Anonymous Referee #1 Received and published: 23 March 2016

This manuscript describes approaches to infer water use efficiency (WUE) across regions using different observations and shows that observations indicate a substantially greater increase in WUE than what is predicted by climate models. I found the manuscript straightforward, well-described, with highly important results and having highly relevant implications. So the manuscript should, eventually, be published. **The reason why I suggest major revisions is that the organization in its present form is disorganized and some valuable information is contained as supplementary information that could very well be placed in the main manuscript.** The present form reminds me of a manuscript version that is submitted to journals like Nature or Science, and so it does not fit well into the organization of a normal journal manuscript. For instance, some of the methodology is described in the results section, and I also feel that the motivation could be improved in that it provides an outline of what is done with different data sources and climate models.

Thank you for your positive review. We have re-organized our method section and added three new sections: 2.3 on how we have calculated the fractional WUE, 2.4 on how we have calculated the global fractional WUE and 2.5 on how we have compared our data based simulations with other observations from Remote Sensing and Earth System Models (see new manuscript).

We also improved our outline of what has been done. The last paragraph of the introduction now reads:
We focus in this study on fractional changes in WUE, which are more likely to be independent of these complex factors. Therefore, we use two very different datasets of WUE, derived from tree ring measurements and eddy-covariance fluxes and aim to model the fractional changes in plant WUE by using atmospheric data alone. We do not assume the applicability of stomatal optimization theories, but instead adopt equation 5 as a parsimonious empirical model for the fractional changes in WUE observed at each measurement site, given suitable fitting parameters a and b. Tests using more elaborate statistical models, with additional environmental variables or vegetation-specific parameters, were not found to produce significant improvements in the fit to the observed changes in WUE despite the introduction of extra fitting parameters. Finally, we have estimated global fractional change of plant WUE and compared those to simulations with complex Earth System Models (ESMs) and focused on regional differences of changes in plant WUE.

Minor comments: line 33: The abstract would benefit from a final, concluding sentence.
Thank you for this remark. We added the following concluding sentence:
Overall, we conclude that our data based analysis shows that the latest climate projections largely underestimate the effects of increasing CO_2 on plant WUE and thereby on either estimates of plant transpiration or photosynthesis.

line 68: Should this not be leaf temperature rather than surface temperature to be consistent?
Thank you, indeed we have changed this to leaf temperature.

line 153: What about the use of remote sensing and climate model output? This should be mentioned in the Materials and Methods section as well.
See new section 2.5

line 175: Perhaps mention that it is because a > 1 that WUE increases faster than CO2?
Thank you we have included *A value of a larger than 1, suggest that*

line 189: It may also be the case that optimality theories on stomatal conductance miss some feedbacks with the atmosphere that are relevant for the optimization.
Thank you we have included that indeed a lack of feedbacks can cause this or *by missing other mechanisms as structural stomatal adaptation of plant species against increase in CO_2 (de Boer et al. 2011)*

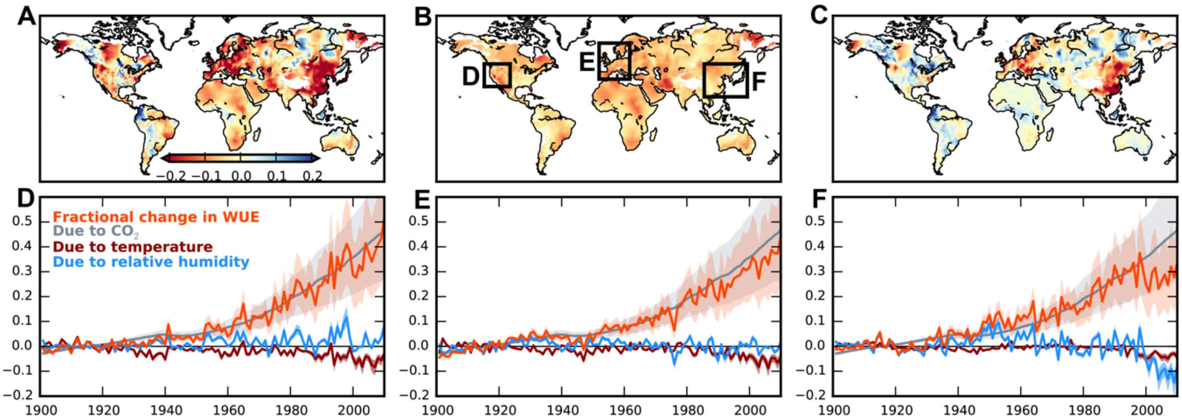
line 204: I think it would be useful to include Fig. S7 in the main text.
We now have included Fig S7 as new figure 2

line 215: The text mentions Jung et al. 2011, but Figure 2 mentions Lin (et al. is missing). I am confused.
Sorry, this must be Jung et al. 2011

Line 229: This should go to the methodology section. line 249ff: This should go to the methodology section.
Thank you, see new section in chapter 2

line 262: I could not find an animation, but I am sure that this could be done in the Copernicus system.
Yes we will upload it via the Copernicus system

line 268: I may be missing something, but I cannot see a slower increase in WUE in the figure.
Thank you, we made a mistake in uploading an old figure. Below you will find the true responses



Now you can see that for E (Europe) a slower increase in WUE is observed which becomes even constant for Asia.

The references are sometimes incomplete (e.g., et al. instead of author names, page numbers are also missing for a couple of references).
We have corrected this.

Figure 5: I am confused by the boxes in (b). These do not refer to panels D-F. Also, the labeling A-F is missing in the figure.
Indeed the labelling is missing, and we have corrected this (now Figure 6)

Anonymous Referee #2 Received and published: 29 March 2016
In this manuscript, the authors used data from eddy covariance measurement and treering observations to derive an empirical relationship that links fractional change in water use efficiency (WUE) to changing atmospheric CO2 and atmospheric humidity deficit. The authors then reconstruct fractional change in WUE during historical period, and compare the results with those from CMIP5 simulations. It is found that reconstructed global fractional increase in WUE is much larger than that simulated by CMIP5 models. The method used in this study is scientifically sound, the analysis is comprehensive, and the results are important for understanding land surface response to increasing atmospheric CO2 and climate. I recommend publication after the following issues are addressed.

Thank you very much

Specific comments:

Line 121: In what years are those data taken from eddy-covariance observations?
This is between 1995 and 2006 and we added this in the manuscript

Line 138: In what years are those data taken from tree-ring observations?
Data are selected since 1900

Line 146: "WUE is estimated using equation 2". equation 2 should be equation 4.
Thank you
Line 157: "We rewrite equation 3". equation 3 should be equation 5.
Thank you we have changed this
Lines 187-190: It would be helpful to the readers to specify some possible missing constraints in the optimization theories.
We have changed this and added also for example the work by de Boer, who found that vegetation can adapt their density against CO2 levels and therefore can change the CO2

Line 248: It would be great if the authors can also discuss the difference in historical WUE change between observational based reconstructions and CMIP5 results at regional scales.
We do this in the next section.

In the following section, the authors discussed substantial regional difference in WUE after all. It would be useful to know at what regions, there exist large discrepancy in WUE change between reconstructions and models, and among CMIP5 model members
Good suggestion, we will zoom in to the regions were we also have tree-ring information. These lat/lon locations will be compared to the CMIP5 model members.

Comment

This discussion paper cites Prentice et al. (2014), but overlooks its significance for water use efficiency (WUE). The new theory introduced by Prentice et al. (2014) replaces the Cowan-Farquhar stomatal optimization principle with a more explicit and comprehensive hypothesis: that plants minimize the sum of the costs (per unit assimilation) of maintaining both the biochemical capacity for photosynthesis and the physical capacity for transpiration.
We showed how this minimum is obtained by maintaining a 'set point' of the ratio χ of leaf-internal to ambient CO_2, whose value is almost independent of ambient CO_2, but dependent on vapour pressure deficit (D) and temperature. See also Discussion paper http://dx.doi.org/10.1101/040246 where the theory is further tested with leaf $\delta^{13}C$ measurements, and extended to include the additional effects of atmospheric pressure.

The exact form of these dependencies (equation 8 in Prentice et al., 2014) can be used to obtain the derivatives of ln (WUE) with respect to different predictors. For ln CO_2, the derivative is always > 1. For example, at 400 μmol mol^{-1} CO_2 and 10C, the derivative is 1.05 and at 30C it is 1.16. For ln D, the derivative is < –0.5 and depends primarily on the value of χ. It is approximately –0.62 for χ = 0.8 (a typical value for cold, wet climates) and –0.73 for χ = 0.6 (a typical value for warm, dry climates). Therefore, the values obtained for these dependencies seem to be more in line with new theory than old. The data would repay a more penetrating statistical analysis that would allow the emegence of dependencies that are explicitly predicted by the new theory.

Indeed we think it is a great idea to use our data in the framework by Colin Prentice and analyze for instance regional differences in the eddy covariance or tree ring data. However, this is beyond the objectives of our paper and would be a new study.

Prentice, I.C., N. Dong, S.M. Gleason, V. Maire and I.J. Wright (2014) Balancing the costs of carbon gain and water loss: testing a new quantitative framework for plant functional ecology. Ecology Letters 17: 82-91. Colin Prentice 4 April 2016