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Research Paper

Intercomparison of surface energy fluxes, soil moisture, and evapotranspiration from eddy covariance, large-aperture scintillometer, and modeling across three ecosystems in a semiarid climate

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ABSTRACT

A comprehensive seasonal and interannual energy partition and flux analyses were conducted to differentiate three ecosystems including sagebrush, cheatgrass, and lodgepole pine in the Snake River Plain of Idaho. The study used 3 years of eddy covariance (EC) and large aperture scintillometer (LAS) flux measurements to evaluate the bio-physical processes that control the surface energy partitioning. A comparison of sensible heat flux (SH) by EC (H_{EC}) and LAS (H_{LAS}) showed H_{EC} was slightly underestimated due to wind turbulence and energy balance closure issues. The Noah Land Surface Model (LSM) was configured with NCEP-NARR ($NOAH_{NARR}$ simulation) or meteorological observation from the EC tower ($NOAH_{Obs}$ simulation). $NOAH_{NARR}$ simulation showed significantly more RMSE compared to $NOAH_{Obs}$ due to biases in downwelling shortwave and longwave radiation and precipitation (P) in the NARR data. Higher leaf area index (LAI) and moderate stomatal resistance (R_S) of lodgepole pine resulted in increased evapotranspiration (ET) (472–535 mm/year) compared to cheatgrass (261 mm to 278 mm/year) and sagebrush (229–353 mm/year). The Budyko ET analysis showed that all the three sites are water deficient and the evaporative ratio was less for the lodgepole pine ecosystem (0.80) when compared to sagebrush (0.94) and cheatgrass (0.93). The residual (attributed to deep percolation and runoff) from the water budget was higher (15–16%) in the lodgepole pine compared to that of cheatgrass (2–5%) and sagebrush (2–9%). Our results indicate the field-scale distinguishing features of heterogeneous ecosystems in the semi-arid environment and emphasize the need for intercomparison of flux measurements for better understanding of energy budget partitioning and improving the accuracy of simulated fluxes.

1. Introduction

The precise quantification of the turbulent transfer of heat and moisture on the land surface has great importance in numerical weather prediction and climate modeling studies since the land surface and atmospheric processes are strongly connected (Betts et al., 1997; Maurer et al., 2001; Pielke et al., 2002; Sridhar et al., 2002; Ward et al., 2014). The land surface acts as a transitional layer between the boundary layer and subsurface soil column and regulates land-atmospheric interaction processes through the transfer of energy and water. The net radiation (R_{NET}) near the land surface is partitioned into latent heat flux (LH), sensible heat flux (SH), thermal radiation, and ground heat flux (GH), thus impacting the flow and thermodynamic structure of the boundary layer (Lee, 2015). In ecohydrological studies and surface energy and water budget analyses, it is important to understand the various processes that control the partitioning of energy and water at the land surface. Spatial heterogeneity in available energy, topography, soil moisture conditions, soil type, emissivity and vegetation are the major drivers influencing surface energy partitioning (Chehbouni et al., 1999; Ward et al., 2014; Yang and Wang, 2014). Turbulent heat fluxes are comprised of LH and SH, which are considered to be the major drivers of atmospheric circulation. GH has great importance in the thermal energy storage of soil columns. The availability of energy, precipitation, and soil moisture imposes constraints on the proportion of LH generated.

LH (latent heat of vaporization (λ) x ET) is directly linked to the amount of water evaporated from the land surface into the atmosphere. ET comprises evaporation from bare soil, a wet vegetation canopy, and transpiration from the vegetation (Eagleson, 1978; Kim and Ek, 1995; Sridhar et al., 2002; Verstraeten et al., 2008; Jaksa et al., 2013; Sridhar, 2013). Apart from meteorological factors, vegetation and its phonological characteristics controls ET when there is sufficient soil moisture.

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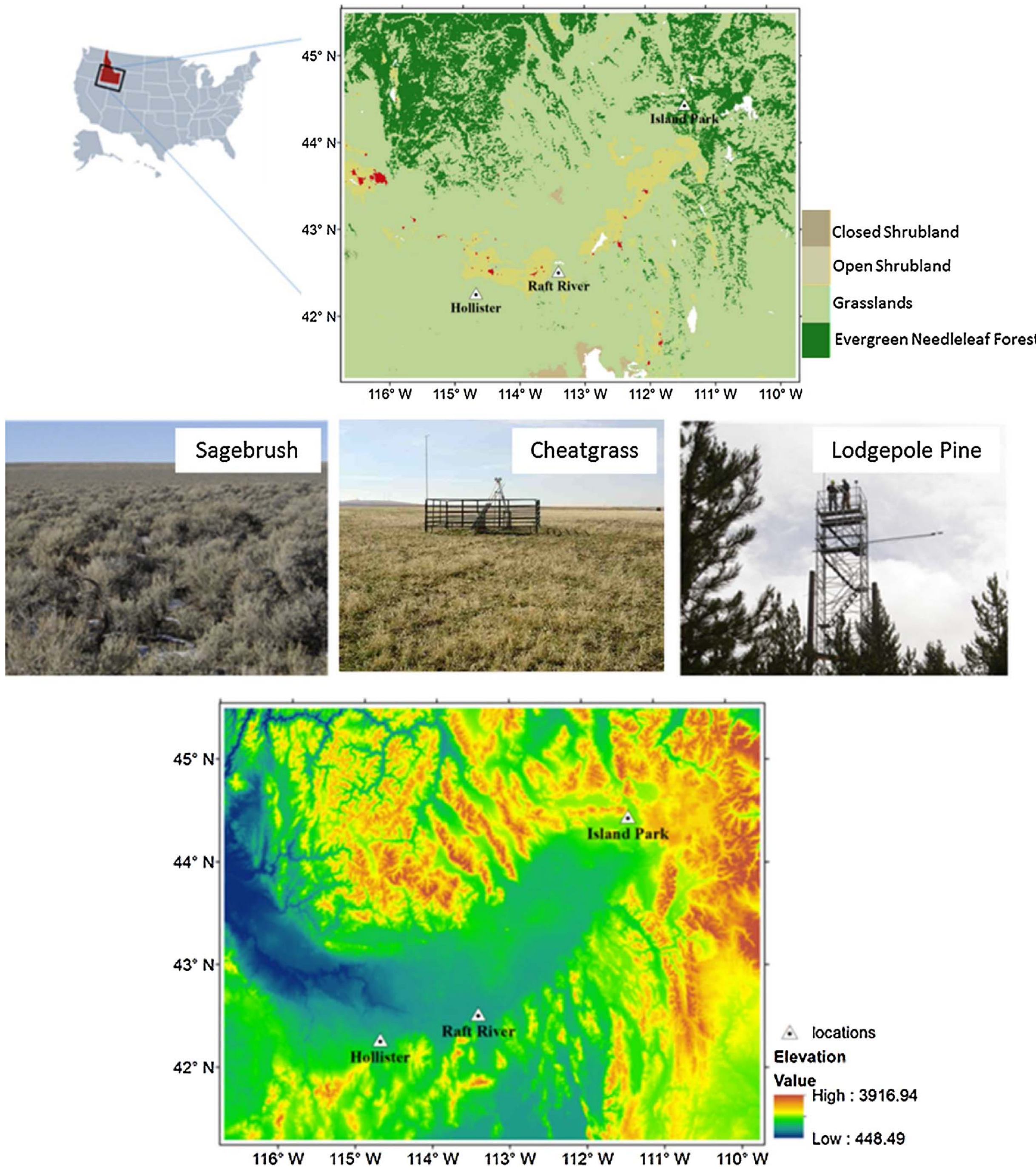

Fig. 1. Location map of LAS and EC sites at Hollister (Sagebrush), Raft River (Cheatgrass), and Island Park (Lodgepole Pine) within the southern Idaho study domain with pertinent land cover and elevation information.

ET comprise 62% of terrestrial water balance. On an annual time scale, the magnitude of ET is approximately equal to precipitation in a semiarid ecosystem (Budyko, 1974; Phillips, 1994; Kurc and Small, 2004). In such ecosystems, precipitation is much less than potential ET (PET) and precipitation recycling is mainly through ET (Kurc and Small, 2007). Donovan and Ehleringer (1994) quantified the water stress among different shrubs in the semiarid Great Basin using xylem pressure potentials and reported that the dry summer water stress (June-July) was strongly correlated to summer precipitation. The shallow rooted shrubs such as Yellow Rabbitbrush (*Chrysothamnus viscidiflorus*) and Sagebrush (*Artemisia tridentate*), developed greater water stress and showed higher water use. A similar study by Kurc and Small (2004) and Templeton et al. (2014) reported that daily ET, Bowen ratio, and evaporative fraction were highly correlated with summer shallow soil moisture in a semiarid region. Based on Bowen ratio flux tower data from a semiarid rangeland, Nagler et al. (2007) showed that ET was more highly correlated to an enhanced vegetation index than precipitation and reported that ET was mainly controlled by the transpiration process.

In this study, we differentiate three water limited semiarid ecosystems (cheatgrass, sagebrush and lodgepole pine) in the Snake River basin with a comprehensive seasonal and interannual flux analysis of 3 years of EC and LAS flux measurements and bio-physical processes that control the surface energy partitioning. The Snake River basin located in southcentral Idaho is a semiarid region, with diverse land cover types including grasslands (cheatgrass), shrubland (sagebrush), needle leaf