Development of a Physically Based Model for Soil Water and Heat Transfer Processes in Semi-Arid Cold Region

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Background

- In general, freezing soil is widely spread in semi-arid cold region.
- In such region, when we simulate the processes of soil water and heat transfer, we need to consider influence of freezing soil.
- So, in this study, we introduce freezing soil process into exist our model.

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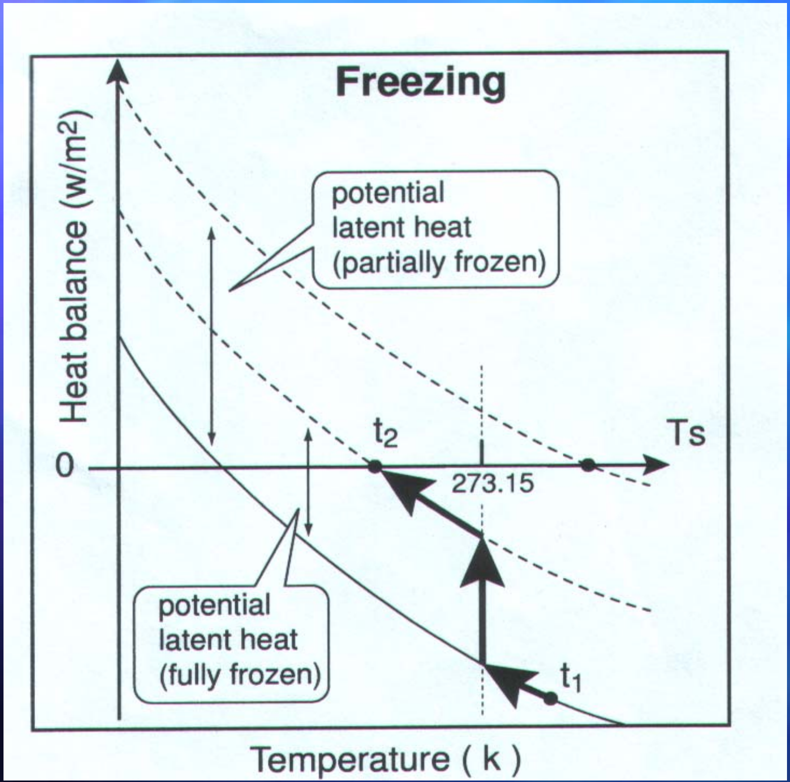
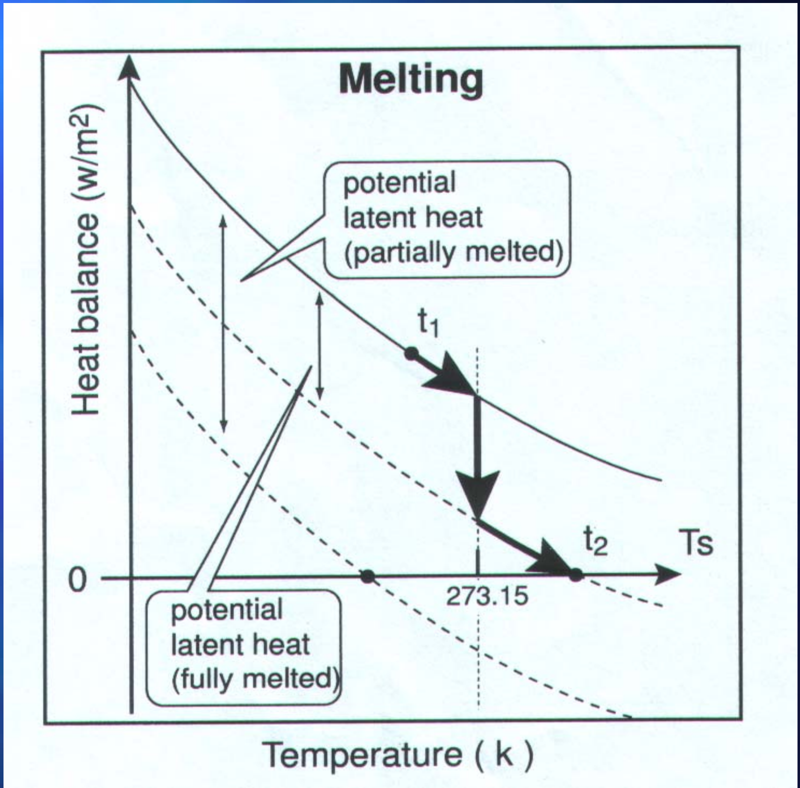
Model Merit

- Phase change process is included

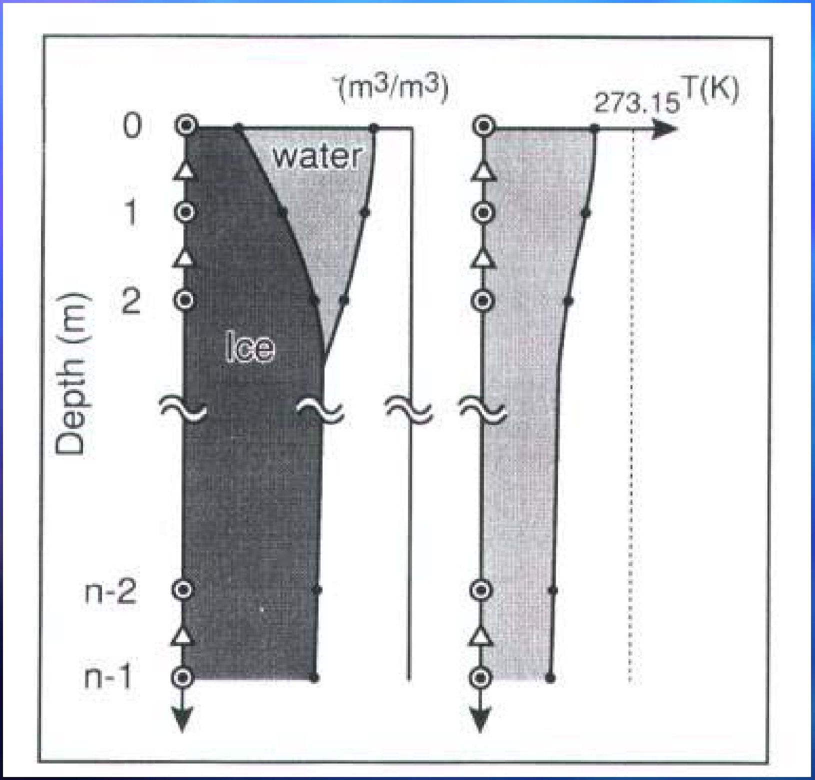
  in order to considered freezing and melting of soil water.
- In this model, the number of layers can be arranged arbitrarily.

Phase change process





Dividing Soil Layer



- We can divide into user-defined number of soil layer.
- Calculation nodes are put at each layer surface
- Triangles of figure are the middle each node.
- Water and heat flux are calculated here

Basic Equations

$$\frac{\partial \theta w}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial \Phi}{\partial z} \right)$$

$$\frac{\partial \rho C T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z} \right)$$

θw : *volumetric Water Content*

K : *unsaturated hydraulic conductivity*

Φ : *total potential*

ρ : *density of soil*

C : *heat capacity*

T : *temperature*

λ : *heat conductivity*

Heat Balance Equation at Land Surface

$$F(T_s) = R + H_{rain} - \varepsilon\sigma T_s^{\,4} + H + lE + G$$

$$R = S\downarrow(1-\alpha) + L\downarrow$$

$$lH = \frac{\rho_a Cp(e_a - e_s(T_s))}{\gamma(r_a + r_{soil})}$$

$$H_{rain} = P / C_w(T_a - T_s)$$

$$r_a = \frac{1}{C_H U} = \frac{1}{C_E U}$$

$$H = \frac{\rho_a C_p(T_a - T_s)}{r_a}$$

$$r_{soil} = \frac{216(\theta_{sat} - \theta_w)^{7.5}}{D_{atm}}$$

Soil Water Characteristics

Soil water characteristic which are used for calculation are represented as soil water function

【Soil water characteristic】

$$\Phi = \Phi_b \left(\frac{\theta_w}{\theta_{sat}} \right)^{-b}$$

$$K = K_s \left(\frac{\theta_w}{\theta_{sat}} \right)^{2b+3}$$

Φ_b : *bubbling pressure*

Φ : *total potential*

Ks : *saturated hydrauric conductivity*

K : *unsaturated hydrauric conductivity*

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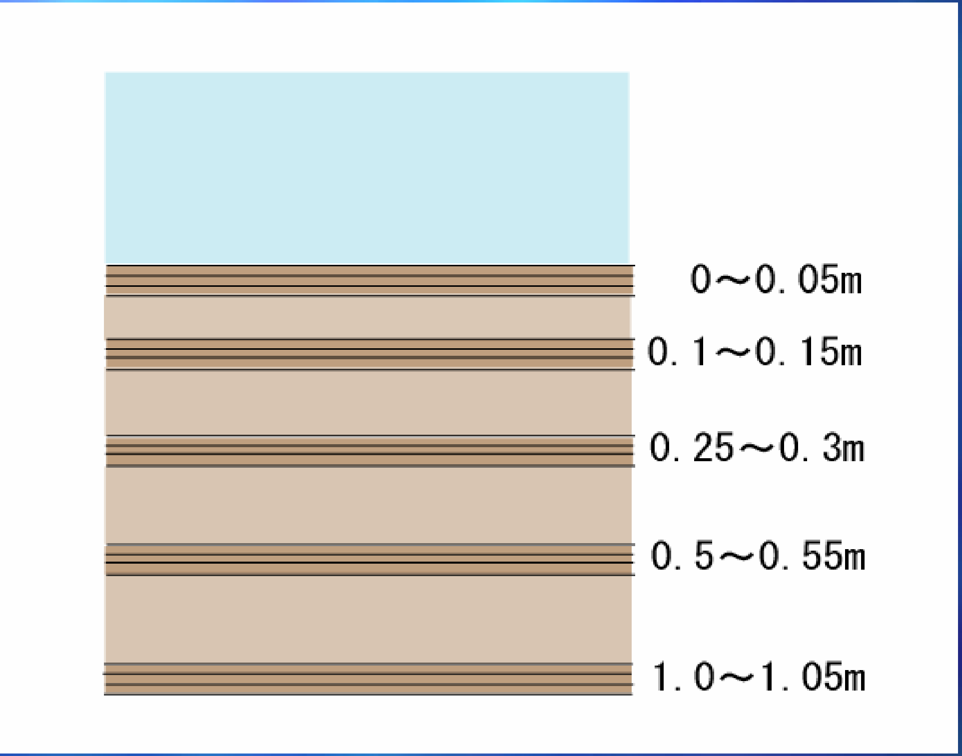
Study Point and Period

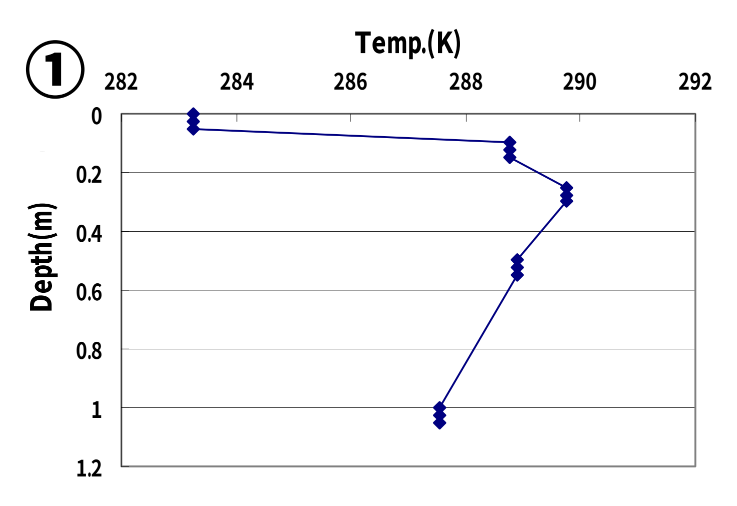
- Point: KBU1 (Kherlen-Bayan Ulaan)
- Period: August 17 to 31, 2003
  - Observed data is not missing.
  - Soil water is not freezing.

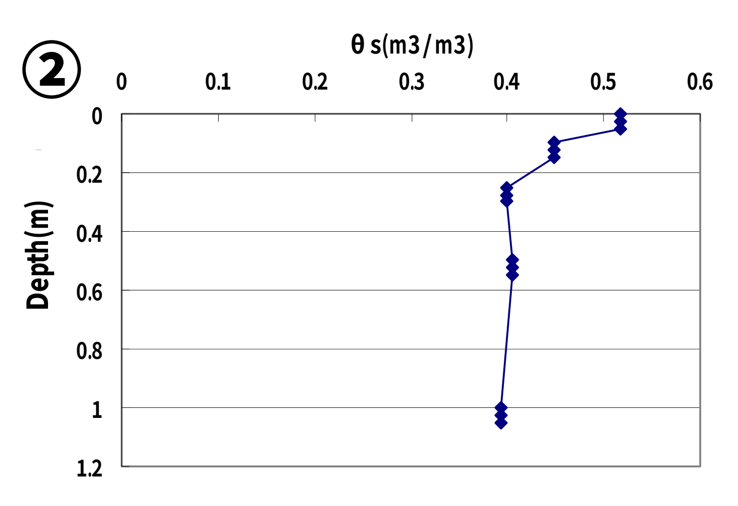
Dividing of soil layers

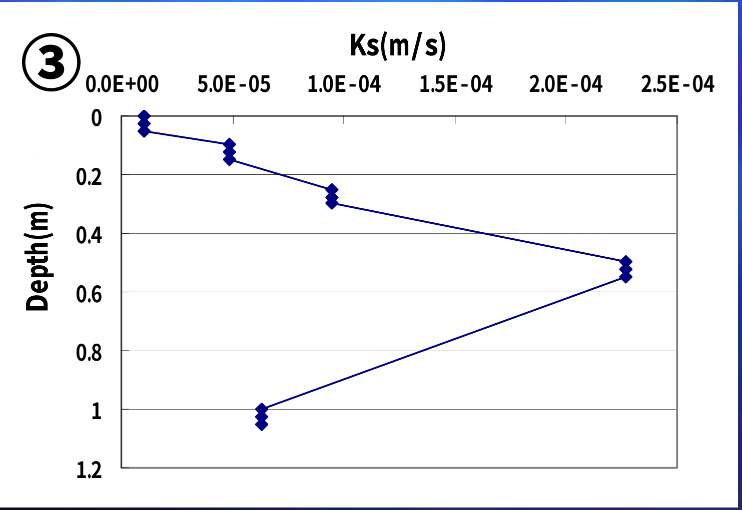


- In this study, calculation nodes are set at top of fifteen layers
- Each measured layer is divided into three computational layers

Observed Soil Conditions







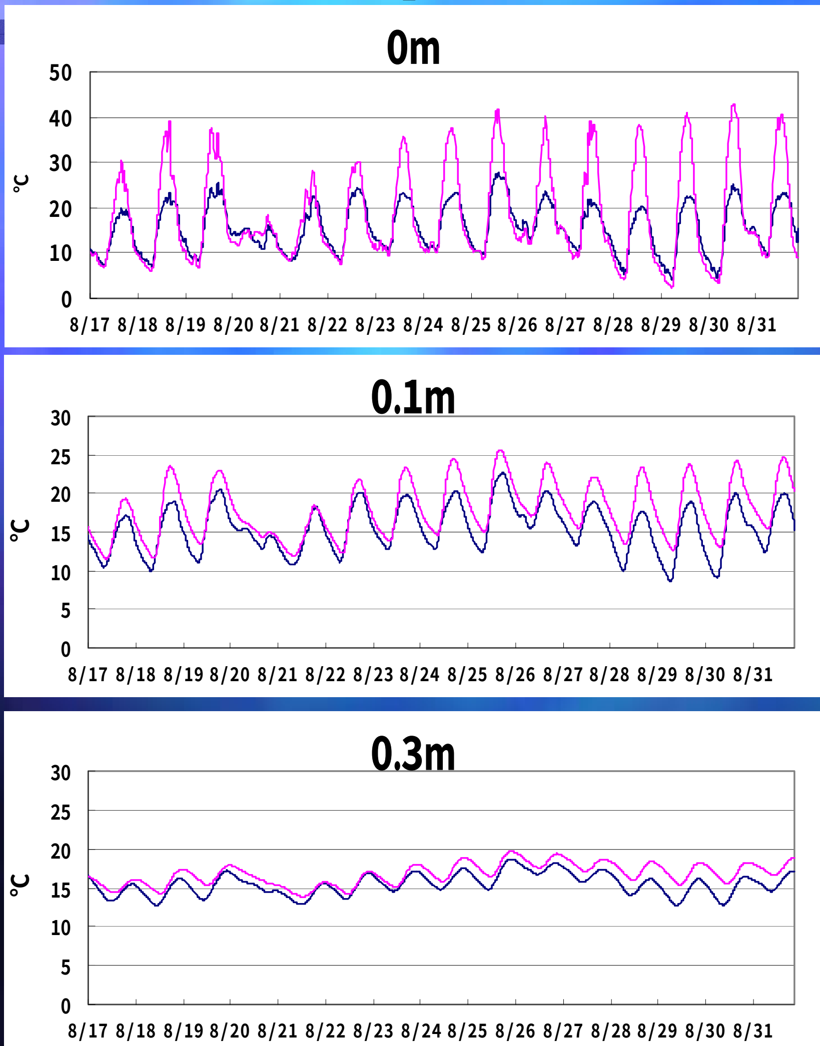
① Soil temperature

② Porosity of soil

③ Saturated hydraulic conductivity

Verification of this model

Soil temperature 1



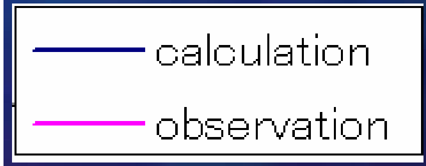
About surface

Night-time observed temp. can be represented quite well.

Day-time value can not be represented.

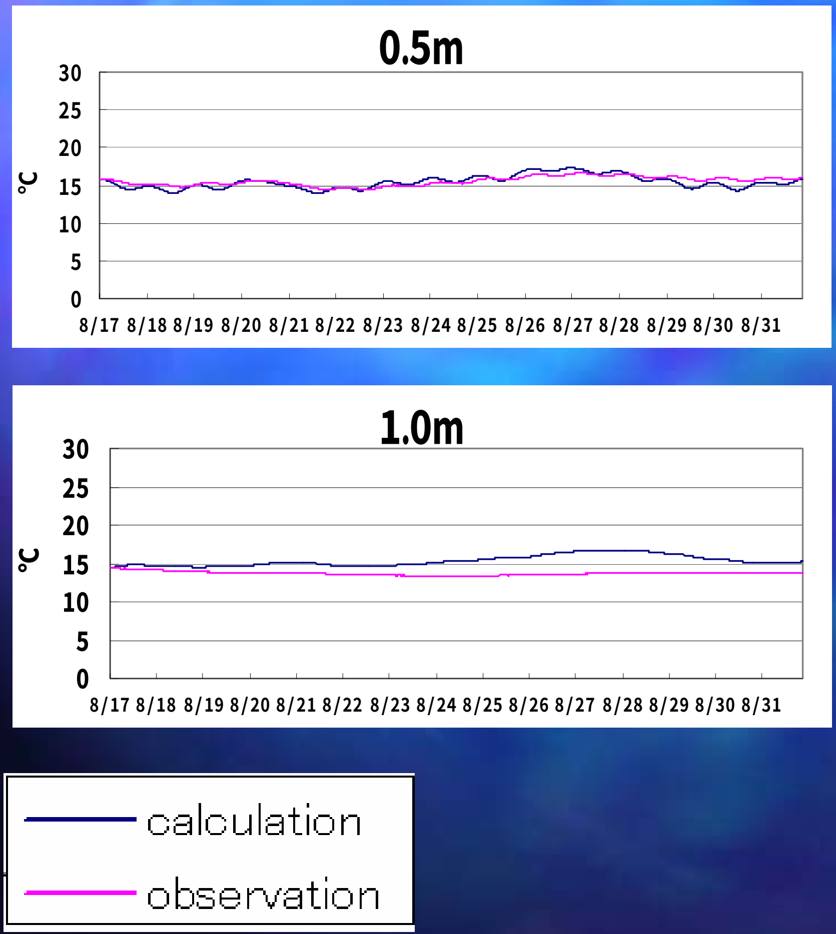
About other depth

Our model underestimated soil temperature.



Verification of this model

Soil temperature 2



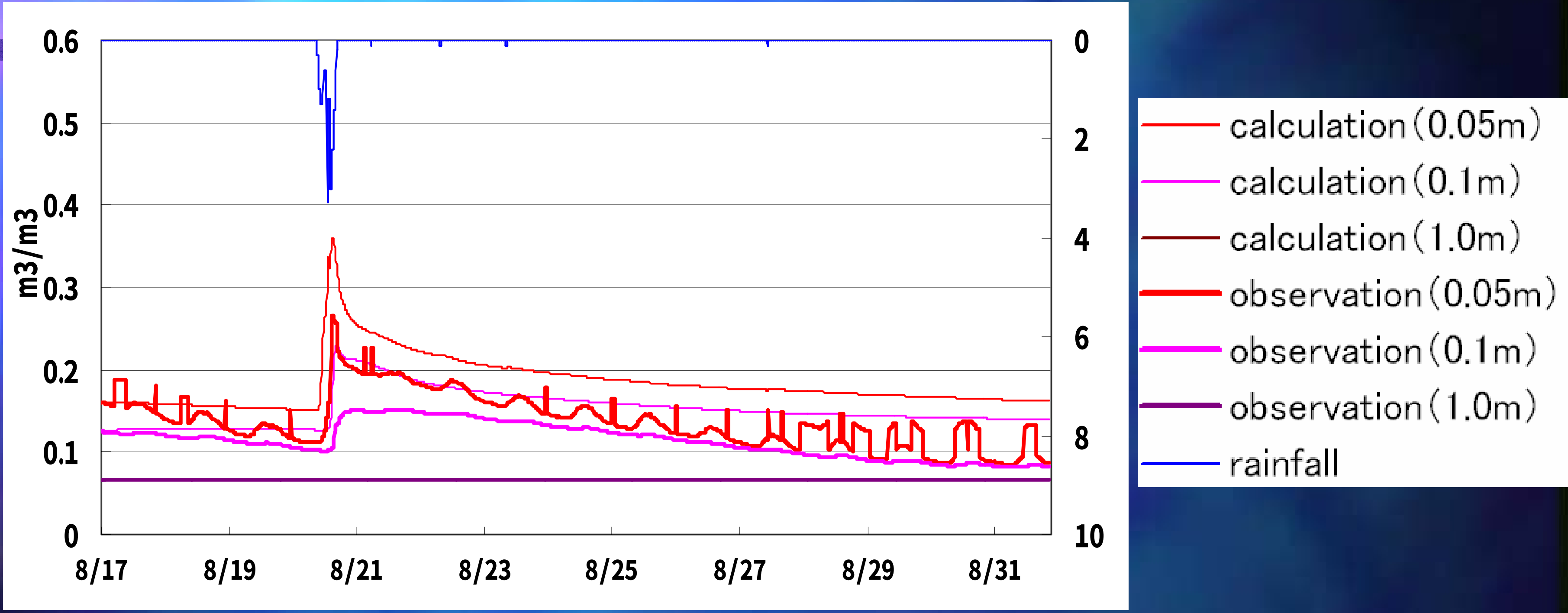
About depth of 0.5 and 1.0m

Calculate tendency is expressed

However, in deeper layer soil temperature is not very influenced from land surface

Especially, at depth of 1.0m is not.

Comparison of calculated and observed volumetric water content



- The behavior of soil moisture and influence from rainfall are represented qualitatively
- The calculated volumetric water content is always higher than observed ones.

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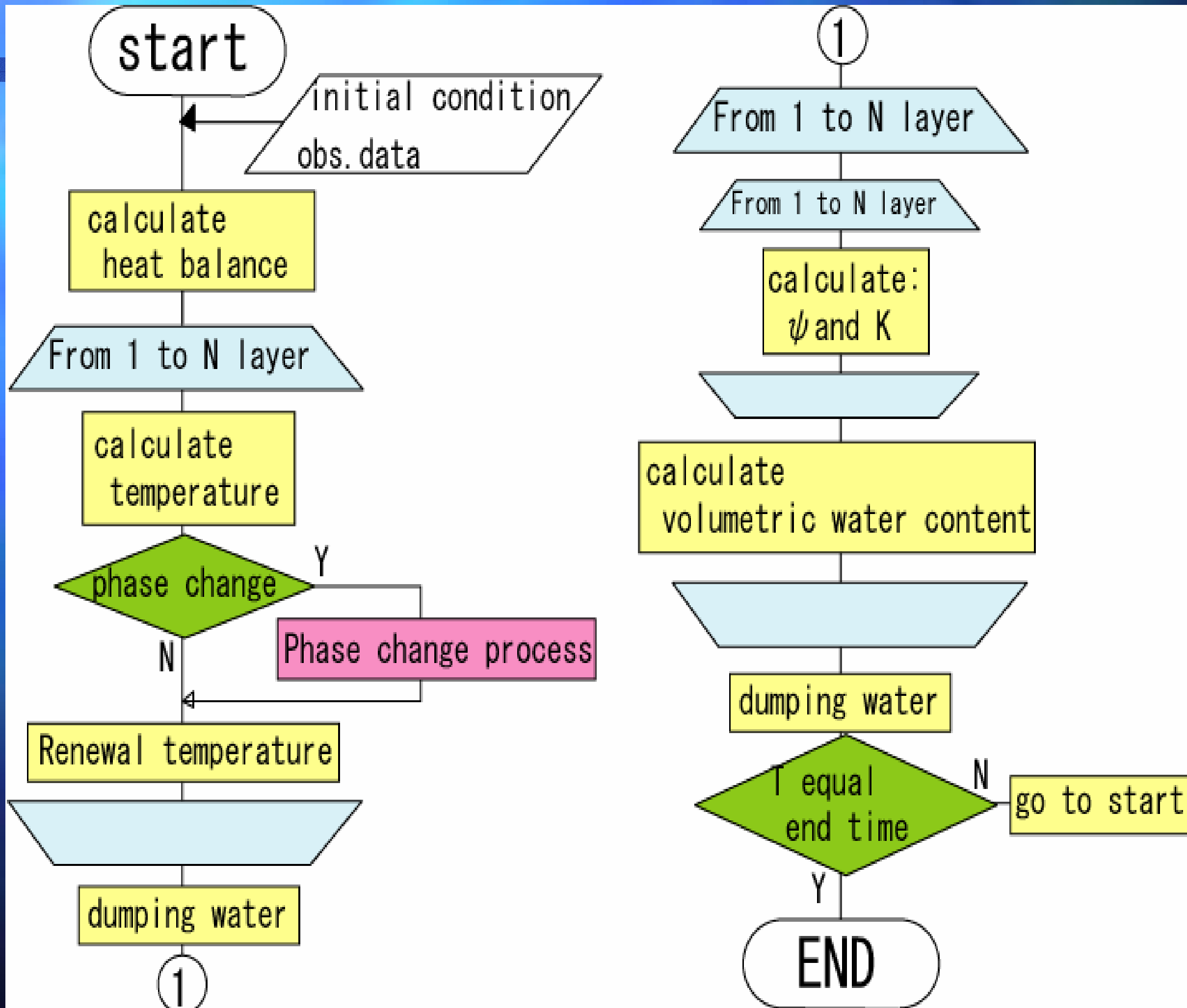
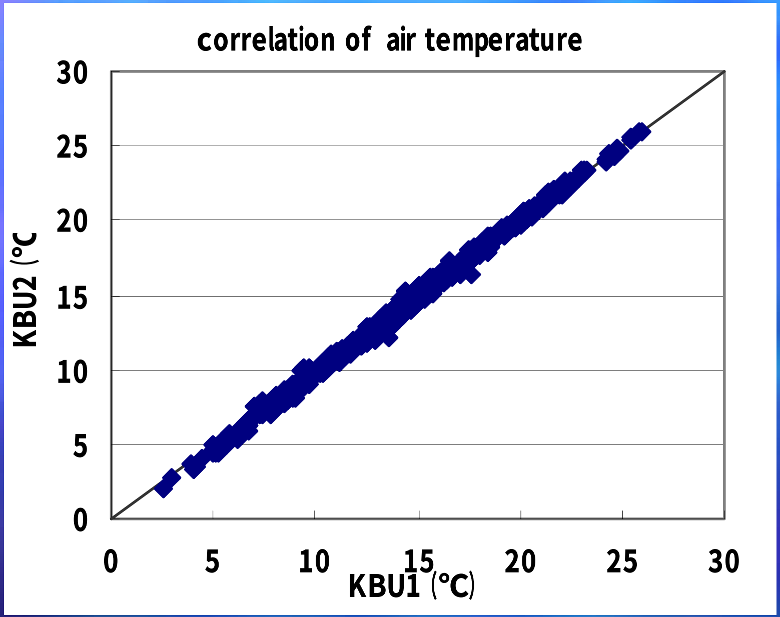
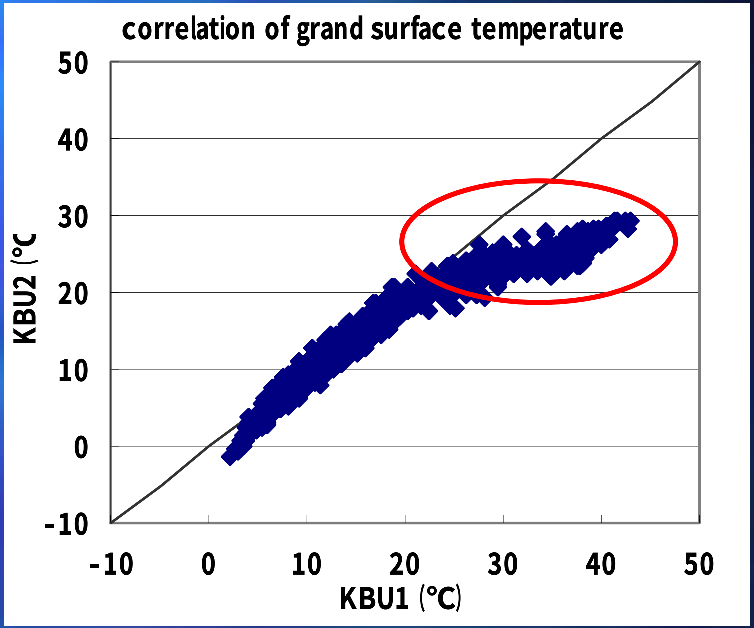
- In this study, we carried out to simulate soil water and heat transfer processes by using our developed model.
- As a result, the tendency of soil temperature and soil moisture is relatively represented.
- However, obtained result may be still not enough.
- In order to improve this model, determination of model parameters is considered to be of great importance.

Flowchart of this model



Correlation of temperature KBU1 and KBU2





Air temp : good correlation

Surface temp : KBU1 shows much higher values than KBU2