Parameterization of the thermal conductivity of soil in the active land layer block of the INM RAS-MSU model

Параметризация коэффициента теплопроводности почвы в блоке деятельного слоя суши модели ИВМ РАН-МГУ

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Abstract: The active land layer block of the INM RAS-MSU model uses a simplified parameterization of heat transfer. More prospective parameterizations of the thermal conductivity coefficient were selected and implemented in the computational algorithm of the model. Switching to a new method for setting the soil thermal conductivity coefficient will significantly improve the accuracy of reproducing heat transfer in the model.

Аннотация: В блоке деятельного слоя суши модели ИВМ РАН-МГУ применяется упрощенная формула расчета коэффициента теплопроводности почвы. Были выбраны и внедрены в вычислительный алгоритм модели более перспективные параметризации коэффициента теплопроводности. Переход к новому способу задания коэффициента теплопроводности почвы существенно улучшит точность воспроизведения теплопереноса в модели.

Motivation:

The active land layer is a significant reservoir of heat accumulation in the Earth system [Beltrami et al., 2002]

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Thermal inertia of soil at depths affect atmospheric circulation over land on time scalesfrom weeks to several months [Fatichi et al., 2020]

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In the models of the Earth system, it's necessary to improve parameterization of heat and moisture transfer in the soil cover

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The model of the Earth system INM RAS-MSU uses simplified parameterization of heat transfer

Objective:

Improving the description of heat transfer in soil cover in the model of the Earth system of the INM RAS-MSU

Tasks:

- Selection of prospective parameterization of the soil thermal conductivity coefficient;
- Evaluation of the effect of their implementation in the INM RAS-MSU model;
- Collection initial soil data for modelling.

Soil thermal conductivity models:

OLD

R. Pielke [McCumber, Pielke, 1981]

$$\lambda_T = 418.7\max(\exp(-P_f - 2.7), 0.00041)$$

- Uses function of the **soil moisture potential**
- **Empirical** relationship
- Type of soil and the amount of liquid moisture are not accounted implicitly
- Porosity, density, structural features, and mineralogical composition have only an indirect effect

NEW

In soil physics

Johansen [Johansen, 1975]

$$\lambda_T = (\lambda_w^n \lambda_s^{1-n} - \lambda_{dry})k_r + \lambda_{dry}$$

+ Based on a theoretical model
+ Parameters are available for measurement
+ Consider porosity, density

Cote-Konrad [Cote, Konrad, 2005]

$$\lambda_T = (\lambda_w^n \lambda_s^{1-n} - \chi 10^{-\eta n})k_r + \chi 10^{-\eta n}$$

+ Developed the Johansen model
+ Parameters are available for measurement
+ Consider soil type and pore space structure

Thermal conductivity of porous media

Fractal model [Qin et al., 2018]

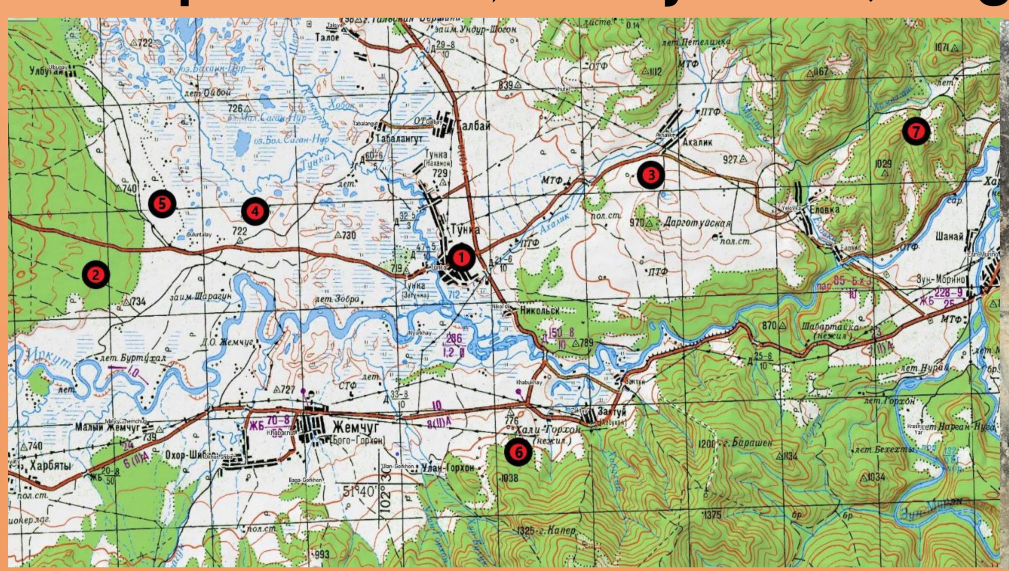
$$\lambda_T = \gamma + \beta \frac{\gamma(\lambda_s - \gamma)}{\lambda_s + 2\gamma}$$

here $\alpha = \frac{D_{Tw} + D_{fw} - 1}{D_{fw}} S_r^{1+\frac{D_{Tw}-1}{D_E - D_{fw}}}$, $\beta = \frac{3(D_{fs}-1)^3 n}{D_{fs}^2(3-D_{fs})}$, $\gamma = [\alpha\lambda_w + (1-\alpha)\lambda_a]$

+ Based on the Fourier's law
+ Input parameters – only porosity, moisture content
+ Include calibration parameters
- Restrictions for using on global grid

Was firstly performed for the Earth system models

Field studies in the Tunkinsky depression, Buryatia (August 2019)



Collected data:

- Soil **density, porosity, initial vertical moisture distribution**
- **7 points** over the basin
- Depths up to **50 cm** with **10 cm** step

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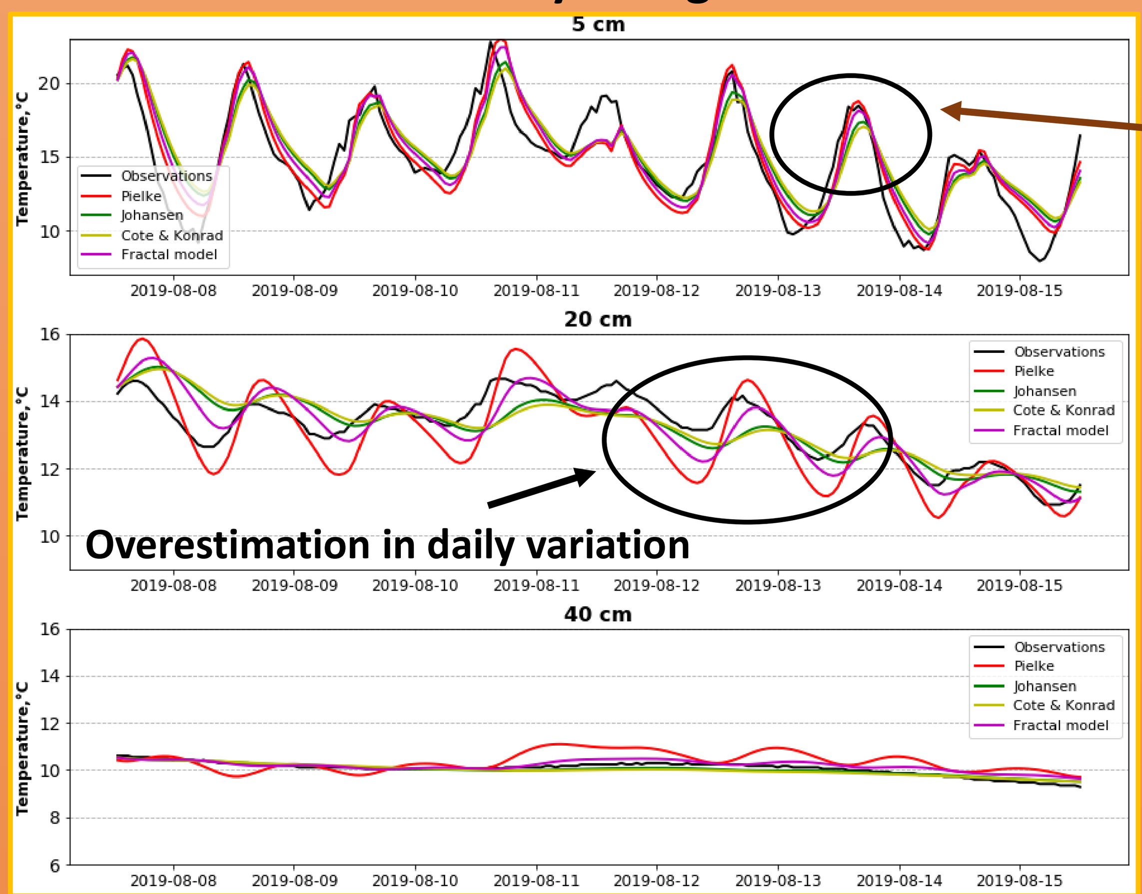
- **3 soil types:** silt and clay, sandy soil, organic soil

Compared with unique measurements of soil temperature at depths up to 10 meters with 1 hour time step

Numerical experiments and results

Time variability in organic soil



- The surface temperature values weakly depend on the parameterization of the thermal conductivity of soil.
- Maximum errors were observed near the surface due to inaccuracies in modeling of heat balance of the surface.

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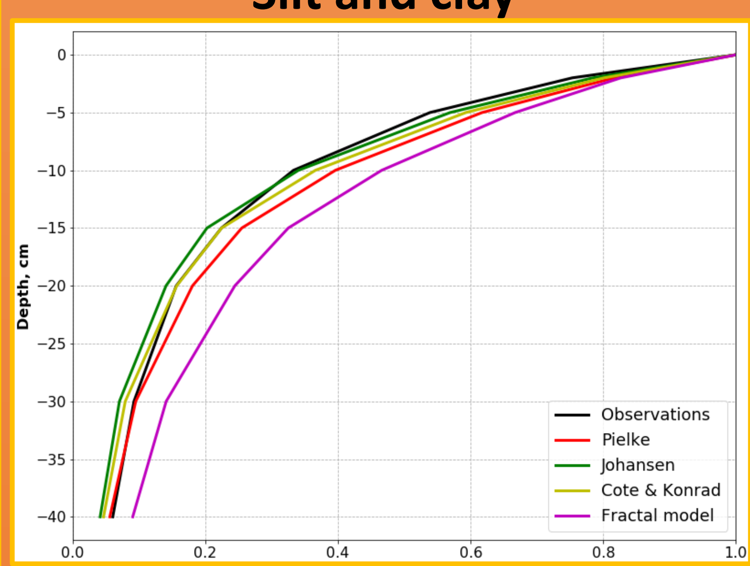
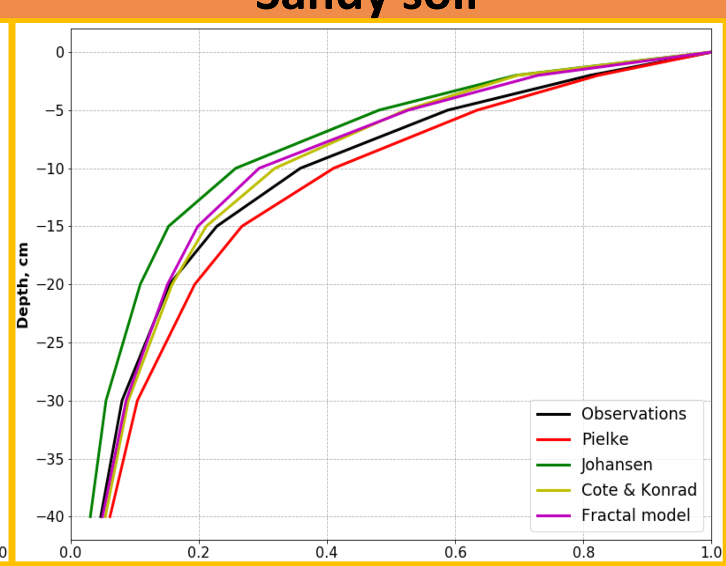
Based on the Fourier's law were introduced new error metric $\sigma_i / \sigma_{surface}$

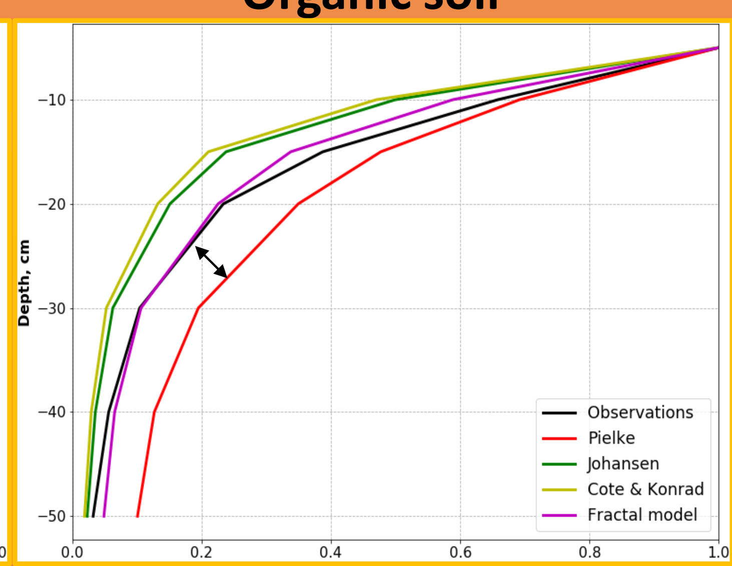
Silt and clay



Sandy soil



Organic soil



For all soil types the Pielke parameterization didn't produce the most accurate results
Choosing the Cote-Konrad parameterization allows to obtain the most approximate results

Conclusions:

- R. Pielke parameterization used in the basic version of the model is less accurate than more modern parameterizations of thermal conductivity.
- The fractal model of thermal conductivity has a greater potential for improving accuracy, but it's limited by the lack of global databases for a number of its parameters.
- **For the global grid of the earth system model INM RAS-MSU, is proposed choosing the Cote-Konrad parameterization of the soil thermal conductivity.**