Interannual and seasonal variation of surface heat balance observed over grassland in Mongolia

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1. Introduction

Recently many studies concerned about the global warming and abnormal climate etc. were conducted frequently. Particularly the climate change was focused as the most important issue because it affects the life of animals and plants largely. The role of the land in the climate system and argued that land is more variable and changeable than the oceans for many of the important coupling processes (Dickinson, 1992). The surface Bowen ratio depends on evaporation from bare ground, wet vegetation and evapotranspiration by the ecosystems of crops, grassland, or forests (Betts et al., 1996). To study its mechanism, the long-term monitoring of surface heat, water and CO_2 balance is necessary. So far, many experimental studies of the surface heat, water and CO_2 fluxes are performed; however, the long-term experiments more than one year are not so much. Over grassland in Japan, the latent heat flux in August was about 85% of net radiation in both years, while the summer in 1993 was relatively cool and wet due to the prolonged rainy season and it was hot and more sunshine duration in 1994 (Saigusa et al., 1998). Over rangeland in Oklahoma of U.S.A., summer-time total evapotranspiration for the non-drought years (1995-1997) was 253□ 12mm but it was 145mm for the drought year in 1998 (Meyers, 2001). Mongolia, located in the interior of the Eurasian continent coincides with the core of the action center, *i.e.*, Siberian high. During summer, the monsoon trough – a heat low of the Asian summer monsoon – extends to Mongolia. Mongolia is one of the representative areas of grassland in mid-latitude of Eurasian continent. Therefore, it is important for understanding the climate system in East Asia to clarify the land-atmosphere interaction over grassland in Mongolia. The purpose of this study is to reveal the characteristics of interannual and seasonal variation of meteorological elements and surface heat balance using long-term observation in northern part of Mongolia. In addition, this study aimed to clarify the seasonal pattern of energy flux responded to the change of vegetation and soil moisture using observed data over grassland in central part of Mongolia.

Location Map

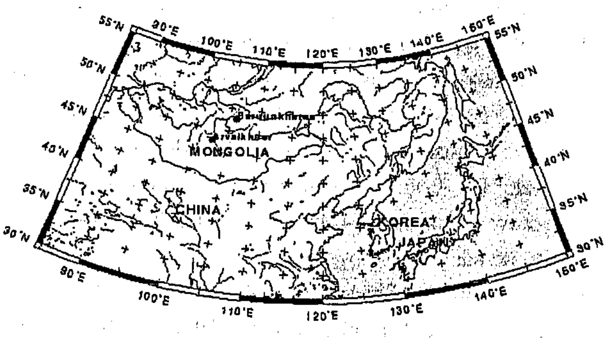

Fig1: Location map of observation site

2. Observational site and method

The long-term observation for surface meteorological elements and heat balance has been carried out at Baruunkharaa (48.9N, 106.1E, altitude; 806.9m) and Arvaikheer (102.78E, 46.27°N, altitude; 1813m) shown in Fig.1.

2.1 Baruunkharaa

The observational site at Barunkharaa is located the center of the village of Baruunkharaa , which has a population of about 4000, and covering an area of 11,000 km^2. The Automatic Weather Station (AWS) used for long-term monitoring of surface meteorological elements and surface heat balance from September 1993 to August 1998 was AANDERA 2704. The AWS consists of a 3-cup anemometer for measuring wind speed, a resistance thermometer for temperature, a hygroscopic humidiometer for relative humidity, and two pyranometers to measure downward and upward solar radiation. The net radiation (Rn) was estimated by using the data of net short wave radiation and the long wave radiation derived from the air temperature, water vapor pressure, and the soil surface temperature. The sensible heat flux (H) was calculated by using the profile method. Soil heat flux was calculated by using the ratio of G to Rn. Latent heat flux (LE) was calculated as the residual of the equation of heat balance. The more detail about observation at Baruunkharaa is described in Miyazaki *et al.* (1999).

2.2 Arvaikheer

Observation at Arvaikheer is one of the activities of GAME-AAN (GEWEX Asian Monsoon Experiment-Asian Automatic weather station Network) Project. This site is located at the southern edge of the Arvaikheer airport where has unpaved runway and covered by grass. The prevailing wind at this site is north-west and grassland expanded more than 4km from the site toward the north-west. The height of observing surface flux was at 7m. Therefore, it is enough fetch for measuring surface fluxes, which is considered greater than 100 times the measuring height (Horst and Weil, 1994). All vegetation at this site is grass of C_3 pant which is mainly composed of Gramineae family, such as *Stipa Gobica*, *Agropyrum Cristum*, and Liliaceae family of *Allium Anisopodium*. The soil consists of sand from surface to 20cm, soil with rock from 20cm to 70cm, and silt lower than 70cm. The AWS for the observation of the surface heat fluxes and other variables at Arvaikheer was Portable Automated Mesonet III (PAM III; Miltzer et al. 1995) developed at the National Center for Atmospheric Research (NCAR) in U.S.A. We calculate Rn from four-component radiation system. The long-wave radiation was corrected by using the temperature of the dome and case of pygeometer with the dome coefficient (=3.0) derived by Shiobara and Asano (1992). The G was observed by the heat plate (model: HFT3.1, REBs) buried 0.05m below the surface. The profile of soil temperature and moisture were observed using the platinum thermometer and Time Domain Reflectmetry (TDR) sensor at the depth of 0.05m, 0.1m, 0.2m, 0.4m, 0.7m and 0.95m. Due to the lack of data in nighttime, we mainly used the daytime (9:00-16:00LST) mean values for this study. Institute of Meteorology and Hydrology of Mongolia (IMH) provided the data of daily precipitation, vegetation biomass and height for each plant. We calculated LAI (Leaf Area Index) from the regression statistic between the LAI and biomass obtained in the intensive observation period in June 2000. PAM III station uses a 3D sonic anemometer (GILL R3A) and a hygrothermometer (Vaisala 50Y) to determine momentum flux and H by applying an eddy correlation technique and for the LE by the bandpass covariance method (Horst and Oncley 1995, Horst et al. 1997). The bandpass covariance method can be alternative method to the eddy correlation method, since it does not require an ideal sensor response that covers a wide frequency range, but gives an essentially direct measurement (Watanabe et al., 2000). They also pointed out that the bandpass covariance method is the best solution for scalar flux in the context of long-term continuous direct method. The detail of bandpass covariance method is described in Toda et al., 2002. For testing the performance of the flux measurement, we check the closure of the surface heat balance by comparing the sum of the turbulent fluxes plus soil heat flux (TFG) with the net radiation (Figures not shown). The regression slope was 0.9326 and 0.9043 in 1999 and 2000, respectively, which imply that the TFG was about 10% lower than Rn. Such kind of shortfall of TFG often called energy imbalance (Panin et al., 1998). The causes of energy imbalance have been reported by many studies (e.g. Marht, 1998; Lee, 1998; Twine et al., 2000; Toda et al., 2002; among others). Except the measurement error, most of studies pointed out that the causes of energy imbalance were effect of non-zero mean vertical velocity, non-stationarity of measured time series, and the development of horizontal energy advections in association with the horizontal inhomogeneity. The energy imbalance observed in this study was less than 10%, which was same as the probable error of available energy (Rn-G) for homogeneous sites showed by Twine et al., (2000). It may imply that the turbulent fluxes observed in this study might have enough accuracy for discussing the quantitative analysis.

3. Results and discussions

3.1 Baruunkharaa

The time series of 5-year (1993-1998) mean values of daily averaged or accumulated values of (a) air temperature (b) specific humidity (c) albedo (d) precipitation (e) snow depth (f) diurnal range of surface temperature (dTs) is shown in Fig.2.

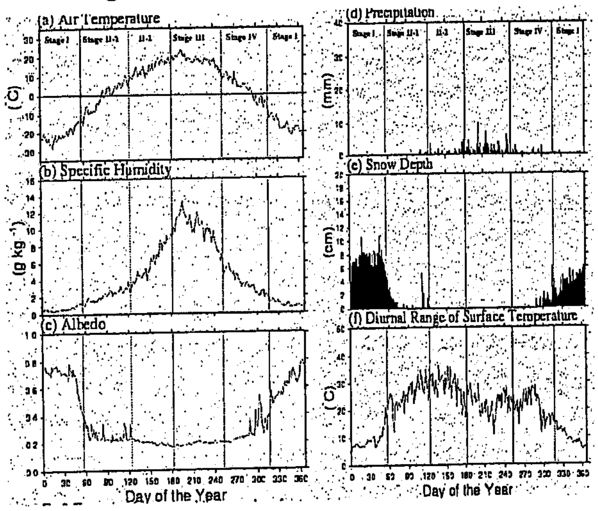

Fig 2: Time series of the 5-year mean value of daily averaged or accumulated meteorological elements at Barunkharaa.

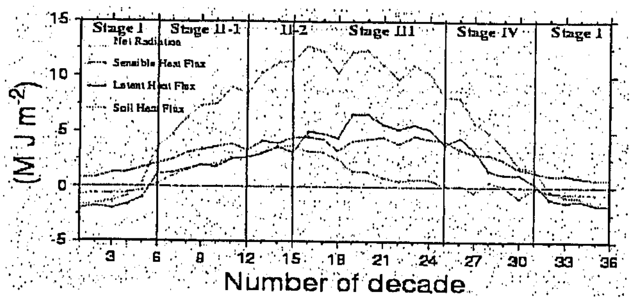

Fig 3: Time series of 5-year mean surface heat balance.

We divided into four stages (from stage I to stage IV), based on the change of surface condition derived from abrupt change of meteorological elements. In stage I (mid Nov. to mid. Feb.) the surface was covered by snow and the air temperature was below -20 ° C. After vanishing snow, the air temperature started to increase rapidly and the dTs became large which may imply the surface was dry in stage II. The surface covered with grass and specific humidity was more than 10 g/kg in stage III. The air temperature started to decrease in stage IV. Fig 3 shows the time series of 5 year-mean surface heat balance at Baruunkharaa. In stage I Rn was always negative while H was positive. H and G became dominant component on heat balance responded to dry soil surface in stage II. At the beginning of stage III, LE dramatically increased and became the dominant component on heat balance responded to growth of the grass and wet surface. In stage IV LE showed the sharp decrease while H was gradual decrease and H became the dominant component on heat balance again.

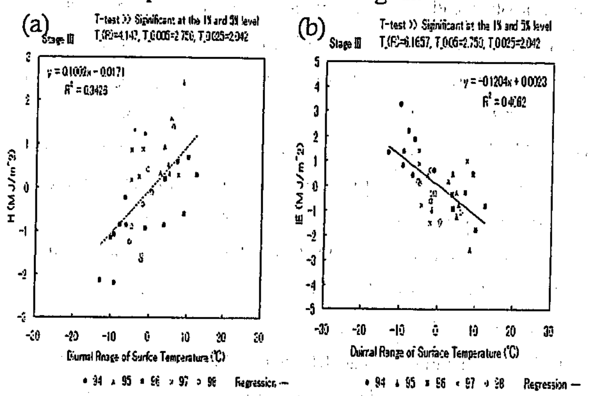

Fig 4: Anomaly of dTs against (a) H and (b) LE in stage III.

To clarify the effect of the surface wetness to the partition of heat balance, the scatter diagrams on the anomaly of dTs against H and LE were shown in Fig 4 (a) and (b). As anomaly of dTs became larger, the H (LE) became larger (smaller). There was strong correlation between dTs and H (LE). During 5-year, the annual precipitation varied from 96.7mm (in 1996) to 455.8mm (in 1994) while the evapotranspiration varied from 92.1mm (in 1996) to 169.2mm (in 1994).

3.2 Arvaikheer

The surface condition is most important parameter for controlling the surface heat budget. The time series of 10 day mean of soil moisture of upper 10cm and the accumulated precipitation with LAI are shown in Fig. 5(a) and Fig. 5(b), respectively. In 1999, the volumetric water content abruptly increased in early June from 6% to 13%. After decreasing again in middle of June, it increased from 6% to 16% in early July. On the other hand, in 2000 the volumetric water content was less than 13% before the abrupt increase in August. During early summer, the volumetric water content in 1999 was always 3 to 5 % higher than in 2000 except in late June. The accumulated precipitation in 1999 was about 5mm lower than in 2000 before early June. However, that in 1999 became about 10 mm to 20mm higher than in 2000 in June and July except early July. From early August to September, the accumulated precipitation in 1999 was about 20 mm lower than in 2000. This seasonal variation of accumulated precipitation was similar to the volumetric water content. In summer time, the vegetation coverage is also important parameter of surface condition. The LAI in 1999 was about twice of in 2000. The maximum value of LAI in 1999 reached about 0.2, which is quite small value, compared with the normal grassland value (about 3.4). The precipitation from middle of May to late July, which is important period for growing the vegetation, was 83mm and 53mm in 1999 and 2000, respectively. In 1999, there was no snowfall in April while it snow in April in 2000 (figure not shown). It is likely that the poor growth of vegetation in 2000 caused by the small rainfall and low temperature due to the snow cover on the surface.

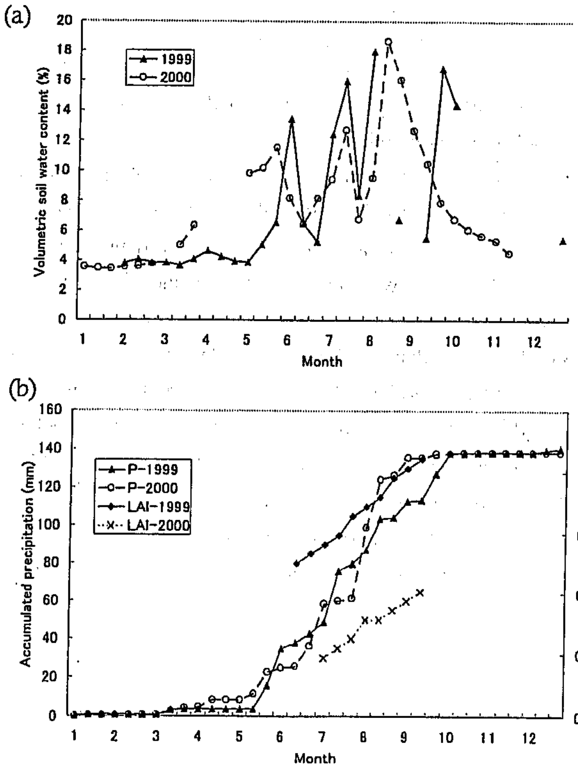

Fig5: Time series of (a) soil moisture (b) accumulated precipitation and LAI.

Also soil surface temperature in 2000 was about 5 to 10 degrees higher than its in 1999 except in late July and wintertime (not shown). Such large difference of soil surface temperature might be related with the large difference of LAI and stored soil moisture between both years. To evaluate the relation between soil moisture-vegetation and evapotranspiration, we showed the time series of the 10-day accumulated evapotranspiration. In 1999, the evapotranspiration reached more than 10mm from early July to late August, while in 2000 the evapotranspiration exceeded 10mm in middle of July, middle of August and late August. The value of evapotranspiration observed here is about one-third of the value observed over the rangeland in Great Plains by Meyers *et al.* (2001). As their annual precipitation and maximum LAI were 750mm and 2 to 3, our value seems to be reasonable. From middle of May to late July the total evapotranspiration was 80.5 mm and 52.0 mm in 1999 and 2000, respectively. Although the precipitation from May to September was 134.1mm and 129.1mm in 1999 and 2000, the evapotranspiration was 126.9mm and 103.7mm in 1999 and 2000.

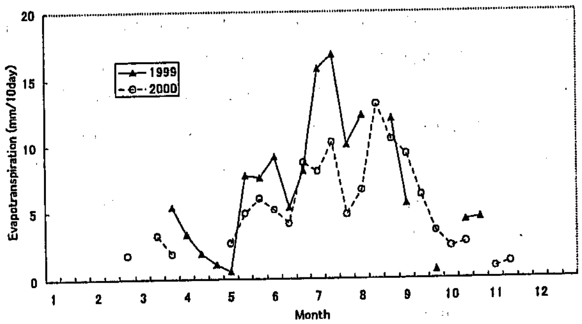

Fig 6: Time series of the 10-day accumulated evapotranspiration

4. Concluding remarks

According to the long-term observational results at Baruunkharaa from 1993 to 1998, there was very remarkable seasonal variation of surface meteorological elements and heat balance. In addition, we found the clear relationship between the partition of heat balance and surface wetness index.

Based on the data in 1999 and 2000 the difference of meteorological, hydrological and biological conditions over the grassland at Arvaikheer in central Mongolia were clarified. Both precipitation and evapotranspiration from middle of May to late July in 1999 was about 1.6 times as large as that in 2000. The LAI in 1999 was about twice of its in 2000 and the soil surface temperature in 2000 was about 5 to 10 degrees higher than its in 1999 except some period.

References

Betts, A.K., J. H. Ball., A.C. Beljaars, M.J. Miller, P.A. Viterbo, 1996: The land surface –atmosphere interaction: a review based on observational and global modeling perspectives. J. Geopys. Res. 101, 7209-7225.

Dickinson, R.E., 1992. Climate System Modeling.; 5 Land Surface, K.E. Trenberth (Eds.), Cambridge University Press, Cambridge, UK, 149-171.

Horst, T. W. and J.C. Weil, 1994. How far is far enough? : the fetch requirements for micrometeorological measurement of surface fluxes, J. Atmos. Oceanic Technol., 11, 1018-1029.

Horst, T.W. and S.P. Oncley, 1995. Flux-PAM measurement of scalar flux using cospectral similarity, Proc. of the 9th AMS Sympo. on Meteor. Measur. and Instr., Charlotte, NC, 495-500.

Horst, T.W., S.P. Oncley, and S.R. Semmer, 1997.Measurement of water vapor fluxes using capacitance RH sensors and cospectral similarity, Proc. of the 12th AMS Sympo. on BL and Turb., 360-361.

Meyers, T. P., 2001. A comparison of summertime water and CO2 fluxes over rangeland for well-watered and drought conditions, Agric. Forest Meteorol. 106, 205-214.

Militzer, J.M., M.C. Miichaelis, S.R. Semmer, K.S. Norris, H.W. Horst, S.P. Oncley, A.C. Delany, and F.V. Brock, 1995. Development of the prototype PAMIII Flux surface meteorological station, Proc. of the 9th AMS Sympo. on Meteor. Measur. and Instr., Charlotte, NC, 490-494.

Miyazaki, S., T. Yasunari, and T. Adyasuren, 1999. Abrupt seasonal changes of surface climate observed in Northen Mongolia by an automatic weather station, J. Meteor. Soc. Japan, 77, 583-593.

Panin, G.N., G. Tetzlaff, and A. Raabe, 1998. Inhomogeneity of the land surface and problems in the paramterization of surface fluxes in natural conditions, Theor. Appl., Climatol., 60, 163-178.

Saigusa, N., T. Oikawa, and S. Liu, 1998. Seasonal variations of the exchange of CO2 and H2O between a grassland and atmosphere: experimental study, Agric. For. Meteorol., 89, 131-139.

Shiobara M., and S. Asano, 1992. The dome emission Effect on the performance of pyrgeometers with Silicon Domes, Pap. in Meteor. and Geophy.s, 43, 17-31 (in Jap.).

Toda, M., K. Nishida, N. Ohte, M. Tani, and K. Mushiake, 2002. Observations of energy fluxes and evapotranspiration over terrestrial complex land covers in the tropical monsoon environment, J. Meteor. Soc. Japan, 80, 465-484.

Watanabe, T., K. Yamanoi and Y. Yasuda, 2000. Testing of the bandpass eddy covariance method for a long-term measurement of water vapor flux over a forest, Bound. Layer Meteorol. 96, 473-491.