Расчетная схема глубины промерзания грунта на основе данных об особенностях сезонного выпадения снегопадов, накопления снежной толщи и изменения температуры.

Calculating scheme of ground freezing depth on basis of data on peculiarities of seasonal snowfalls deposition, snow cower accumulation and temperature variation.

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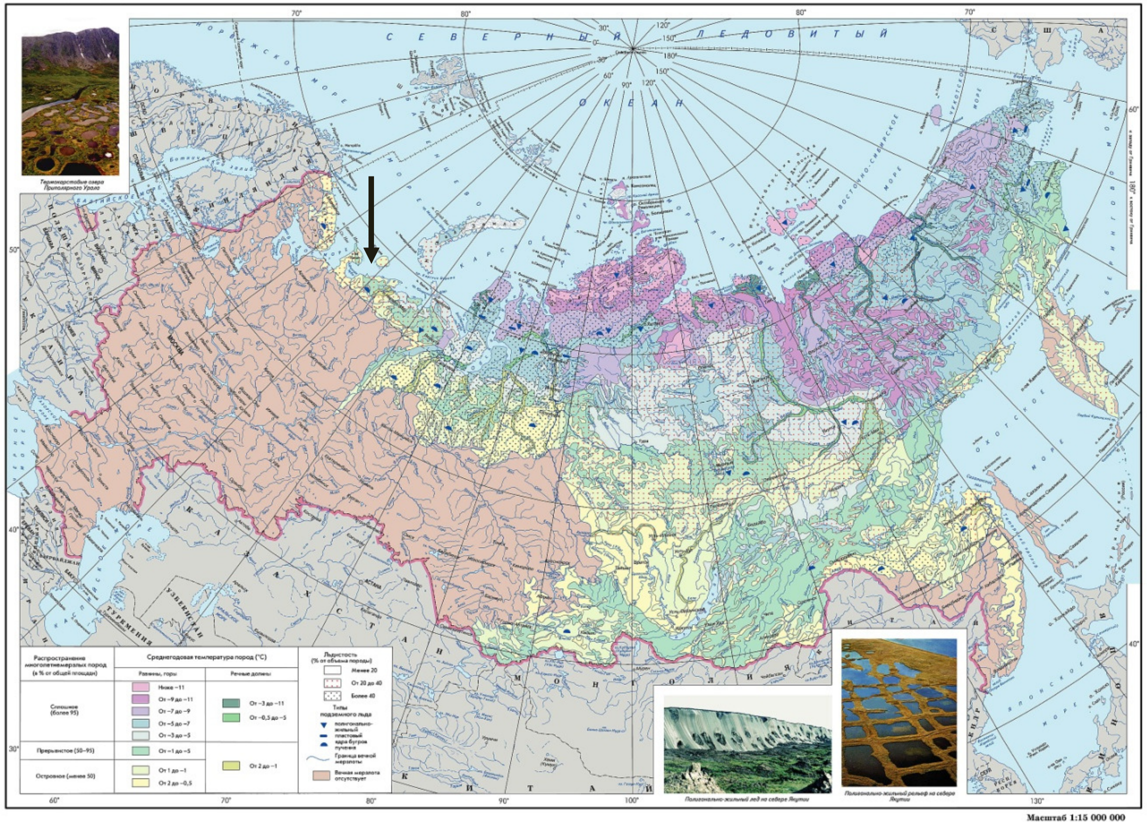
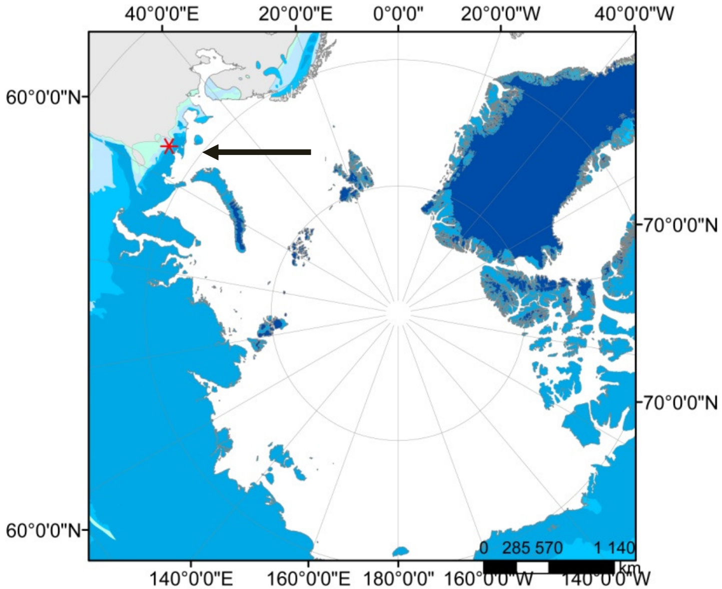
The considered region is
with discontinues permafrost
on the north of the European territory of Russia:



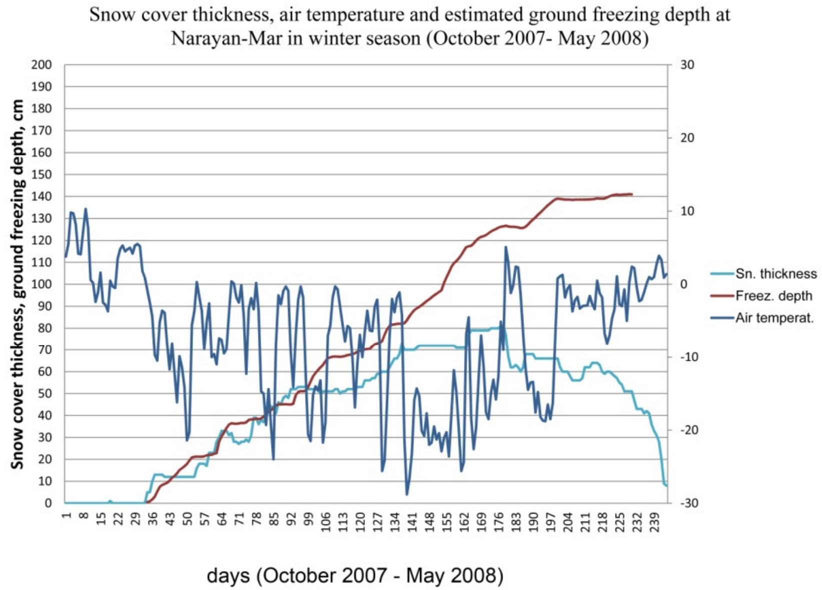
Map of distribution of permafrost grounds

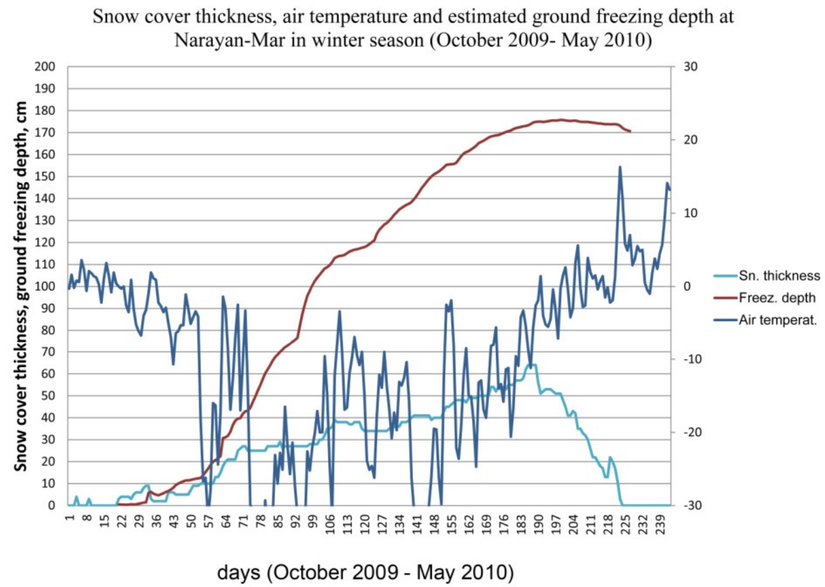


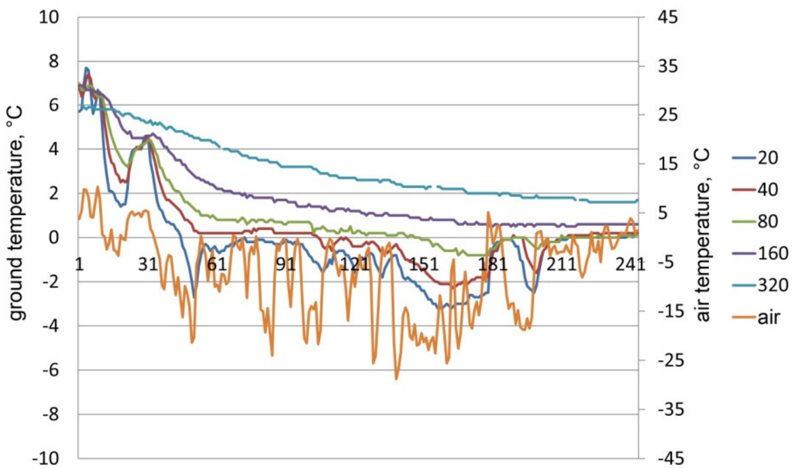
Circumpolar map of permafrost

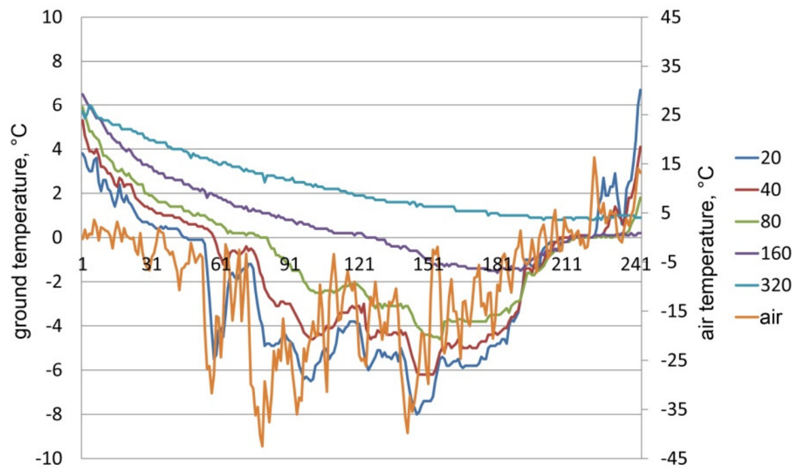
(http://национальныйатлас.рф/)

Snow cover thickness, estimated ground freezing depth and observed temperature of air and ground on different depths at Narayan-Mar in winter seasons of 2007/08 u 2009/10.









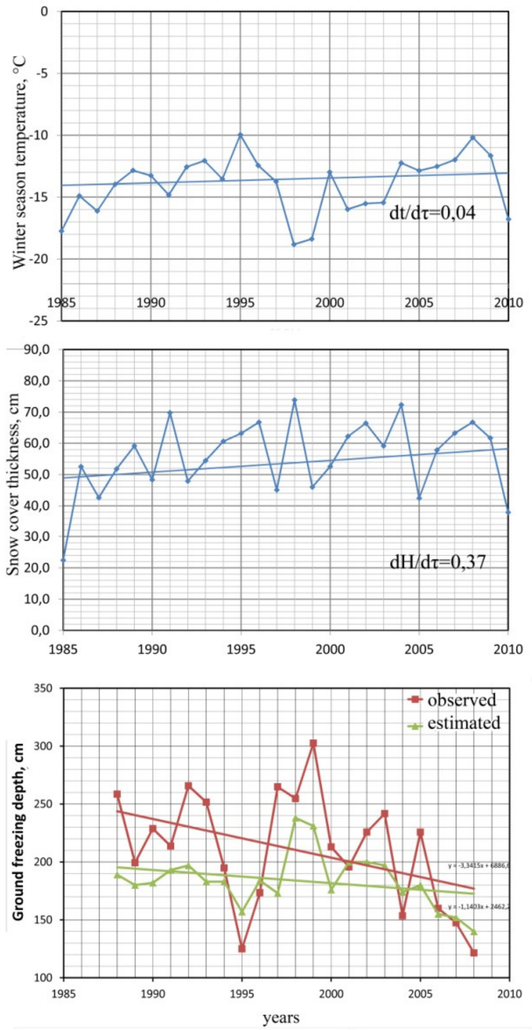
Variations of winter temperature, snow cover thickness and observed and estimated ground freezing depth

Narayan-Mar
(1985-2010)

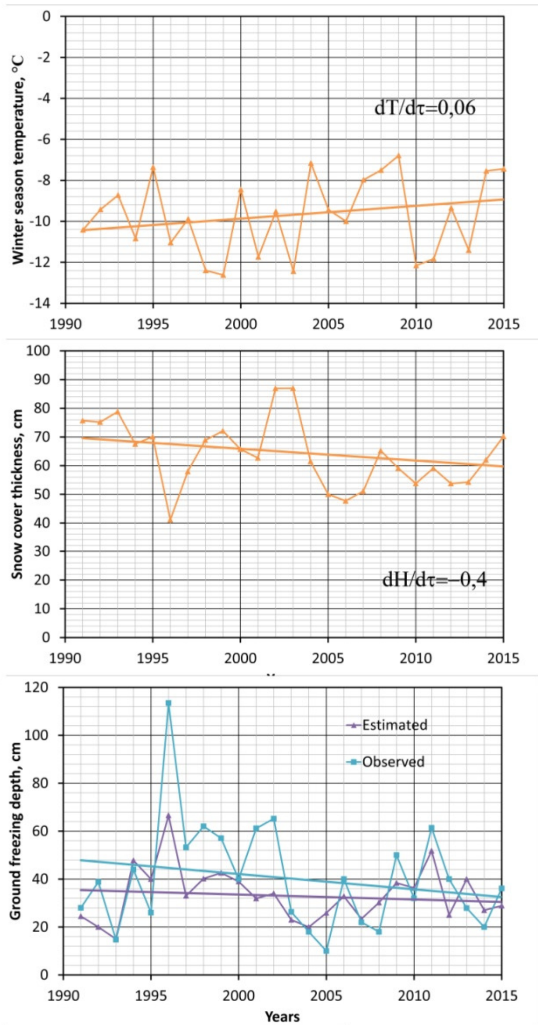
Winter season temperature, °C

Snow cover thickness, cm

Estimated and observed ground freezing depth, cm
Correlation 0.76



a



b

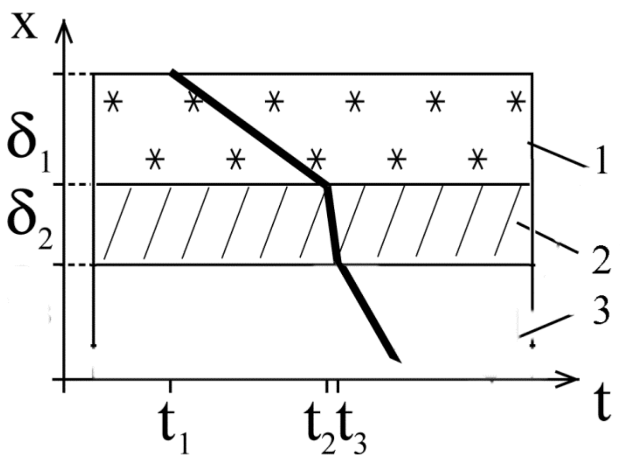
Syktyvkar:
(1990-2015)

Winter season temperature, °C

Snow cover thickness, cm

Estimated and observed ground freezing depth, cm
Correlation 0.77

Stepwise calculating scheme



Calculation scheme considers ground freezing (3) below the massif of frozen ground (2), covered with snow cover (1) in winter season on the base of daily data on air temperature and snow cover thickness. The equation of heat balance is written as: $F_1=cLV+F_2$, where

F_1 – is heat outflow through snow cover and frozen ground from ground freezing interface (W/m^2);

cLV – heat value for phase transition in the ground,

c -ground moisture content (1-4 kg/cm*m^2),

L - energy of H_2O phase transition (335 kJ/kg), V - rate of movement of ground freezing interface (cm/s);

F_2 – heat outflow for cooling of thawed ground in front of ground freezing interface (W/m^2).

Heat flux is expressed according to Fourier law by means of temperature gradient and heat conductivity as $F=\lambda$ (grad T). Heat conductivity and heat flux through combination of two media (snow and frozen ground) can be expressed as:

$$F_1=\lambda\frac{\Delta T}{\Delta x}=\frac{\Delta T}{\left(\frac{\Delta x_s}{\lambda_s}+\frac{\Delta x_{fg}}{\lambda_{fg}}\right)}=\frac{T_{air}}{\left(\frac{h_s}{\lambda_s}+\frac{l_{fg}}{\lambda_{fg}}\right)}$$

Here T_{air} – air temperature,

h_s и l_{fg} – snow cover thickness and ground freezing depth, and

λ_s и λ_{fg} – heat conductivity of snow and frozen ground.

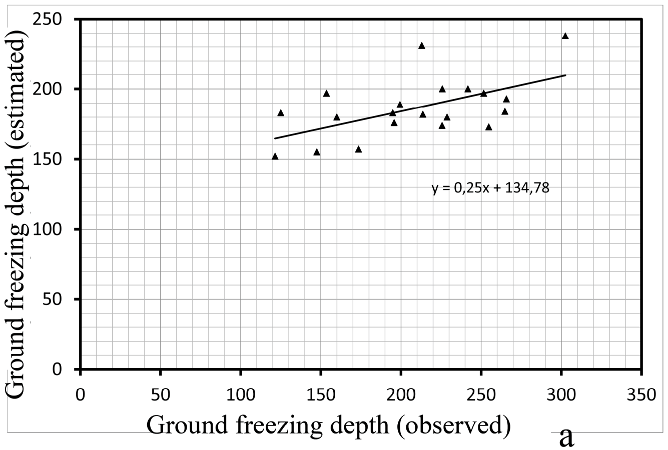
Stepwise calculating scheme

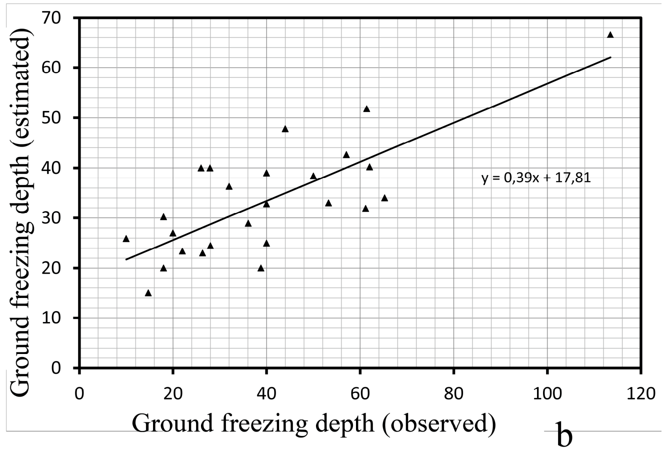
It was supposed, that on the depth of 10 m in ground there is a point of zero annual temperature oscillation with temperature value T_0 about 3°C. That is why

$$F_2 = \lambda_{fg} \frac{\Delta T}{\Delta x} = \lambda_{fg} \frac{T_0}{10 - l_{fg}}$$

Calculations were done with the step-size of one day. For initial conditions it was supposed that frozen ground thickness l_{fg} was equal 0.5 cm. For each time step (for each day) the rate of movement of freezing interface V and the value frozen ground thickness l_{fg} for the next day (time-step) were calculated. Averaged heat conductivity of snow was assumed to be equal 0.18 W/m °C. Averaged heat conductivity of thawed and frozen ground were assumed to be equal 1.5 and 1.8 W/m °C.

Correlation of observed and estimated ground freezing depth in Narayan-Mar in 1988-2008 (a) and in Syktyvkar in 1991-2015 (b) is equal 0.76 and 0.77.

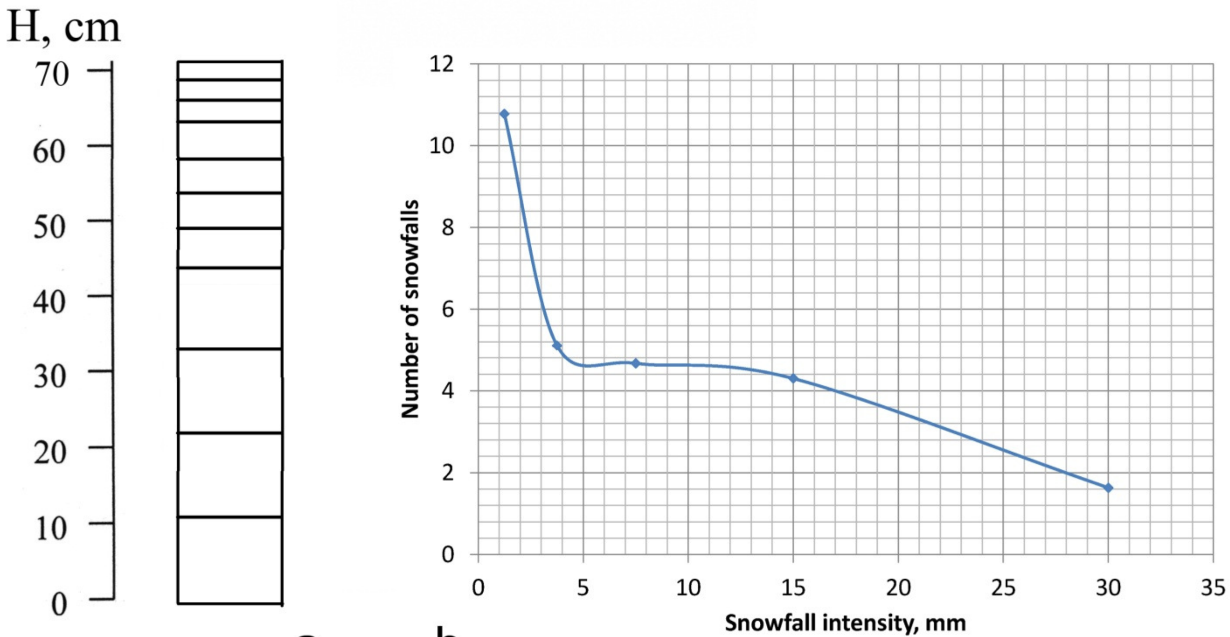




CONCLUSION

We suggest calculating scheme on basis of three layer media heat conductivity problem (snow cover, frozen and thawed ground) with phase transition on the boundary of frozen and unfrozen ground. Heat balance equation includes phase transition energy, inflow of heat from unfrozen ground and outflow to frozen ground, snow cover and atmosphere. The heat flux is calculated on basis of Fourier law as a product of heat conductivity and temperature gradient. It is supposed, that temperature change in each media linearly. The assumption that snow cover consists of different layers deposited by different snowfalls and having different structure and density and heat conductivity depending on its density is also taken. The density and heat conductivity of each layer and the whole thickness of snow cover are determined and the regional stratigraphic column for snow cover is compiled and the calculation of ground freezing intensity and freezing depth is conducted. The comparison of estimated with calculating scheme and observed values of ground freezing depth is performed and the correlation of equal 0.76-0.77 of them is stated. For validation of calculating scheme the experiment of one-direction freezing of covered with snow sand sample was also conducted in refrigerated chamber under the action of negative temperatures. The intensity of freezing and rate of movement of phase transition front are determined and stated to be in good agreement with the obtained ones by calculating scheme values.

Taking into account of layered structure of snow thickness:



a b

$$\frac{\lambda}{\Delta x} = \frac{1}{\frac{\Delta x_1}{\lambda_1} + \cdots + \frac{\Delta x_n}{\lambda_n}}$$ c

(a) - generalized stratigraphic column of snow cover for meteorological station Narayan-Mar for 1988-2008,

(b) - plot of average number of snowfalls of particular intensity according data of meteorological station Narayan-Mar for 1988-2008 and

(c) - formula of heat conductivity of multilayer media

Validation of calculating scheme with the experiment of one-direction freezing of covered with snow sand sample

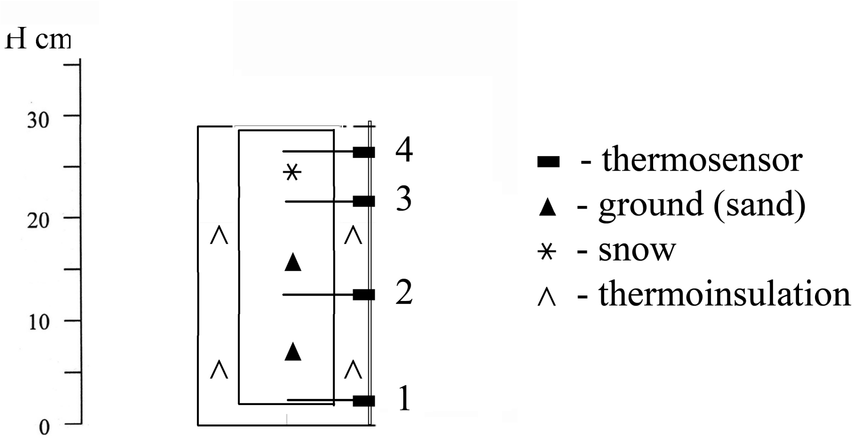
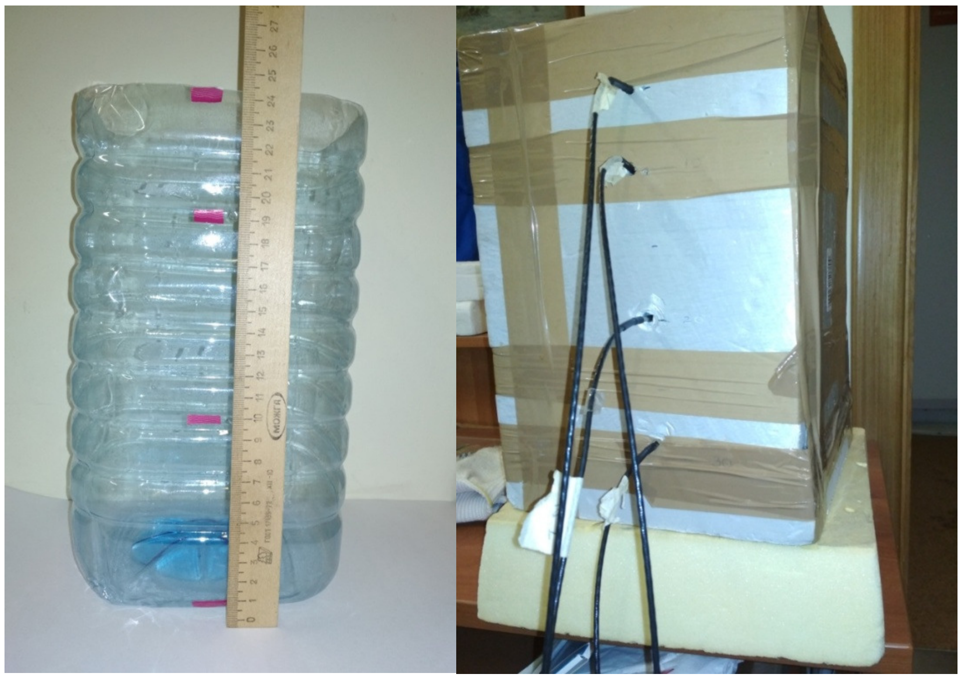
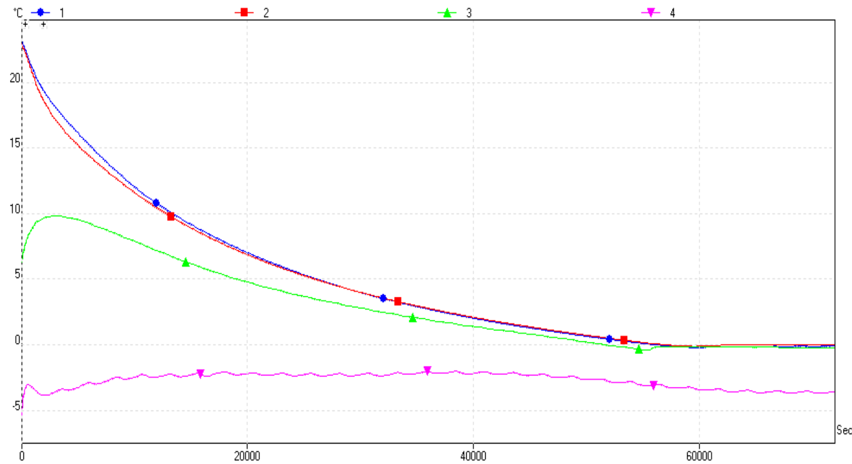
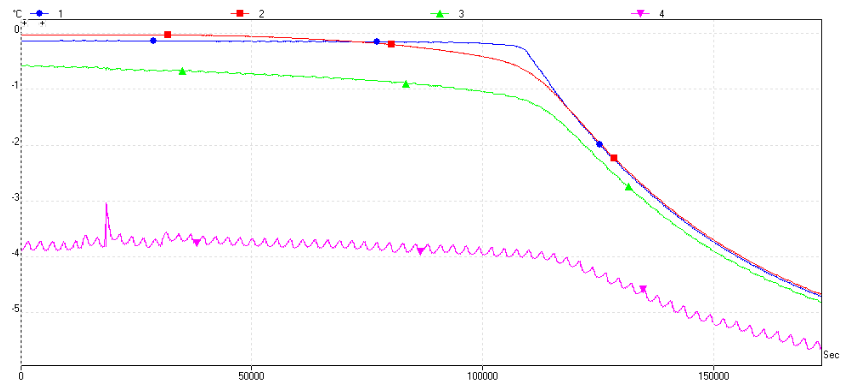


Рисунок 2 . Вид ёмкости с расположением датчиков







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