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Summertime soil hydrological cycle and surface energy balance on the Mongolian steppe

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Abstract

We conducted combined measurements of soil water balance and surface energy fluxes at four sites within the Mongolian steppe region during the summer of 2001 to investigate the present state of the soil hydrological cycle, surface energy balance, and the role of vegetation in those processes. The summer total precipitation comprised 71–91% of the annual total ($=100\pm6$ mm) at the sites, and was approximately equal to summer total evapo-transpiration. Moreover, the net infiltration flux was always balanced by changes in water storage within the uppermost 20 cm of the soil layer, suggesting that very little percolation occurs to depths in excess of 20 cm. The mean residence time of water stored within the layer is estimated to range from 20 to 25 days during summer. We observed a strong linear relationship (correlation coefficients ranging from 0.72 to 0.85) between latent heat flux (lE) and water-content at 3 cm depth (θ_3). The ratio of the lE change to the θ_3 change increases with increasing vegetation cover. This fact indicates that steppe vegetation helps to drive the observed rapid water cycle, and controls the surface energy balance via a strong constraint on lE.

Keywords: Soil water balance; Land–atmosphere interaction; Energy budget; Semi-arid grassland; Ecotone

1. Introduction

The Mongolian steppe region is situated within an ecological transition zone (i.e. ecotone), with a strong climate gradient between the Gobi Desert to the south and the

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Siberian taiga to the north. The ecotone is highly vulnerable to future scenarios of climate change such as global warming (Roberts, 1994), especially as northeast Asia has one of the strongest warming signals on earth (Hansen et al., 1999; Chase et al., 2000).

The region is further at risk of desertification resulting from human activity (Sneath, 1998). Numerical experiments indicate that desertification in the Mongolian steppe region will act to reduce rainfall over and around the region through modification of the surface energy balance (Xue, 1996). In fact, summertime precipitation over the region has shown a significant decrease since the mid-1950s (Yatagai and Yasunari, 1995). Although there remain uncertainties with regard to whether the trend is human-induced or natural, a decrease in precipitation may naturally accelerate further desertification because the storage of soil moisture strongly regulates both vegetation activity (Kondoh and Kaihotsu, 2003; Miyazaki et al., 2004) and biodiversity (Ni, 2003) in the region.

Most of the Mongolian steppe region is located within a large internal drainage basin (the Central Asian Internal Drainage Basin; Batnasan, 2003), within which perennial rivers are either nonexistent or terminate in interior land-locked basins. For this hydro-geographical situation, we can expect that precipitated water will result in little discharge to rivers or ground-water: water exchange between grassland and the atmosphere through precipitation and evapo-transpiration is the main branch of the hydrological cycle. Thus, changes in the soil–hydrological balance resulting from climate change may have dramatic effects on the water resources stored within the region (Bradley, 1999, p. 310).

Water and energy exchanges between the terrestrial biosphere and the atmosphere are important not only in arid/semi-arid regions but also all over the globe (Betts et al., 1996); consequently, large-scale field experiments have been planned and executed under various climatic settings (Sellers et al., 1997). There are, however, few observational studies that link the soil hydrological cycle and the surface energy balance within desert-like ecosystems. This lack of information is partly due to difficulties in obtaining accurate ongoing measurements of water/energy fluxes and storage under severe weather conditions. Consequently, we lack the observational data necessary to understand interactions between the hydrological cycle, climate, and vegetation under considerably arid conditions and to test or improve numerical models used to assess the impacts of global warming on desertification and/or water resources.

In the present study, we conducted combined measurements of soil water balance and surface energy fluxes during the summer of 2001 at four sites within the Mongolian steppe region. The objectives of the study are: (1) to reveal the present state of the soil hydrological cycle in the region; (2) to assess the effect of transient soil-moisture conditions on energy fluxes under an arid climate; and (3) to understand the role of steppe vegetation in water/energy exchanges between the land surface and the atmosphere.

2. Materials and methods

2.1. Study area and field monitoring

Under the framework of the ADEOS II Mongolian Plateau Experiment for Ground Truth (AMPEX; Kaihotsu et al., 2002), Automatic Weather Stations (AWS) were deployed at four sites (Mandalgobi (MGS), Dergertsogt (DGS), Deren (DRS), and Bayantsagaan (BTS); Table 1; Fig. 1) in central Mongolia for soil–hydrological and micrometeorological monitoring. A number of ephemeral river channels occur within the