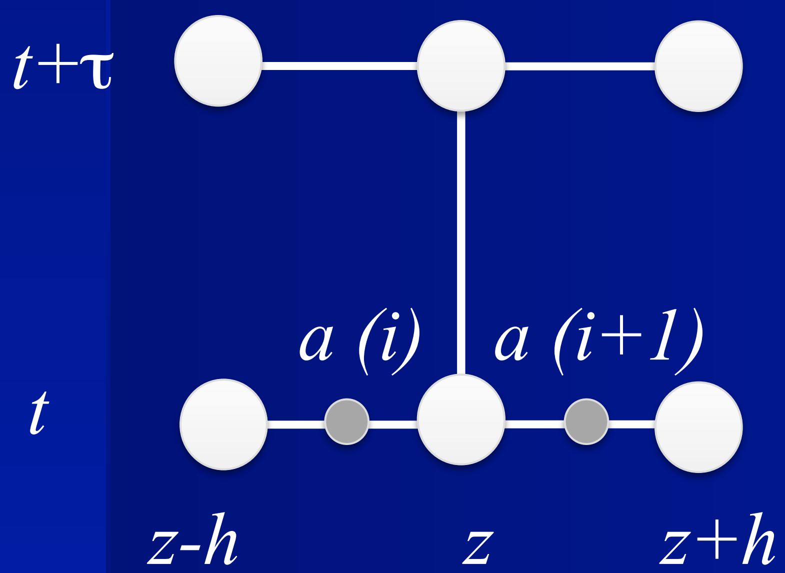
Numerical methods

Numerical soluton of heat equation

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(a(z)\frac{\partial T}{\partial z}\right)$$



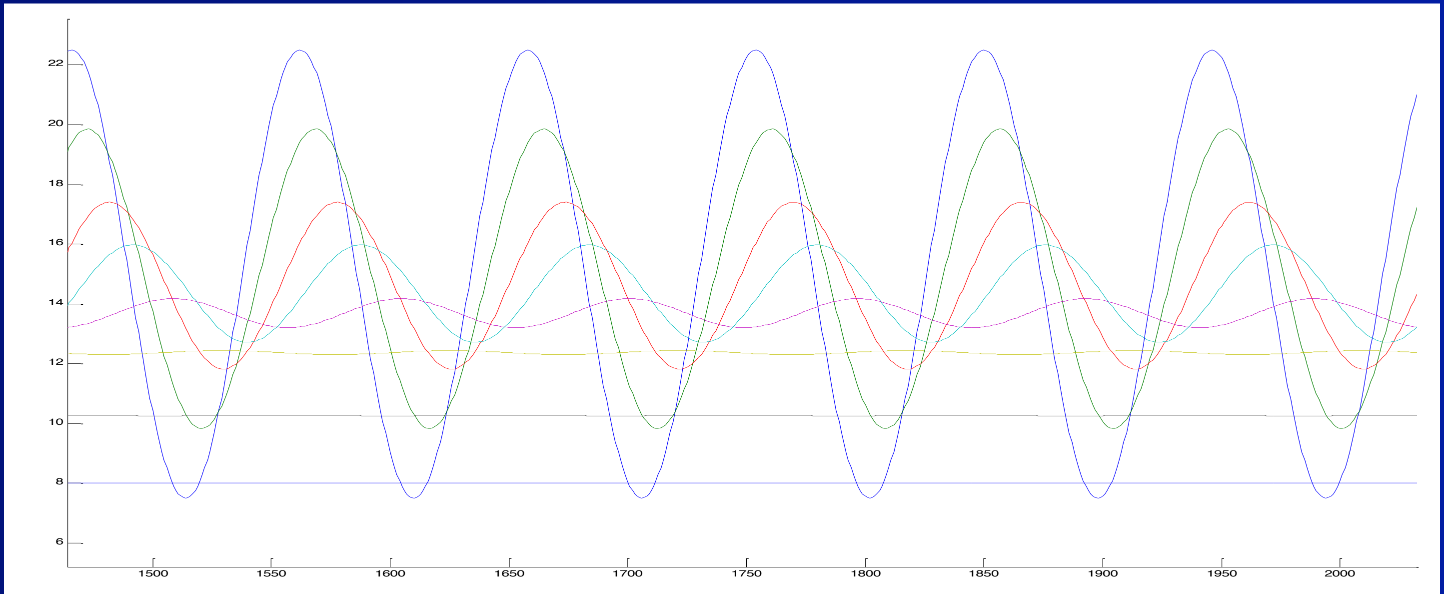
- Semi-explicit scheme
- Boundary condition of 1 type
- 8 layers

Model data
- regular oscillations.
Direct solution.

$a = const = 200\ cm^2/day$

$T0 = 15 + 7{,}5 \sin(2\pi t)$

temperature, °C



time

Inverse problem

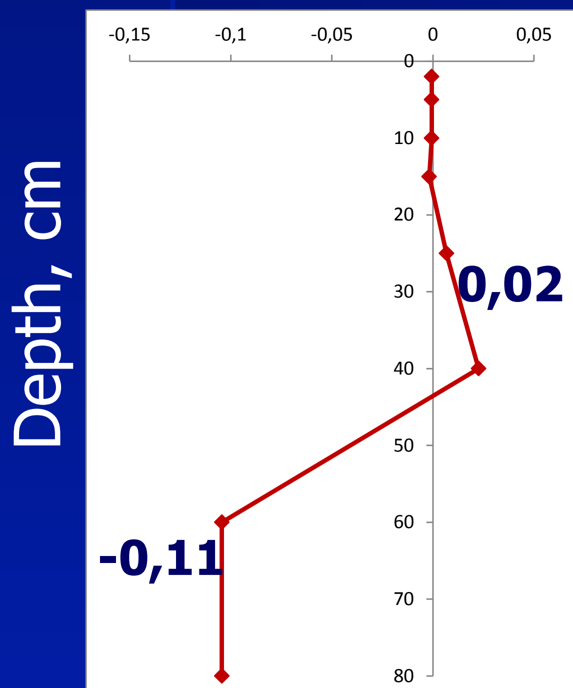
- Initial condition - a0(z)
- Model spin-up - 3 days
- Minimization of function

$$J(a) = \frac{1}{N-2}\frac{1}{M-m}\sum_{j=m}^{M}\sum_{i=2}^{N-1}\left(T_{ij} - T_{ij}^{\;0}\right)^2$$

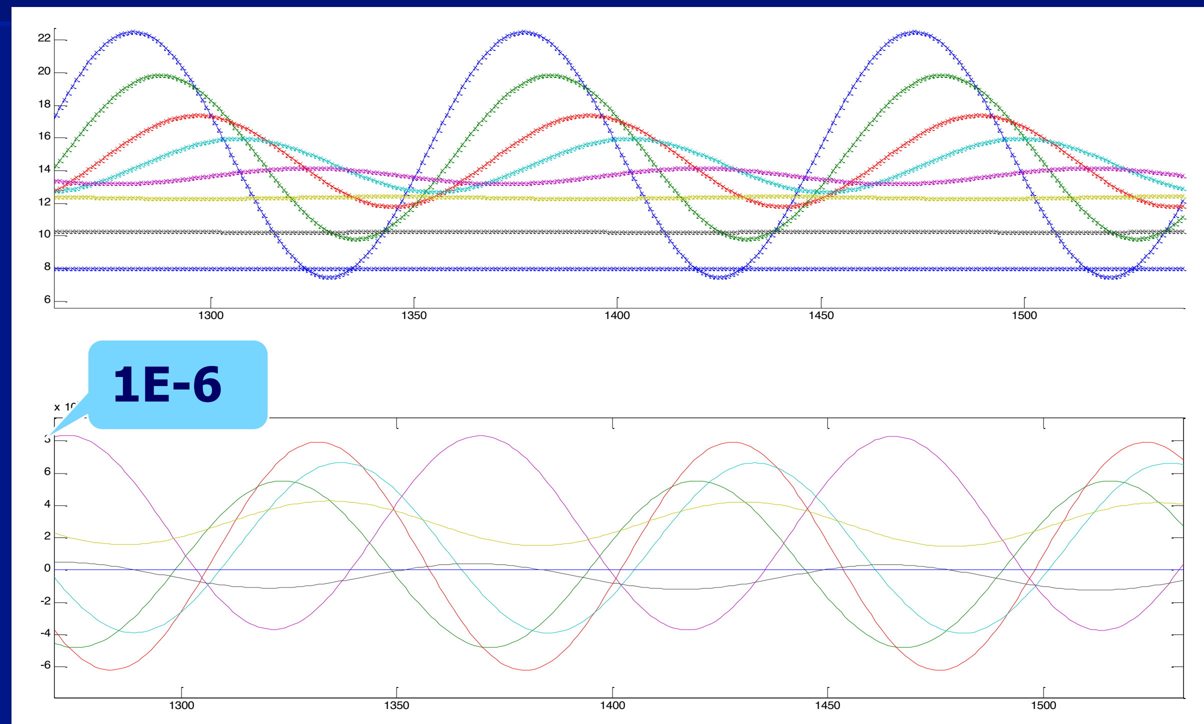
- Iterations for accurate definition a(z)

Inverse problem (a=200)

Heat diffusivity error

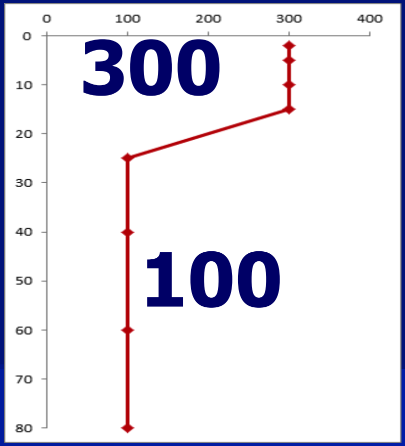


Temperature



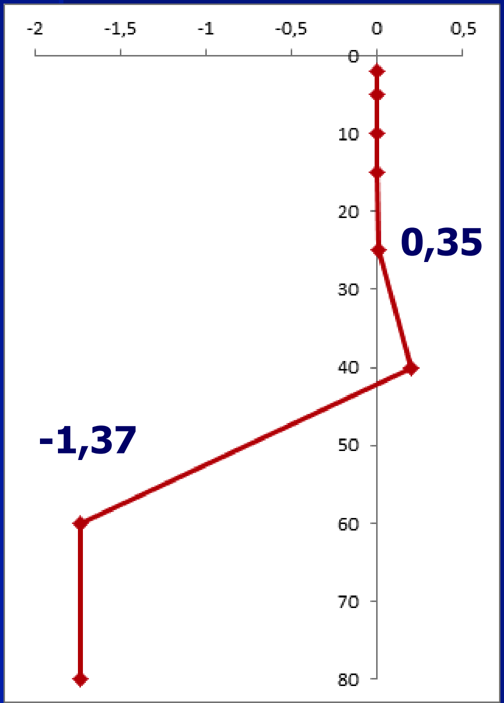
Error of temperature
dT = T(modeled) – T(measured)

Two layers: $a_1 = 300, a_2 = 100)$

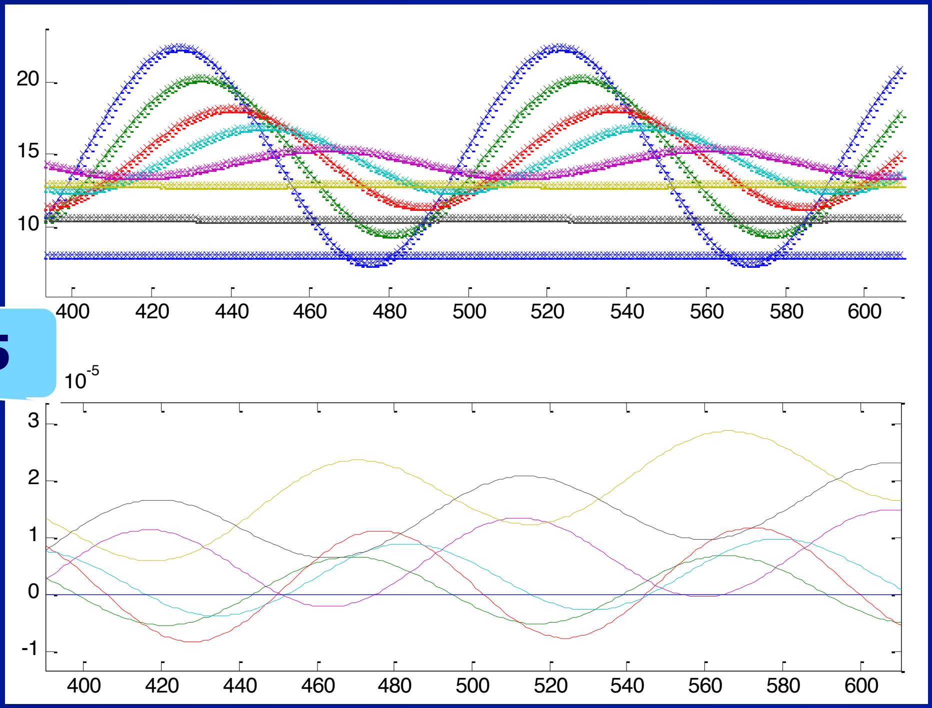


Heat diffusivity error

Depth, cm



Temperature

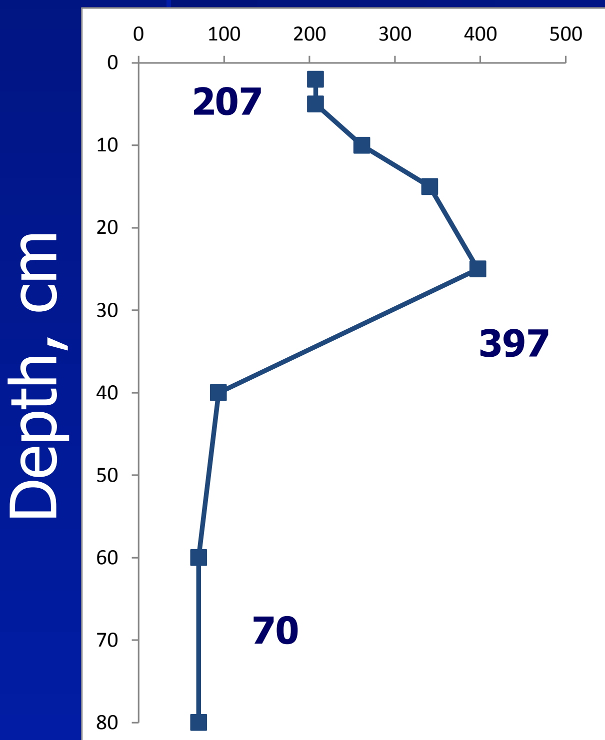


Error of temperature

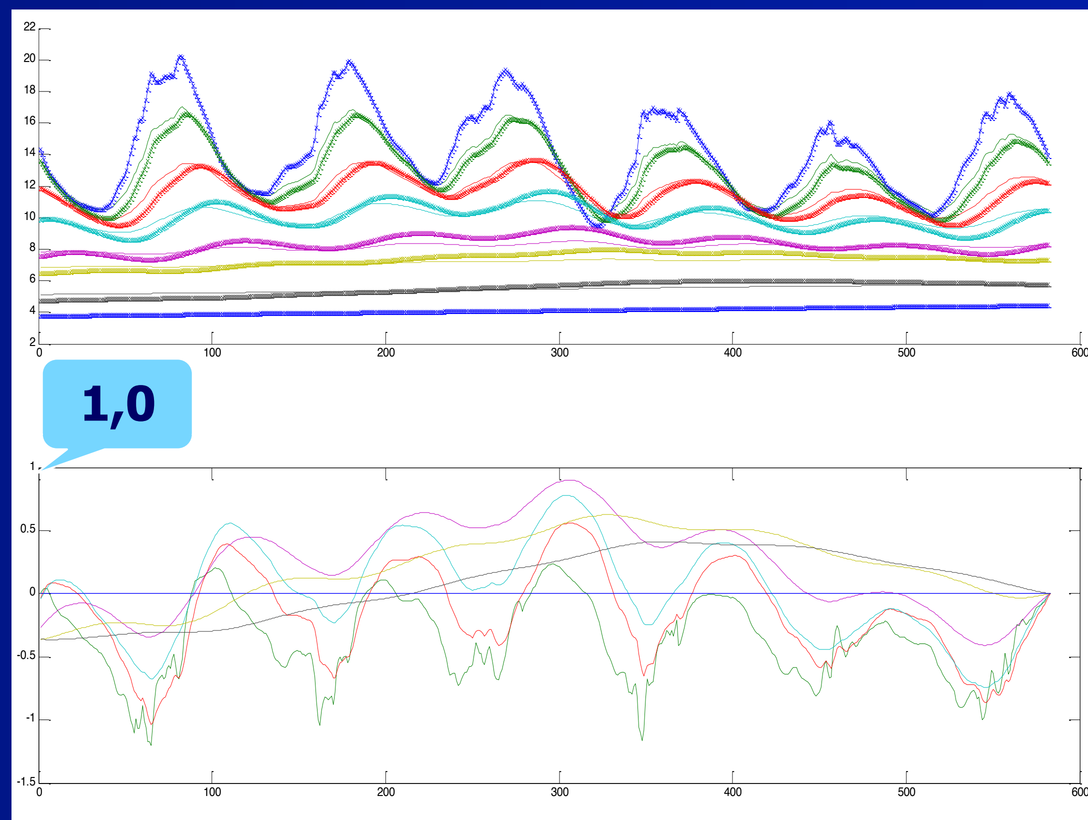
dT = T(modeled) – T(measured)

Real data – soil temperature august 2009

Heat diffusivity error



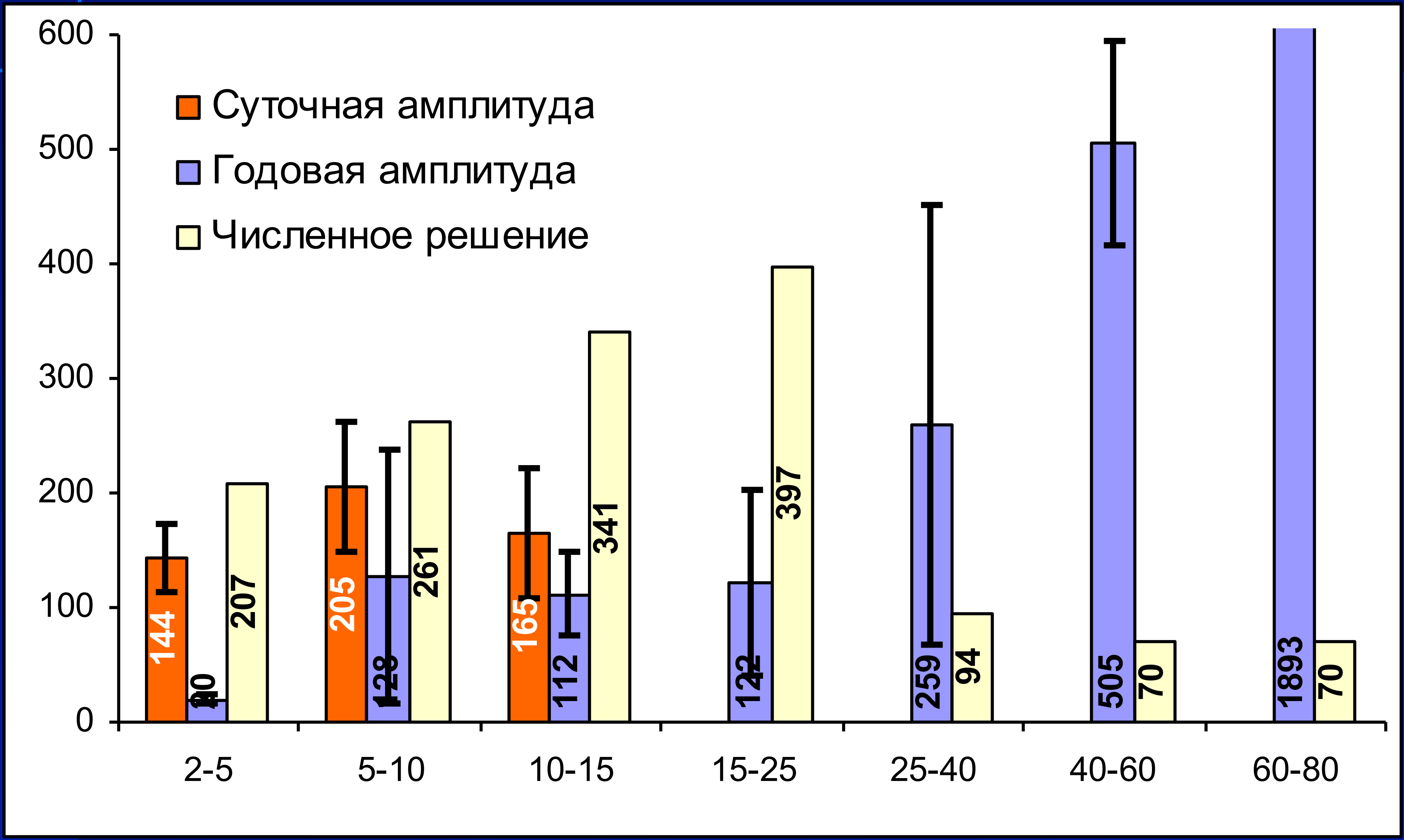
Temperature



Error of temperature

dT = T(modeled) – T(measured)

Heat diffusivity, cm²/day. Methods comparison.



layer

Tasks

- Winter period

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(a\frac{\partial T}{\partial z}\right) + f$$

- Evaporation, freezing, melting
- Heat conduction at water infiltration


Спасибо за внимание!
Foto: S.V. Smirnov