Review #4

This paper summarizes recent advances and gaps in our knowledge which are re- lated to dryland ecohydrology and climate change. The authors have done a very good job in identifying and summarizing this topic and it is clear that they have put much effort and thought in doing so. Thus the paper has a scholastic attribute, and can definitely educate a wide range of people that are interested or even actively in- volved in such research. I recommend accepting this paper for publication in HESSD after some reorganization and additions, as follows: 1. With the approval and appre- ciation of this paper, as well as with most other remarks, I agree with the previous referees. Especially I would like to point out to the fact that I too, feel that the divi sion into 'Critical issues' and 'Technical advances' is somewhat peculiar and that the choices made here are not straight forward. Of course one paper cannot cover all rel- evant topics and some selection must be made, but while in 'Critical issues' quite a few important and interesting aspects received attention, 'Technical advances' focused on two, relates lengthily to each (especially the RESTREND method), and they are both questionable. My recommendation is either to drastically decrease the length of this section, or add a table summarizing more technical advances, as one of the other referees mentioned (amongst many other advances I can suggest to also relate to the new crop of geophysical tools such as GPR and EMI, phencam, improved modeling efforts, and geo-spatial informatics engines).

As suggested, we added a perspective paragraph to discuss the reason to choose discussing certain techniques. The section of RESTREND was significantly reduced and we also added a new conclusion section to summarize new techniques.

Newly added perspective:

"As already noted, the variability and distribution of water availability in the landscape is of paramount importance for drylands. There are a number of exciting developments in monitoring tools useful for ecohydrological research over the last decade. For example, field deployable laser based spectroscopy approaches that determine the ratios of hydrogen and oxygen isotopes (Lee et al., 2005; Wang et al., 2009d; Wang et al., 2012a), cosmic-ray (Zreda et al., 2008) and electromagnetic imaging (i.e., EMI) based plot to watershed scale in situ soil moisture monitoring, development of distributed-temperature sensing (DTS), and remote sensing based estimates of key hydrological variables such as soil moisture, ET and water level (Alsdorf et al., 2000) are revolutionizing the scales and precision of information sources to inform ecohydrological measurement and investigation. The modeling and conceptual advances in soil moisture (Rodriguez-Iturbe et al., 1999; Guswa et al., 2002), scale and scaling (Blöschl and Sivapalan, 1995; Rodriguez-Iturbe et al., 1995; Wilcox et al., 2003) also enhance our understanding of dryland ecohydrolocial processes. It is impractical to exhaust all the advances and here we select remote sensing and stable isotopes as examples and discuss three areas in details. First we discuss recent methodology advances to differentiate human vs. climate induced desertification using remote sensing product and time series analysis, corresponding to the critical issue 2.3; the second and third parts focus on using remote sensing and stable isotope based techniques to better characterize the water budget at various scales, which apply to all the critical issues. Remote sensing has the advantage in temporal and spatial duration and stable isotopes have the advantage in detecting mechanisms."

Newly added summary:

"In this synthesis, based on hydrological principles and published literature, we highlight current critical issues in drylands ecohydrology ranging from societal aspects such as rapid population growth and the resulting food and water security implications, development issues, and natural aspects such as ecohydrological consequences of bush encroachment and differentiation of human versus climate induced desertification. We identify a number of research priorities to better address knowledge gaps. It should be noted that while some of the issues identified are not necessarily unique to drylands themselves (e.g., food and water security), the level of severity and urgency is certainly higher in drylands and deserves focused attention.

To improve current understanding and inform upon the needed research efforts to address these critical issues, we identify some recent technical advances in terms of monitoring dryland water dynamics, water budget and vegetation water use, with a focus on the use of stable isotopes and remote sensing. Stable isotopes have proven to be a powerful tool in tracing hydrological processes and vegetation water sources. Recent developments in spectroscopy have revolutionized the temporal and spatial resolution of isotopic monitoring, providing foundations to use isotope-based techniques to partition ET and characterize large-scale vegetation water use. Similarly, rapid developments in remote sensing based hydrological monitoring provide unprecedented temporal and spatial coverage in estimates of soil moisture, ET, water level and other important ecohydrological aspects of the system. For example, both active and passive microwave based systems are available for remote estimation of soil moisture, with each representing a compromise between spatial and temporal resolution. Combing microwave-based passive and active systems with infrared-based sensors allows for the spatial and temporal resolution of precipitation structure and pattern to be significantly improved. In addition, the capacity to monitor vegetation structure and vegetation health provides additional benefits for ecohydrological monitoring using remote sensing.

Due to inherent length limitations, there are a number of related technical advances in in situ measurements, such as field portable 3D LIDAR systems for plant canopy analysis, distributed temperature sensors (DTS) for soil heat flux and connected waters measurement, and electromagnetic imaging (EMI) and cosmic ray soil moisture observing systems (COSMOS) for soil moisture that were not covered in detail. Further information of such advances can be found in a number of synthesis papers devoted to some of these techniques (e.g., Robinson et al., 2008; Zreda et al., 2012).

Overall, the analysis techniques, observation systems and monitoring advances discussed herein can all help to address some of the key ecohydrological issues of water and food security, consequences of bush encroachment and differentiation of human versus climate induced desertification. Inevitably, development issues in drylands require a hydrological, ecological and socio-economic understanding of the dryland ecosystem. An effective management of dryland systems demands that advances in monitoring, together with informative techniques for data analysis, should be linked within an interdisciplinary interpretive framework. Only then will the capacity to address the myriad issues facing dryland systems in the coming years be realized. ”

2. I suggest relating more in-depth to how climate change is expected to change not only precipitation amounts but also the temporal pattern of precipitation. Some studies indicate that increased storm intensity will most likely result with deeper infiltration depth in drylands, thus increasing plant, and especially tree water availability. Changes in precipitation pattern and increased storm intensity will also effect interception, which is mentioned in section 2.5.1 / 2. 3.

A new paragraph was added to discuss the effect of rainfall intensity change on infiltration.

“Climate change predictions show that the total precipitation amount will general decrease in drylands (Solomon et al., 2007) with concurrent increase in storm amounts (Ohmura and Wild, 2002). The intensified storms have been shown to increase soil water holding by deeper infiltration. These soil water is less susceptible to evaporation, thus the increased storm intensity may increase the water availability for shrubs/trees (Raz-Yaseef et al., 2012), but this depends on soil texture and rainfall intensity and need further investigation for other areas.”

The topic of tree/shrub vs. intercanopy patches, which is noted in Pg. 4789, could also receive more elaboration. A few studies have been conducted recently showing large differences in soil carbon, grass productivity, and soil evaporation between these ecosystem components. Correctly defining the differences between them is critical for upscaling plot to ecosystem processes.

A new paragraph was added to discuss the open canopy and under canopy interactions.

“5. Many studies have shown higher nutrient levels (e.g., Charley and West, 1975; Schlesinger et al., 1996; Ravi et al., 2009; Wang et al., 2009c) and higher soil carbon concentrations (e.g., Wang et al., 2009b) under the shrub/tree areas compared with open areas. In fact, woody plant encroachments affect both soil moisture and soil biogeochemical processes through physical (e.g., shading effect to decrease evaporation) and biotic factors (e.g., water uptake through deep rooting). And soil moisture itself strongly control soil biogeochemical cycles in water-limited systems (e.g., Austin et al., 2004; Wang et al., 2009a). How to separate the woody plant and soil moisture effects on soil biogeochemical cycles is important to better understand the dynamic differences between under canopy and open canopy and the tree-grass interactions. This information is important to upscale the plot-scale observations to larger scales. ”

Specific remarks: Pg. 4783 LN 23: “. . . increasingly dependent on more water resources than they do not control . . .”. This sentence is not clear.

“than” was changed to “that”

The division into sections 2.2 and 2.3 is confusing and it seems there is some overlap between the two.

These two sections were combined and modified to reduce redundancy.

Pg. 4794 LN 22: ". . .more specific catchment-specific data . . .". Please try to rephrase.

This sentence was rephrased.

"These regional studies reinforce the notion that more catchment-specific data are needed for both the ecological (e.g., tree rooting depth, canopy architecture and structure, depth of water intake) and hydrological (soil texture and hydraulic conductivity, soil moisture availability, hydrological connectivity) components of these systems, in order to improve our catchment wide modeling of the likely ecohydrological effects of vegetation change."

Pg. 4794 LN 27: The use of 'groundstory' is to me less familiar than 'understory'.

All the "groundstory" were changed to "understory".

Pg. 4800 section 3.2.1 Soil moisture: It would be worthwhile to mention that COSMOS can separately define soil moisture at the topsoil and soil moisture in the subsoil.

We added this in the revised manuscript, after checking with researcher who is in charge of the COSMOS deployment.

"In addition, the hydrogen in the top layer has more sensitivity to the neutron counts, thus COSMOS has the potential to discriminate soil moisture at the topsoil and soil moisture in the subsoil, if combined with modeling to separate the various hydrogen pools in the average measurement."