Thermal symbiotic system of permafrost and forest, northeast of Mongolia

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Abstract:
We evaluated symbiotic system of forest and permafrost using land-surface hydro-meteorological datasets obtained at northern Mongolia, southern boundary of Eurasian permafrost. Analysis indicated that greatly reduced radiation by forest shading is fundamental agent for permafrost preservation underneath northern forested slopes. Furthermore, organic- and pore-rich soil layers are also important. Such soils have been fed by fallen leaves from larch forest. This is another symbiotic system of forest and permafrost.

Keywords: forest, permafrost, energy budget, symbiotic system

Introduction

Forest of the northern Mongolia is situated at the southern boundary of Siberian Taiga, the widest forest on the earth. This forest is known to be the symbiotic system of permafrost. Impermeabilities of permafrost fed to grow Taiga, remaining active layer to be wet even under the semiarid climatic condition. Also dense forest cover shades incoming solar radiation onto ground surface and prevent ground from summer warming, due to which permafrost could be preserved.

Quantitative understandings of this system needs for comparable hydro-meteorological observation on permafrost and adjacent permafrost-free slopes. For this we, IORGC, have been comparably monitoring land-surface energy interaction at the representative forest and pasture slopes of Shijir river basin, Terelj. Permafrost was identified only on the later slope (Ishikawa et al., 2004).

Sites, Measurements and Theory

AWS was installed at two sites, both of which measure upward, downward (long- and short-wave) radiation, relative humidity, air temperatures, rainfalls, snow depth, soil heat flux and soil temperatures and moistures at the several depths.

We applied Bowen ratio approach for atmospheric heat flux components. Spurious data were removed prior to analysis. Soil conductive and non-conductive heats were quantified by simple one-D energy conservation model (Ishikawa et al. 2006) as,

$$j_h = -k_h \frac{\partial T}{\partial z} \tag{1}$$

$$r_h = \frac{\partial}{\partial t}[c_h T] + \frac{\partial}{\partial z} j_h \tag{2}$$

where j_h is the conductive soil heat flux, k_h is bulk thermal conductivity, T is temperature, and z is depth. For eq. (2), r_h is the non-conductive heat component expressed in W/m^3, c_h is the bulk heat capacity and t is the time. The total thermal energy stored, $Q_{g\text{-}c}$, is the summation of conductive and non-conductive heats of the layers as:

$$Q_{g-C} = \sum_i (j_h^i + r_h^i d^i) \tag{3}$$

where the subscript i represents each soil layer from surface, and d^i is the thickness of the i-th layer. The calculation needs for thermal parameters of k_h and c_h, spatio-temporal variation of which is known to largely dependent on the contents of soil water and ice, and soil compositions. Formulations for them often neglect air in spite that it has the greatest thermal conductivity. We considered conventional parameterization that neglects air and organic matter,

$$k_h = k_m^{1-n} k_s^{n-\theta_w} k_w^{\theta_w} \tag{4}$$

$$c_h = (1-n)\rho_m c_m + (n-\theta_w)\rho_s c_s + \theta_w \rho_w c_w \tag{5}$$

and that consider mineral, water, ice, organic contents and air.

$$k_h' = k_a^{n-\theta_s-\theta_w} k_o^{\theta_o} k_m^{1-n-\theta_o} k_s^{\theta_s} k_w^{\theta_w} \tag{6}$$

$$c_h' = \theta_o \rho_o c_o + (1-n-\theta_o)\rho_m c_m + \theta_s \rho_s c_s + \theta_w \rho_w c_w \tag{7}$$

where θ is volumetric fraction, n is the porosity, ρ is density, k is the thermal conductivity, c is the specific heat(subscripts, o: organic matter, s: ice, m: mineral, w: water).

Results

Observational results (net radiation, air temperatures, rainfall, snow cover thickness, soil temperatures and moistures) are shown in Figures 1 and 2. Clearly net radiation on the forest floor is significantly low (9.7 W/m^2 in mean), corresponding to one 8th of that on grass site (85.7 W/m^2). Mean air temperatures from March 03 to March 05 were -1.9 and -4.7 ℃ for the grass and forest sites, respectively.

This situation results in the lower ground temperature and permafrost occurrence of the forest sites, mean ground temperature of which was -0.2 ℃ for the upper four depths, and -0.9 ℃ for the lower four depths. High contents of organic matter and pore for the upper layers were encountered (Figure 3).

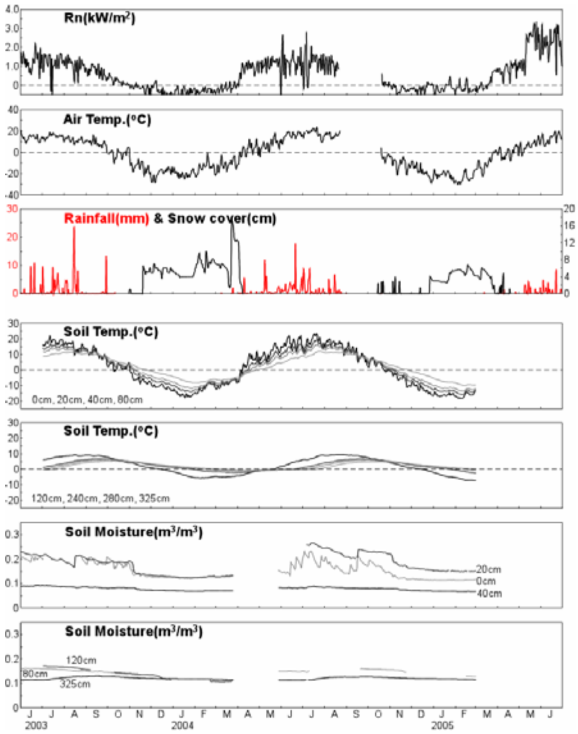

Figure 1. Data records at the grass site

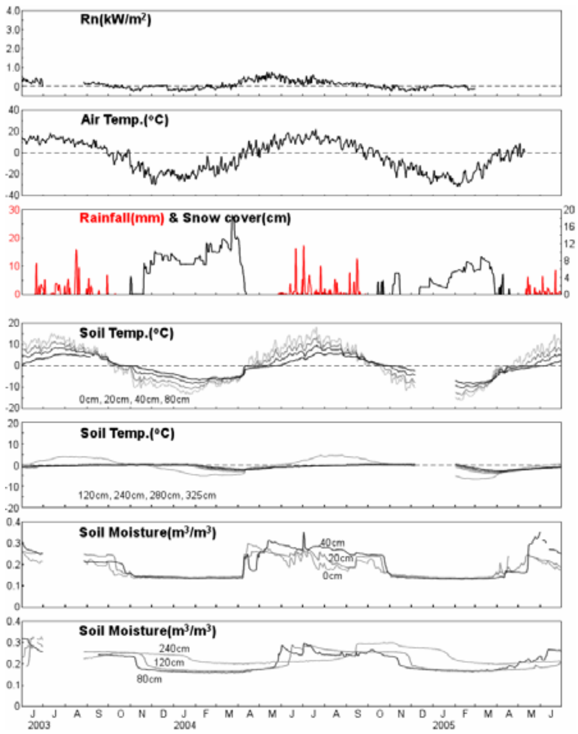

Figure 2. Data records at the forest site

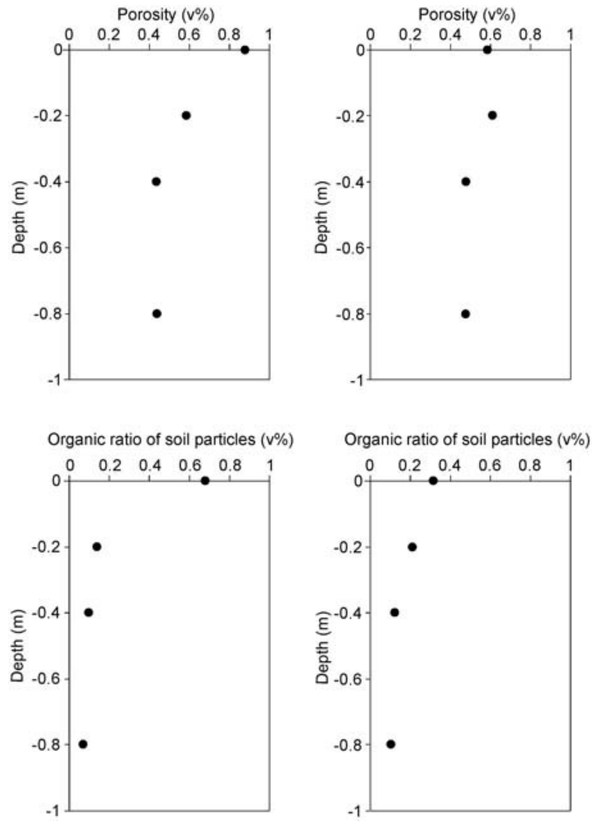

Figure 3. Porosity and organic ratio of soil particle at the forest (right) and grass sites (left).

Discussions

Figure 4 displays summer heat budget between atmosphere and active layer, revealing some symbiotic features of forest and permafrost. Large imbalances were encountered between atmospheric and active layer heat flux components, if we use soil thermal parameters to be not considered organic and soil pore effects. On the contrary, they were well agreed if we consider the thermal contribution of organic matters and soil pores occupied by air.

This condition indicates that thermal insulation of air contributes significantly for preventing ground to warm. In other word, removing pore rich surface layer would result in permafrost degradation even though forest still shades the ground surface.

We postulate that fallen leaves provided from larch during autumn fed such organic- and air-rich soil layers. This is another symbiotic system of forest and permafrost, in addition to well-known forest shading.

References

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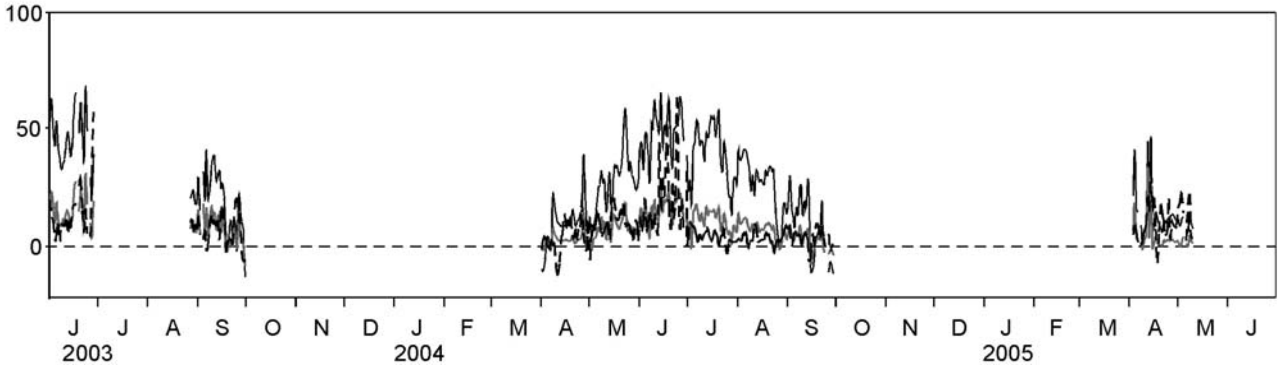

Figure 4. Summer heat budget on the forest floor (W/m^2). Solid black line: total soil heat storage estimated from equations (1), (2) and (3) using equations (4) and (5) as soil thermal parameters, Dashed line: total soil heat storage using (6) and (7) as soil thermal parameters, Solid grey line: differential between net radiation, and atmospheric latent and sensible heat fluxes