Observational Study of Hydrological Land-surface Processes on Semi-arid Grassland Underlain by Warm Permafrost in Mongolia

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Abstract

Since July 2002 to June 2004, intensive observation, including micrometeorology, phenology, heat budget and soil heat/water condition, has been conducted at site on sparse grassland in Mongolia, locating in southern periphery region of Eurasia cryosphere. Hydrological land surface processes at study site, including the role of snow cover and grass playing in water fluxes at ground surface, has been investigated in this work.

Key word: Mongolia, Grassland, evapotranspiration, soil moisture

1. Introduction

The climate of Mongolian territory, which is distributed in southern fringe of the Siberia permafrost occurrence, is characterized by a long and cold winter and a short but warm summer. Due to far from oceanic influences, characteristic feature for Mongolian climate is the combination of low relative humidity values with rather low precipitation. The feature of land-surface hydrological processes characterized by a few precipitation, high potential-evaporation, developing of semi-arid vegetation and presence of permafrost.

To improve our understanding of water cycle processes at the periphery of the Eurasian snow cover/frozen ground region, a series of observation sites were established on a semi-arid grassland, as part of the project “Observational study of the impact of the water cycle and thermal conditions at the periphery of the Eurasian snow cover/frozen ground region in relation to climate formation and climate change”, funded by the Frontier Observational Research System for Global Change of Japan. The observation terms include radiation and heat fluxes, meteorology, phenology of grassland and water condition of surface ground layer. The data has been gained continually by a full annual cycle, and analyzed preliminarily.

2. Observation site and terms

An observation site was established on sparse grassland, of Nalaikh in north-eastern Mongolia at $47^{o}45'$N, $107^{o}20'$E, 40 km southeast of Ulan Bator, in a field in a mountain plain in the Tuul River basin (Fig. 1). The site located on a sediment plain in the vast valley, nearest mountains is far than 10 km, the topography of and around this site is very smooth.

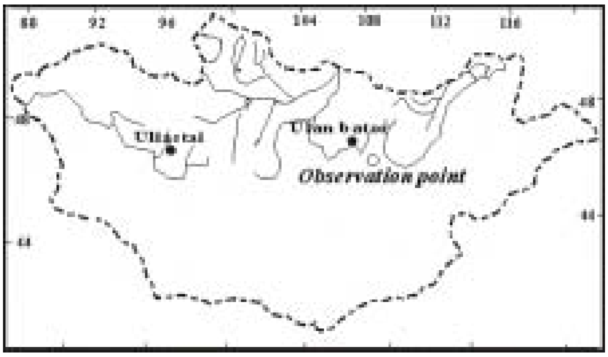

Fig. 1: Location of the study site

The soil in the study region is sandy, with a barren organic. From ground surface to 60 cm depth, soil porosity is decrease by range of 58-34%, and bulk density r increase from 1.17 gcm^3 to 1.71 gcm^3. From surface to 50 cm depth, soil water capacity range 17.2 to 6.5 %, and wilting point range from 4.1 to 2.8%.

Observation site is located in the periphery region of sub-arctic permafrost (Sharkhuu, 2001). The permafrost is characteristic by thick active layer and higher ground temperature. From the borehole observation of 30 m depth at study site, the ground has been clarified to be underlain by warm permafrost (Ishikawa et al, 2003). The maximum of downward thaw front reach about 5 m, and relative moist zone with gravity soil moisture about 10% was found at same depth.

In the two years from July 2002 to June 2004, precipitation was observed to be 272.5 mm, 79% of the precipitation was occurred in the warm season (May to

September). Air temperature, humidity and wind speed were averaged to be –4.1°C, 61% and 2.6 m/s respectively.

The annual mean global radiation flux was observed to be 168.5 Wm^{-2}. The all-wave radiation albedo shows clear seasonal variation. That was low and stable in snow-free period (0.12) but high and variable in snow cover period (0.71). Accordingly average net radiation was 60.0 Wm^{-2} and –6.0 Wm^{-2} respectively.

Since July 2002, meteorological and heat budget data were obtained using an automatic climate observation system (ACOS), in which air temperature, humidity and wind speed profile were measured at height of 0.5, 1.0, 2.0 and 4.0 m respectively; short-wave radiation, long-wave radiation and photosynthesis active radiation (PAR) were measured both in up- and downward respectively; the sensors of air pressure, inferred radiative thermometer for surface temperature and net radiation were installed at 1.5 m above ground surface as well.

Soil moisture was observed both automatically and manually. 7 TDR probes and 7 Pt thermometers, installed parity at depth of 0, 0.2, 0.4, 0.8, 12, 2.4 and 3.0 m respectively; moreover, 2 sets of heat flux meters were set at 0.02 and 0.2 m. In addition, the soil moisture profile was observed with manual samples from a 7-m-deep borehole every month. The soil moisture in the surface layer (0-60 cm) was measured using manual sampling.

Phenology observations, including the coverage and biomass of grass, were made from July to September at 10-day intervals. Plant coverage is sparse, generally it reaches about 38-42%. Also, plant type and species over pastureland are poor. About 60 percent of them occupied Artemisia frigita. Others are occupied by Arenaria and Leymus chinensis. The maximum grass height in mid July was less than 20 cm.

3. Results and Analysis

3.1. Atmosphere and ground surface control on evapotranspiration

Evapotranspiration (*E*) has been calculated using heat budget method and displaying in second panel of Fig. 2. And precipitation (*Pr*) and surface soil moisture (θ) are showing by same period in top and third panel of the figure. The lines show declining processes of components, black lines show processes relating to precipitation water, and dash lines shows processes relating to snow melting water.

Pr was variable even in annual basis. In the two years from July 2002 to June 2004, 65% of precipitation occurred in 2003. The summer of 2003 was moister than others.

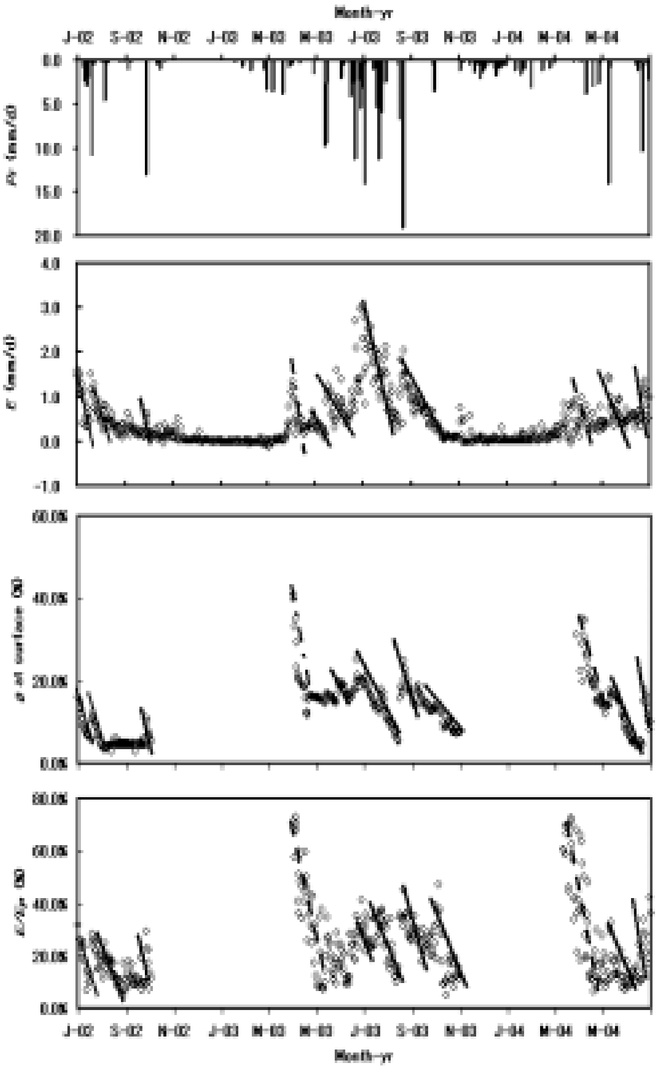

Fig. 2: Seasonal variation of precipitation (*Pr*), calculated evapotrans ration (*E*), surface soil moisture (θ at surface) and evaporation coefficient (*E/Ep*) in the pre-grow and grass growing period (early-growth to senescence) at study site since July 2002 to June 2004. The lines show declining processes of *E*, θ and *E/Ep*, black lines show processes relating to precipitation, and dash lines shows processes relating to snow melting water.

Most notable of the processes shown in Fig. 2 is the sensitive response of *E* to precipitation events or snow melting. It can be seen clearly that *E* tentatively correlated well to coupling to *Pr* varying through θ at surface. Every declining process of *E* and θ at surface can be initially corresponded to the precipitation events (beside of declining relating to snow melting water).

Firstly, the declining of *E* can be seen in the period just after snow disappearing. The snow disappeared at end of the March or beginning of April. By coupling by very shallow melting ground, water contented in ground surface layer was penetrated from snow melting but rarely relate to precipitation. From the Figure 2, it can be seen also that declining process of surface soil moisture causing by snow melting. Within ten days, θ at surface dropped intensively from 40 to 20%, leading notably decrease in *E* and *E/Ep*.

General seasonality of evapotranspiration is theoretically limited by available energy, expressed in potential evapotranspiration (*Ep*) as well, which is a useful index to investigate the controlling of ground surface condition to evapotranspiration (*E*) processes. If *Ep* completely determined by atmospheric condition, *E* normalized by *Ep* should depend on only surface (Soil/vegetation). However, most concepts of *Ep* involving net radiation, which relating to surface condition as well. In this study, *Ep* has been calculated, and it's normalized index of *E/Ep*, so called evaporation coefficient, showing in lowest panel of Figure 2.

All of the declining processes in *E/Ep* can be dressed tentatively in temporal variation of θ at surface, including that just after snow melted. The results that *E/Ep* indicate the controlling of ground surface condition to evapotranspiration (*E*) efficiently in study region. Surely, sustained period of every declining process was different relating to precipitation and soil water capacity, which partly determined by grass growing situation. Therefore, on such semi-arid sparse grassland, all peaks of evapotranspiration variation can be elucidated by precipitation events or snow melting.

It is necessary to noted that all the declining line were not exactly linear, that imply the evapotranspiration at the study site not determined by precipitation completely, but anticipated to affect by vegetation as well, for instance, even if with lower biomass, grass still uptake water through its root from soil to supply transpiration.

3.2. Role of grass playing in water cycle and its response to atmospheric forcing

Using the parameterization soil surface moisture, evapotranspiration (*E*) has been partitioned to be soil evaporation (*Esoil*) and transpiration (*Etrans*) at study site (Table 1).

Phenological observation at study site show biomass of grass in summer of 2003 was higher than others of 50%. However, it didn't lead a anticipated increase in *Etrans*. *Etrans* has been totaled to be 23.2 mm in summer of 2003 proportioned just of 15% in *E*, which was a moister summer with lower *AT*. *Etrans* was partitioned of 34-39% in drier and warmer summer. The transpiration determined by two parameters: leaf conductance and leaf-to-air specific deficit. leaf conductance has been concept clarified to be a function of temperature. The analysis shows *Trans* tentatively increase as temperature rising. When temperature is high, higher leaf conductance lead grass uptake water even if soil moisture is lower but higher than wilting point, which has been measured to 2.8 to 4.1% in root zone. Once precipitation event occurring, lower temperature plus lower leaf-to-air specific deficit, causing by higher air humidity.

Tab. 1: Integrated ground surface water budget over growth periods at study site: Precipitation (*Pr*), Air temperature (*AT*), Evapotranspiration (*E*), Soil evaporation (*Esoil*) and Transpiration (*Etrans*).

Period (mm/dd/yy)	Surface condition	*Pr* (mm)	*AT* (^{o}C)	*E* (mm)	*Esoi/E* (%)	*Etras/E* (%)
7/1-10/2/02	Sparse grass	39.4	12.7	48.9	66	34
10/3/02-3/31/03	Snow/ frozen	17.9	-19.5	7.5		
4/1-4/30/03	Bare ground	2.2	1.5	14.6	100	0
5/1-10/7/03	Sparse grass	141.0	10.4	163.0	85	15
10/8/03-2/26/04	Snow/ frozen	26.4	-19.5	13.1		
3/27-4/30/04	Bare ground	9.9	0.3	15.3	100	0
5/1-6/30/04	Sparse grass	35.7	11.8	39.1	61	39
Total/mean		272.5	-4.1	301.6	78	22

Comparing to *Etrans*, *Esoil* is more sensitive to surface soil moisture. The later transfer vapor to atmosphere by taken water from very thin soil layer, the former transfer water from soil through mechanism of root-stalk-leaf, and could be taken water a thicker soil layer to transfer into atmosphere. In the period just after snow disappeared of 10-15 days, *Esoil* was equal to *E* perfectly. Therefore, *Etrans* is anticipated to be steadily to soil moisture variation comparing to *Esoil*. To investigation of dependence of soil evaporation efficiency on the availability of stored water show that

Esoil/Ep increases near linearly with ground surface moisture when the volumetric water content is less than 30%, but does not increase with moisture content beyond that level. This stresses the importance of the critical value of soil moisture of 30%. When soil moisture is less than 30%, the soil evaporation process is restrained by the deficiency of available water. An similar critical value has been noted on near bare soil ground surface in Tibetan Plateau and on Siberia tundra.

3.3. **Seasonality of water budget at ground surface**

Having considering the ground surface condition, water budget at study site could be analyzed in accordance with period of ground surface frozen/snow covered, bare ground surface and grass-growing.

The ground surface at study site was frozen/snow covered for near half year. From snow survey observation, *Pr* has been estimated to be 17.9 and 26.4 mm in winter of 2002/03 and 2003/04 respectively, which was taken of 16% to annual precipitation. Correspondingly, sublimation was 7.5 and 13.1 mm, proportioned of 7% to annual *E*. More than half of precipitation accumulated on ground surface as snow cover.

In the period just after snow disappeared but before grass growth, ground surface melted but barred, snow cover still affect evaporation process. Snow-melting water penetrated to thin thawed layer leading soil near saturated. Soil evaporation partitioned of 10% to annual coupling precipitation just of 4%. By accounting the penetrated snow-melting water, *Pr-E* was near balanced in the period.

From July 1 to Oct. 2 of 2002, the period before ground surface starting frozen, the *E* was totaled to be 48.9 mm coupling precipitation of 39.4 mm. *E* and *Pr* was totaled to be 177.6 mm and 143.2 mm during April 1 to October 7 of 2003, and to be 54.5 mm 45.6 mm during March 26 to June 30 of 2004. The ratio of *E/Pr* was 1.24, 1.24 and 1.20 respectively. *Pr* was nearly to be balanced by *E* in whole study period. Even if grass-growing period is quite short in such periphery region of cryosphere, but water fluxes between atmosphere and ground surface in the period contribute significantly to annual water cycle. 88% of *E* occurred in grass growing period (early-growth to senescence) coupling to 94% precipitation.

In the observation period from July 2002 to June 2004 consisting two cycle of cross pre-growth to senescence period, evapotranspiration was totaled to be 301.6 mm coupling to precipitation of 272.5 mm. Partition of transpiration was 22%.

4. Discussion

By analysis based on data for two year on the sparse grassland in fringe region of cryosphere, it has demonstrated that evapotranspiration is sensitive to precipitation forcing, which show a clear declining process initial from significant rainfall events. On such semi-arid grassland, evapotranspiration shows a fast response to precipitation (Scott *et al*., 1997).

Scott *et al*. (1997) has dress that soil evaporation and vegetation transpiration behaves differently in response to atmosphere forcing. Increasing in evapotranspiration for moister summer was dominant by increasing in soil evaporation leading by more precipitation. By contrast, transpiration was higher in drier summer determined by higher temperature through enhancement in grass leaf conductance. Miyazaki *et al*. (2001) dressed an increasing in evapotranspiration of 20% coupling same summer precipitation but twice LAI of grass and warmer soil temperature. The results from this work imply that semi-arid grass affect land surface processes not only by its changes in albedo and roughness (Li *et al*., 2000) but also changing in transpiration. Transpiration is anticipated to enhance drought in warm and drier summer.

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