

## ***Interactive comment on “Evaluation of an extreme-condition-inverse calibration remote sensing model for mapping energy balance fluxes in arid riparian areas” by S.-H. Hong et al.***

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The authors present work that compares SEBAL's estimation of energy budget components (mostly latent heat exchange) for 3 arid riparian areas, (Owens valley, CA, Middle Rio Grande Valley, NM, and San Pedro, AZ) with ground based measurements. This work could be used to identify potential issues regarding the calibration and validation of remote sensing energy budget data specific to SEBAL against ground based measurements. However, as currently written, the manuscript appears unfocused due to either unnecessary detail and/or indirect writing. Due to the unfocused nature of the manuscript it is difficult for the reader to interpret the results or the validity of the study.

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Answer: See our response to the second major comment of reviewer 1. However, we have inspected and improved our writing.

Moreover, it is hard to discern what the primary objective of the paper is. For example, section 3.3 (Comparison of SEBAL flux predictions to ground measurements) seems to be (at least partly) the heart of the paper, but is under the methods section and is currently written as part methods and part discussion that appears to repeatedly fault ground based measurements for being inadequate to verify SEBAL results. However, from the title and introduction, I thought the purpose of the paper was to evaluate the performance of SEBAL in arid riparian areas, and not 'address the issues of comparing satellite based energy budget data to ground based data'. Furthermore, at L4-5 on page 13496 the aim is restated to 'evaluated the challenges of SEBAL flux perditions in arid riparian areas using a validation approach', which is more in line with sections with section 3.3's discussion. However, the approach discussed in section 3.3 leads me to believe that ground based measurements may not be an appropriate method to validate SEBAL and that comparisons to other satellite based methods are warranted given the scale differences between ground based measurements and satellite observations. However, the decision of whether or not to include further comparisons hinges on what the specific purpose of the paper is, which needs to be better defined by the authors.

Answer: We have replaced and restated portions of the manuscript to hopefully make the descriptions and discussions more clear and consistent. The overall goal of this study is to conduct a thorough evaluation of the performance of SEBAL in arid riparian in New Mexico, Arizona and California as stated in the introduction. Our original intent was a straightforward comparison between ground measurements and satellite based energy budget data. Comparison with other remote sensing methods is not an option since there are no other remote sensing ET algorithms available that have the high spatial resolution and accuracy of the SEBAL and METRIC approach (see Karimi and Bastiaanssen, 2015). However, it turned out that such a simple straightforward method would not be adequate because of issues with the energy balance closure and the

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representativeness of the net radiation measurements. We do respect your opinion and valuable comments but also strongly believe that it is high time to inform the hydrologic community about the challenges of using energy balance measurements for validation of remote sensing ET algorithm even if this leads to complex papers.

Major Comments:

Page 13481 L13-L14: It is actually not clear to me that the work presented here provides evidences that SEBAL yields reliable estimates for actual evapotranspiration rates in riparian areas of the southwestern United States. Primarily, because of the issues presented in section 3.3 as well as the results section that painstakingly point out the issues with ground based measurements, which are the only set of validation data used in this study.

Answer: Issues with ground measurements and remote sensing observations should be painstakingly pointed out. We conclude use a combination of both to come up with the best possible energy balance and LE. We have implemented what we understand to be the more accepted means of data analysis and error correction for both ground-based measurement and RS-based measurements. Comparison of ground and RS-based measurements is consistent with accepted practice.

Page 13487 L4-L6: Why is it safe to assume that soil moisture is constant? Especially for arid environments where ET usually is a large part of the water budget? What are the implications of this assumption?

Answer: We refer to a daily soil moisture change that typically will not cause a large effect on total daily ET. We have changed the text from "Where soil moisture does not significantly change" to "Where daily soil moisture does not significantly change".

Page 13487 L17-L18: Support for the assumption that  $G_{24} = 0$  should also be stated here rather than later at Page L13492, L26-L27. Regardless this to me seems to be a rather large assumption that has consequences as the land surface and soil column

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in these environments will experiences seasonal (larger then daily) scale warming and cooling.

Answer: We write "close to zero". This is a common assumption for soils that has been backed up by measurements. Of course, although we can ignore the daily changes of soil heat flux for the daily energy balance, we cannot ignore the sum of the daily changes totaled over a season. In this study we deal with the daily energy balance.

Page 13491 L3-L8: Why do you exclude data where the sum of the H and LE is 65% less then or 110% greater than of the available energy? This criteria seems to eliminate much of the available data. Is this an indication of poor observational conditions, such as days that are not clear or have variable weather?

Answer: A riparian area with its high variability in roughness length, mesoscale temperature heterogeneity, short fetch distances, and maybe heat storage in the woody parts of trees and bushes is arguably one of the most challenging locations for EC measurements. The poor energy balance closure is therefore not a surprise. Since satellite images are only useable under clear sky conditions, the meteorological conditions should generally be consistent and variable weather would not be expected to impact the analysis. The poor closures may be caused by large low frequency eddies and horizontal heat advection that are both triggered by the mesoscale temperature variability between the desert and the riparian area. We amended the text as follows: "Wilson et al. (2002) found the average energy balance closure at FLUXNET sites to be between 53 to 99%. Since these numbers represent average closures and since data points at the lower end of the range raise greater concerns for data quality, we chose to shift the range up.

Section 3.4 Footprint model: There are important concepts that are partly presented here regarding the problems of validating SEBAL using ground based measurements, which I believe contributes to a lot of the issues of calibrating and validating SEBAL. Mostly reconciling scale issues between satellite observations and point scale(ish)

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measurements. These issues are cryptically mentioned in sections 3.3.2 and 3.3.3. For example the difference between the heat plate scale of 0.001 m<sup>2</sup> and 900m<sup>2</sup> Landsat pixel. Unfortunately, the scale of measurements and the scale of the SEBAL pixel is never clearly or coherently presented, rather some information about the scale is peppered throughout the paper.

Answer: The scale of SEBAL is largely tied to the 30 to 60 to 120 m scale of Landsat, due to the strong impact of thermal signals on the energy balance. We have attempted to employ this scale in the manuscript.

Minor Comments: Page 13483 L13-L22: These two sentences have unnecessary detail that can be summed up as field measurements are slow and costly, in contrast satellite measurements are fast. Please be more direct. Answer: We have shortened this section.

Page 13483 L20: Change ‘...86000 ha of the office...’ to ‘...86000 ha from the office...’ Answer: Done.

Page 13483 L22: The phrase ‘expert months’ is not clear. Answer: This phrase has been eliminated.

Page 13484 L6-L8: “Another difference with previous studies is our focus on all components of the energy balance during the instant of satellite overpass ...” Is this the only difference? Did the other validation studies not focus on arid riparian areas? Also, did those validation studies have the same problems with ground based measurements discussed in section 3.3? Answer: Actually, we don’t know of any other studies in arid riparian lands that offer the amount of detail included in this study. Many studies conduct a simple comparison between eddy covariance ground measurements and remotely sensed fluxes without the scrutiny of this study. Not taking into account the common well-known problems with ground based measurements will lead to less accurate remote sensing ET algorithm.

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Page 13485 Equation 2 and 3: Is H instantaneous or daily? It appears the notation is not consistent. Answer: H is used for both the instantaneous and daily sensible heat flux but in the caption of Tables and Figures we inform the reader whether H, G, R<sub>n</sub> or LE is instantaneous or daily. Using subscripts would have deteriorated the readability of the transcript.

Page 13487 L17: Why is C<sub>ef</sub> set to 1.0, which would then have no effect on equations 5 and 6? Answer: We have now included C<sub>ef</sub> as a variable in the equation for 24-hour ET. This is consistent with the testing of C<sub>ef</sub> = 1.0 and 1.1 later in the paper.

Page 13493 L19 – Page 13494 L10: This paragraph is an example of indirect writing. I assume the point of the paragraph is the last sentence, “Therefore, in this study rather than trying . . .” In scientific writing, the point should be stated up front and supporting details follow the main point. Answer: We have restructured this section.

Page 13500 L19: ‘Incoming short and longwave radiation’ and for that matter outgoing short and longwave radiation. These terms can be separated from R<sub>n</sub> in your equations and in many energy balance equations can be calculated/measured separately. Perhaps the terms should be presented as separate components of the energy balance equation (equation 1). Answer: Good suggestion. We have done so.

Page 13503 L22: The phrase ‘traditional SEBAL’ is awkward. Answer: We agree and change to “original SEBAL”.

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