Hydrol. Earth Syst. Sci. Discuss., 7, C547–C558, 2010
www.hydrol-earth-syst-sci-discuss.net/7/C547/2010/

Hydrology and
Earth System
Sciences
Discussions

Interactive comment on "Roles of spatially varying vegetation on surface fluxes within a small mountainous catchment" *by* G. N. Flerchinger et al.

G. N. Flerchinger et al.

gerald.flerchinger@ars.usda.gov

Received and published: 17 April 2010

We thank Reviewer #2 for the helpful and constructive comments. Both reviews expressed concerns and/or desired more information about the water balance. As a result, the water balance aspect of the paper, which was a relatively small part of the original manuscript, will become a more important part of the revised paper. However, we do not want the water balance to dominate the paper, so we will use it to demonstrate the quality of the measurements. Major proposed revisions in response to Reviewer #2 comments include: introducing model simulations and validations in support of assessment and extrapolation of missing data; model simulation to include

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the influence of fir on the catchment water balance; expanded literature review and discussion regarding the influence of vegetation on surface fluxes; and more details and discussion of footprint analysis and representativeness of measured understory fluxes. Responses below correspond to each of the paragraphs in Reviewer #2's review.

1. We appreciate the encouragement and appreciation of the unique dataset. A more thorough literature review in the revised manuscript will include discussion of previous work that compared seasonal and annual fluxes for different vegetation types and ecosystems. Assessment of errors related to removing certain periods due to data screening and extrapolating missing periods will be accomplished by including some model simulations in the paper.

2. As pointed out by the reviewer, using eddy covariance in the lower part of the forest canopy should rightfully be subject to much caution because the underlying hypotheses are generally not valid in the prevailing understory conditions, i.e. low wind speed, strong heterogeneity, and intermittent turbulence. Despite these limitations, several studies have used eddy covariance systems to measure understory fluxes. Marks et al. (2008) presented an analysis of the snow cover energy and mass balance (including sublimation) showing that eddy covariance measurements below a pine canopy closely matched simulated values and the measured and observed mass balance. Molotch et al. (2007) used measurements above and below a sub-alpine forest canopy to partition sublimation of snow from the snowpack and intercepted snow. Jarosz et al. (2008) partitioned carbon and water vapor fluxes between the understory and overstory of a pine forest canopy using eddy covariance measurements. Roupsard et al. (2006) was able to validate understory measurements of evaporation within a coconut plantation by differencing total evapotranspiration measured above the canopy with sap flow measurement to measure transpiration. Scott et al. (2003) used eddy covariance measurements above and below an open woodland canopy to demonstrate that the moisture source for the understory and overstory were largely decoupled. Misson et al. (2007) used 10 sites within the FLUXNET network to demonstrate that while un-

derstory eddy covariance measurements are problematic at night due strong inversion layers, measurements during the daytime were generally reliable. Reba et al. (2009) presented data quality parameters of measured sublimation from the same sagebrush and aspen understory sites that were found to be of high quality in comparison to published criteria for data quality.

Undoubtedly, proximity to canopy elements and spatial variability within the understory will have an influence on measured fluxes. Wilson and Meyers (2001) addressed the issue of spatial heterogeneity in a forest understory by comparing the variability of three eddy covariance systems beneath a deciduous forest canopy; while a measure of variation in measured fluxes was 0.14 for their collocated systems compared to 0.54 for systems separated by 30 m, variability between systems decreased as the number of half-hour sampling periods used to obtain mean fluxes was increased. After forty-eight hours, variation decreased to 0.07 and 0.09, respectively. This suggests that by averaging fluxes over several days during each monthly observation period in our study, our average fluxes should be representative of average fluxes within the aspen understory.

As suggested by Lamaud et al. (2001), energy balance closure represents a powerful test to determine whether the eddy flux measurements are representative. They used the energy balance closure to demonstrate the validity of eddy covariance measurements in the understory of a pine forest. Granted, our initial analysis using all available data yielded unsatisfactory energy balance closure, but after removing the net radiation data that clearly were not representative of the overall understory due to gaps in the canopy shading, a reasonable energy balance was obtained.

3. A more thorough literature review as suggested will help put the current study in a more focused context with other research. In addition to the studies mentioned in #2 above, numerous studies have been conducted that contrast and compare the influence of vegetation type on energy and carbon fluxes within different ecosystems. Baldocci et al. (2004), for example, contrasted the partitioning of the surface energy

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balance and evapotranspiration response of an oak savanna and a grassland in response to available soil moisture. They found that the grassland senesced and quit transpiring earlier than the oak trees due in part to the trees being able to tap deeper water sources. Scott et al. (2003) and Paco et al. (2009) found similar results in the apparent decoupling of the moisture source for the understory versus the overstory of the open woodland canopies due also to the trees tapping deeper moisture. Chen et al. (2009) assessed the influence of human activity on surface conductance to modify the partitioning of the turbulent energy fluxes for cropland, and degraded steppe in comparison to a fenced steppe ecosystem.

4. The influence of the topography surrounding the sagebrush site is a point well taken. The sagebrush site is located on a gently rolling hilltop. Within the 50-m footprint for the measured fluxes, the site slopes approximately 2.4% to the north and west, 1.8% to the south, and is level to the east. This could potentially result in differences in average daytime incident radiation of 4 to 6 W/m2 on very clear days. Noontime incident radiation could vary by upwards of 15 W/m2 on very clear days. Admittedly our previous analysis to examine differences in the energy balance was limited and focused primarily on the influence of the tower. Subsequent analysis of the energy balance for wind coming from each of the four cardinal directions revealed that the slope of the energy balance closure ranged from 0.78 for east winds to 0.89 for north winds compared to 0.82 for all directions. A dummy-variable regression analysis (Fox, 2008, Chapter 7) found that the slope of the energy balance closure for north winds was significantly different from the slopes for other wind directions. Figure 1 in the uploaded pdf file displays the energy balance closure for the north and east directions. Although it would be interesting to explore the subtle differences between the energy balance closure for the different wind directions, we do not feel it is warranted to remove the energy balance from any of the quadrants, as all close the energy balance reasonably.

5. More detailed data recently available on the breakdown in vegetation indicates that aspen/willow account for 26% of the catchment, fir accounts for 5%, and sagebrush ar-

eas account for 69%. Unfortunately we do have evapotranspiration (ET) measurements of fir within the watershed and there is inadequate fetch to deploy an eddy covariance tower over the fir patches. While we expect evapotranspiration from the fir to be similar to the aspen, it would certainly be more desirable to have a separate estimate of ET from the fir. Thus, detailed simulations with the Simultaneous Heat and Water Model (Flerchinger et al., 1996) will be used to estimate ET from the fir. This model has been previously validated for fir forest canopies (Link et al., 2000) and separate simulations will be presented in the revisions to validate the model for the energy balance simulation of the sagebrush and aspen within the catchment.

6. In order to address concerns about extrapolating data for missing months (and also the concern about representativeness of fluxes after removing portions of the data expressed in comment #8 below), the SHAW model was applied and validated to each of the sites. Table 1 in the uploaded pdf file gives regression coefficients and Root Mean Square Deviations between simulated and measured monthly averaged hourly fluxes. For all months where measured fluxes were available during the 2007 water year, ET was extrapolated from the portion of the month that was measured to the entire month based on the ratio of simulated ET for the measured portion to that for the entire month. For the aspen understory during September 2007 and for above aspen from October 2006 through January 2007 when measured latent heat fluxes were not available, ET was estimated based on the relation between measured and simulated ET for the remainder of the year. The resulting estimated annual ET for the above aspen is 510 mm. If instead these the missing months were filled in using a simple regression between measured ET at the sagebrush and above aspen sites, the annual above aspen ET would be 506 mm.

7. Dual-gauge systems especially designed for the windy and snow-dominated conditions prevalent in the area were used to measure precipitation (Hanson et al., 2004). This method was tested during the WMO solid precipitation measurement intercomparison and was shown to be equivalent or superior to the use of either the Wyoming or

Alter shielded precipitation gauges across a wide range of snowfall conditions (Hanson, 1989; Hanson et al., 1999, Yang, et al., 1999).

Precipitation measurement for the aspen site was made in a clearing in the aspen stand approximately 100 m from the aspen eddy covariance tower. Spatial variability in precipitation is a dominant feature of the hydrology within the Reynolds Creek Experimental Watershed and has been documented by many investigators (Johnson and Hanson, 1995; Flerchinger et al., 2000; Chauvin et al., 2010 ; Hanson, 2001; Marks and Winstral, 2001; Marks et al., 2001a,b&c, 2002; Winstral and Marks, 2002; Liston and Elder, 2006; Winstral et al., 2009; Seyfried et al., 2009; Nayak et al, 2008, 2010; Reba et al., 2009).

8. The SHAW model was used to assess the representativeness of fluxes after removing portions of the data due to data quality screening and, particularly in the case of the above aspen site, inappropriate wind direction. Missing values for each monthly averaged hourly value accounted for approximately 22% for the sagebrush and aspen understory and 52% for the above aspen. Differences in monthly averaged daily fluxes simulated by the SHAW model using only the hours with observed fluxes versus using all hours for each period ranged from approximately -5 W/m2 for net radiation to 8 W/m2 for latent heat flux at the above aspen site. By comparison, differences in simulated values with or without missing periods were within 3 W/m2 at the sagebrush and aspen understory sites. While the differences in simulated daily average net radiation and sensible heat flux varied from positive to negative, simulated average latent heat flux using only the hours with observed fluxes above the aspen was always lower than that using all the hours in the period. Thus, there may be less evaporation demand when winds are from the north and east, and as the reviewer suggested, latent heat flux above the aspen may be biased by removing the fluxes when the wind is from this direction. Rather than trying to correct the data for these missing periods for the Seasonal Comparison of Fluxes section of the paper, we will note the discrepancy. However, adjusting the ET data as described in #6 above with implicitly correct for the

bias for the catchment water balance.

9. The paragraph in the manuscript discussing data quality and selection of the periods for analysis will be revised to read as follows:

“Flux data were filtered for spikes, instrument malfunctions, and out-of-range signals. Out-of-range water vapor and CO2 concentration accounted for approximately 90% of the poor quality data. Data were screened for representative periods during each month of 2007 when plotted turbulent fluxes from the three sites looked reasonable. Composite hourly averages were computed for typically 10 to 20 day periods within each month. These periods were selected because they had generally complete EC and meteorological data. Even so, approximately 22% of the hourly values for these periods were rejected for the sagebrush and aspen understory, and approximately 52% above the aspen due to either data quality or undesirable wind direction.”

The caption for each of the graphs in the revised manuscript will state which months are missing from the data.

10. Numerous approaches exist for footprint analysis. The method described by Schuepp (1990) was chosen for its simplicity and robustness. As pointed out by Schmid (2002), the flux footprint relationship developed by Schuepp (1990) is derived using crude assumptions, but its overall characteristics are the same as those of more sophisticated modern footprint models. We acknowledge the limitations of this approach for our situation, but this quantitative tool is nonetheless helpful to estimate the representativeness of our measurements. Equations and assumptions used in the footprint analysis will be included in the revised manuscript.

Although stable conditions of the aspen understory, which were common at night, may be biased by upwind vegetation due to excessive fetch, these periods were not removed from the analysis. It is expected that systematically removing these periods with strong downward sensible heat flux would bias the results more than the influence of the upwind vegetation.

11. Areal precipitation for the catchment was estimated based on a weighted average of precipitation measured within the respective vegetation zones. Flerchinger et al. (2000) demonstrated that this approach worked adequately for a catchment with similar variability in vegetation and precipitation within the Reynolds Creek Experimental Watershed. PRISM-type interpolation would not work in this catchment because, while precipitation is generally correlated to elevation over large mountainous regions, it is not well correlated to elevation within mountain catchments where wind exposure and vegetation cover strongly influence patterns of snow deposition.

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Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/7/C547/2010/hessd-7-C547-2010-supplement.pdf

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