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Interactive comment on "Temporal interpolation of land surface fluxes derived from remote sensing – results with an Unmanned Aerial System" *by* Sheng Wang et al.

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Response to the review of Referee 3. We have copied the comments of the referee hereunder with our comments appearing after the referee's comments.

1. General comments "Temporal interpolation of land surface fluxes derived from remote sensing – results with an Unmanned Aerial System" describes the use of a suite of simple models to interpolate surface fluxes and surface state variables between sporadically available land surface measurements. A model dubbed the SVEN was created by augmenting a Priestly Taylor model with new components to enable its use at timescales as short as 30-min. Instantaneous remotely sensed variables recorded

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Discussion paper

mainly using a UAS were used to calibrate the model, and the model was then used to fill in the extensive gaps between measurements. This work introduces and demonstrates of the technique, which was designed to be used with both satellite and UAS remote sensing measurements. It is a solid manuscript, with room for some improvement. Because one of the primary stated goals of the paper is the development of an application to satellite remote sensing, the omission of actual satellite measurements is conspicuous. I suggest that more attention be given to the topic of using satellite data. For example, what might be the shortcomings of applying the model to satellite-based measurements? Were UAS measurements relied upon for this paper rather than space-based measurements due to the inadequate spatial resolution of satellite measurements? At this site in-situ and UAS measurements are available (and used), but how well will the model work for the rest of the Earth's surface? Clarify the purpose of the model (including the parameter fitting) in the broadest sense, and develop, test, and describe the results accordingly. In addition, more care needs to be taken with the way remotely sensed measurements are handled. They are misleadingly referred to as "ground truth" or direct measurements throughout the manuscript, when most of the variables derived from remote sensing data were modeled or inferred, rather than measured directly. Uncertainties due to this also require more attention. The writing should be reviewed carefully by a native English speaker. Some examples are included in the specific comments below, but the manuscript includes many errors in writing and sentence structure.

Reply: We appreciate the reviewer's insightful comments and suggestions, which were very helpful to improve the manuscript. We totally agree that the great potential of utilizing the simple but effective land surface models to fill gaps between observed surface states and fluxes from remote sensing. We have thoroughly revised the manuscript to improve the presentation of this work. We have also added the discussion on the shortcomings of applying this model to satellite-based measurements and the rest of the Earth's surface. For instance, the SVEN model is a very simple water balance model, which has limited capacity to simulate soil water dynamics particularly in re-

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gions with complex landforms. In our study, SVEN also achieved moderate performance to simulate soil water dynamics. In addition, the soil layer depth refers to the maximum root water uptake depth, which may vary with time, but the model simplified this soil depth parameter to keep it consistent. Thus, in our study, SVEN also achieved moderate performance to simulate soil water dynamics. Meanwhile, the PT-JPL model has the limited performance to simulate ET in the dryland regions. There also remain challenges to get the reliability of atmospheric forcing such as radiation, precipitation and wind speed, particularly for data-scarcity regions. Moreover, the remote sensing based estimates of land surface temperature and soil moisture have uncertainties, which could be propagated to induce significant errors in the simulated continuous land surface variables. In addition, satellite based observations or estimates can have large uncertainties due to the coarse resolution. The integration of land surface model and satellite earth observation might be challenging than the integration with UAS derived variables. Please find the details in the discussion 4.4 (P22-23). We have also revised the words on "ground truth". We have changed the words to the UAS derived observations or estimates. We have also thoroughly revised the language and improve the manuscript writing. Here, we have also addressed your comments point-by-point.

2. Specific comments P 1, ln 7-8. With the exception of Ts, all of these variables are determined using remote sensing products based on a suite of different models and assumptions. For example, different vegetation indices can be measured remotely, but GPP cannot. The same applies to ET, SM, and Rn – none of these variables are measured directly using remote sensing, but the first sentence misleadingly indicates otherwise. Without detracting from main point of this sentence, a word such as "inferred" or "derived" could easily be included for more accuracy.

Reply: Thank you for your suggestion. We have revised the terminology to use "derived" to indicate that variables such as GPP, ET, SM (θ) and Rn were estimated from remote sensing data.

3. P 1, ln 20. Delete the word, "well" from, "...SVEN can well estimate...". Awkward

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as written.

Reply: Thank you for your suggestion. We have deleted this word. Please see L20 on P1 in the revised clean version.

4. P 2, ln 2-3. “Minimum parameterization” is awkward as written.

Reply: Thank you for your suggestion. We have deleted these words. Please see L1 on P2.

5. P 2, ln 7. “Mostly needed” is awkward as written. Also, replace “high frequency” with “prevalence.”

Reply: Thank you. We have deleted “mostly” and have replaced “high frequency” with “prevalence”. Please see L6 on P2 in the revised clean version.

6. P 2, ln 11. Replace “flexibly” and “favorable” with more precise descriptors.

Reply: Thank you. We have revised “flexibly” with “favorably”. Please see L10 on P2.

7. P 2, ln 14. Replace “still just provide” with “still only provide.”

Reply: Thank you. We have revised “still just provide” with “still only provide”. Please see L20 on P2.

8. P 2, ln 16. Replace “uncovered” with “unknown.”

Reply: Thank you. We have revised “uncovered” with “unknown”. Please see L22 on P2.

9. P 2, ln 25. “using statistical interpolation could be challenging…” is awkward as written.

Reply: Thank you. We have revised this sentence to be “the statistical method to interpolate for variables that change substantially at sub-daily or daily time scales in response to the surface energy dynamics, e.g. Ts, Rn, SM, ET and GPP, could be challenging”. Please see L30 on P2.

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10. P 2, ln 28-29. "can be better" is awkward as written.

Reply: Thank you. We have revised this sentence to be "has great potential". Please see L1-2 on P3.

11. P 2, ln 30. Delete "a" in, "in a variable climate conditions."

Reply: Thank you. We have deleted "a".

12. P 3, ln 6. "as for example the turbulent fluxes are typically. . ." is awkward as written.

Reply: Thank you. We have deleted the sentence.

13. P 3, ln 7. "simpler but operational models based interpolation" is awkward as written.

Reply: Thank you. We have revised the sentence to be "Simple model based interpolation can be utilized to interpolate snapshot remote sensing estimates of land surface variables." Please see L12-13 on P3.

14. P 3, ln 11. Delete "the" at the beginning of this line.

Reply: Thank you. We have deleted that. Please see L14 on P3 in the revised version.

15. P 3, ln 15. Rewrite as, "limited meteorological inputs, and parameters that. . .".

Reply: Thank you for your suggestion. We have revised this sentence to be "We aimed at using prescribed vegetation dynamics from EO based vegetation indices, limited meteorological inputs, and parameters optimized from remote sensing derived fluxes to estimate temporally continuous land surface variables". Please see L19-21 on P3.

16. P3, ln 21-22. "now becomes" is awkward as written.

Reply: Thank you. We have revised the words to be "serve as". Please see L27 on P3 in the revised clean version.

17. P4, ln 4. Add the word, "it" after "forcing".

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Reply: Thank you. We have added “it” after “forcing”. Please see L10 on P4.

18. P4, ln 17. Change, “onboard have been conducted” to, “onboard were conducted.” And “Details refer. . .” to, “For more details refer...”.

Reply: Thank you. We have changed the sentence to be “were conducted” and “for details, please refer to”. Please see L22-23 on P4.

19. Figure 1. This is exactly the same as Figure 1 from Wang et al. (2018b). I don’t know HESS’s rules regarding this type of thing, so I will refer to the Editor for guidance. I would never reuse a figure like this myself, but if this is actually acceptable, the original usage should certainly be referenced. In addition, a small wind rose would be a nice addition to the figure; at a measurement height of 10 m (Wang et al., 2018b), the flux footprint will extend well beyond the edges of the figure in some conditions. As an aside to be passed onto the site manager, if the eddy covariance instrumentation were closer to the top of the canopy, it would help alleviate this problem.”

Reply: Thank you for the comment. We don’t want to reuse a figure from another paper. There are several differences between this figure and the one in Wang et al. (2018b). For instance, the new figure used the pseudo-color multispectral imagery (Red: 800 nm, Green: 670 nm, Blue: 530 nm) as the base map, while the one in another paper used a normal RGB photo as the base map. The new figure does not have markers to indicate the samples of soil moisture as Wang et al. (2018b). However, we admit that these two figures are similar. We have revised the figure to have more differences with Wang et al. (2018b). For instance, we have added the wind rose to Figure 1. Regarding the measurement height, Wang et al. (2018b) did not use CO2 and water vapor eddy covariance data and the measurement height of 10 m refers to the meteorological observations such as wind speed, solar radiation, and longwave radiation. To make this clear, we have added more explanation to the data section. The CO2 and water vapor eddy covariance system was adjusted to around 2 m above the maximum canopy height. This means that 2 m (before willow growing) to maximum 4

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m (maximum canopy height of 6 m) above zero plane displacement. So, in most cases except for few stable conditions in night, the footprints of eddy covariance did extend beyond the edge of willow plantation. For details, please see L10-15 on P5.

20. P5, ln 24. “Data of few UAS flight campaigns” is awkward as written.

Reply: Thank you for the comment. We have revised this sentence to be “UAS data on June 24th were missing as shown in Table 1”. Please see L10 on P6.

21. P5, ln 26. Replace the word, “resemble” with more appropriate verbiage. Reply: Thank you. We have changed the word to be “simulate”. Please see L12 on P6.

22. P5, ln 27. Clarify that the “ground truth” SM measurements were not actual SM measurements, and describe the uncertainty and shortcomings of the remotely sensed SM product in detail.

Reply: Thank you for your suggestion. We have revised the “ground truth” words. For model calibration, the instantaneous values of the Ts and θ estimated from the seven UAS flights were used as reference.

23. P5, ln 29. “which corresponded to the willow emerging period with a high growth rate” is awkward as written.

Reply: Thank you for your suggestion. We have revised this sentence. The minimum revisit time was 10 days in the willow emerging period between May 2nd and May 12th. Please see L14-15 on P6.

24. P7, ln3. “and can facilitates to temporally interpolate” is awkward as written.

Reply: Thank you for your suggestion. We have revised the sentence to “can temporally interpolate the instantaneous land surface variables”. Please see L11 on P7.

25. P8, ln 24-26. Clarify that this includes the existence of a canopy. As written, it reads like a simple soil diffusion-based approach, that neglects the existence of vegetation. There is a transfer coefficient for the canopy (Cveg) described on P9, along with LE

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etc., so I assume this all adds up correctly (I am not a modeler), but a more complete initial description is wanted on P8.

Reply: Thank you for the comment. This model is proposed to simulate GPP and components of evapotranspiration (transpiration, evaporation from the intercepted water, and soil evaporation). Therefore, this model has the vegetation module to calculate the heat exchange between vegetation and ground. To make this clear, we have added more explanations at the beginning of the model description. Please see L16-17 on P7 in the revised clean version.

26. P9, ln 24-25. Change to, “k is the von Karman constant.”

Reply: Thank you. We have revised this sentence. Please see L13 on P10.

27. P12, ln 20. “The rest of constraints,” is awkward as written.

Reply: Thank you. We have revised this sentence. Other constraints such as thermal regulation reflect changes in LUE due to environmental factors. Please see L9-10 on P13.

28. P12, ln 21. “are the same modifying,” is awkward as written.

Reply: Thank you. We have revised this sentence. “are the same for regulating ETc” Please see L10 on P13.

29. P13, ln 6. Change to, “UAS-derived observations,” or otherwise clarify that many of these UAS variables were not measured directly.

Reply: Thank you. We have revised the sentence. The model inputs of this study were obtained from meteorological data, UAS derived observations or estimates.

30. P14, ln 1. Change, “facilitate,” to, “facilitates.”

Reply: Thank you. We have revised the word. Please see L8 on P15.

31. Eq 34 description. Clarify what time period (e.g. 30 min or 24 h) was used for this

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EC measurement adjustment, and how missing data were handled.

Reply: Thank you. The EC data energy balance closure errors were corrected at 30 mins using the Bowen ratio approach. We have elaborated this in L18-19 on P15. Regarding the missing data, the data gaps were filled with based on the R-package REddyProc (Wutzler et al., 2018) using the meteorological data as inputs. For details, please refer to L13-15 on P5.

32. P14, ln 25. "well represent" is awkward as written. Reply: Thank you. We have revised the words to be "the indicators of". Please see L9 on P16.

33. Validation at the daily time scale Section. Augment the discussion of uncertainty in the UAS-derived measurements (as compared to direct measurements).

Reply: Thank you. We have added the discussion on the uncertainties of UAS derived estimates compared to the direct measurements. Please see L9 on P19.

34. P16, ln 24. "that the better UAS based snapshot estimates of SM. . ." is awkward as written. Perhaps, "that improving the UAS-based estimates of SM. . .".

Reply: Thank you for the comment. We have revised this sentence. Please see L13 on P19.

35. P16, ln 34. "has a large coverage" is awkward as written. More accurately, it could be replaced with something like: "extended well-beyond the edges of the Willow forest of interest".

Reply: Thank you. We have revised this sentence. During the night time, the eddy covariance footprint extended well-beyond the edges of the willow forest of interest, due to the stable atmospheric conditions. Please see L22 on P19.

36. P18, ln 1. "are be good" is awkward as written.

Reply: Thank you. We have revised this sentence to be "To check the model simulation performance under cloudy conditions". Please see L6 on P20.

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Discussion paper

37. P18, ln 3. “do not show difference” is awkward as written.

Reply: Thank you. We have revised this sentence. There were no significant differences for the residuals of the simulated Ts, Rn, SM and LE under low and high diffuse radiation fraction conditions. Please see L7-8 on P20.

38. P18, ln 5. “do to that the model” is awkward as written.

Reply: Thank you. We have revised this sentence to make it clearer. Please see L6-10 on P20.

39. P18, ln 6. “enhancement diffuse radiation effects” is awkward as written.

Reply: Thank you. We have revised this sentence. Please see L6-10 on P20.

40. P18, ln 19. Perhaps change, “R2 for Ts. . .” to, “R2 for monthly Ts. . .”

Reply: Thank you. We have revised the sentence to be monthly Ts.

41. P20, ln 10. Change, “understanding on the” to, “understand of the”.

Reply: Thank you. We have revised the words. Please see L7 on P24.

42. Conclusions. What would the effects of using space-based remote sensing measurements be, rather that UAS measurements? Also discuss how well this method will work in areas where in-situ measurements are unavailable to better parameterize the UAS and SVEN measurements.

Reply: Thank you for your comments. We think there would be four major effects of using space-borne remote sensing measurements rather than UAS measurements. First of all, the space-borne remote sensing data have much coarser spatial resolution. If we move the simulation to the large scale with satellite data, we need to find accurate gridded meteorological data as forcing. UAS imagery has limited coverage and thus this study only used one meteorological station data as forcing. As satellite data have coarser pixel sizes, we also need to consider the sub-grid heterogeneity and identify the

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Discussion paper

effective values for model parameters. Note all parameter values of models were obtained from parameter calibration with remote sensing based estimates. For instance, in our study, we used the look-up tables with soil texture information to identify soil parameter values. In the large-scale simulation with satellite data, the plant functional type and soil type parameterization scheme for different ecosystems and environmental conditions would be needed. However, the integration of accurate remote sensing estimates with land surface models would be beneficial to reduce the dependency of plant functional type parameterization scheme and achieve a higher accuracy to predict land surface variables. In addition, coarse resolution satellite data may have limited accuracy to predict land surface fluxes compared to the detailed UAS data. Applying SVEN with satellite data to large scale, we also need to be careful about the accuracy of remote sensing based estimates and the error propagation from the model inputs to the outputs. Satellite data in the optical and thermal ranges can only provide observations during the sunny weather conditions. However, the UAS data in this study were collected in both sunny and cloudy conditions. We envision that using satellite based data to calibrate model may lead the model estimates biased towards the sunny conditions. Regarding the second question on applying this method in areas where in-situ measurements are unavailable to parameterize SVEN, there could be challenges to get reliable estimates of land surface fluxes. As shown in the model implementation of Fig. 4, the major challenges in data-scarcity regions would be lacking meteorological inputs and soil information. Such meteorological variables could be obtained from the online weather forecasting, although these data might not be as good as the standard weather station measurements. Soil parameters (e.g. hydraulic conductance, soil wilting point, and saturated soil moisture) could be obtained from soil texture maps or using model calibration with remote sensing based soil moisture estimates. For example, the soil moisture with high frequency across the entire growing season could be very helpful to identify the soil wilting point and saturated soil moisture, which could be close to the minimum and maximum values of soil moisture time series respectively. We also admit that estimating land surface fluxes in the data-scarcity regions is challenging and our

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proposed approach could potentially have more uncertainties compared to the performance in the regions with rich in-situ measurements. But we believe using the remote sensing data from satellites or UAS can facilitate the prediction of land surface fluxes in data-scarcity regions. We want to keep the conclusion streamlined, so we have added the content into the discussion part to address the potential challenges for applying such methodology to satellite data and data-scarcity regions. Please see L8-34 on P23 in the revised version.

43. Equation and variable abbreviations. I cheated and read the other Reviewer Comments. I disagree with Referee #2 regarding their objection to the use of multiple letter abbreviations; I am already familiar with LUE, PAR, GPP, ET, etc., so their usage made it easier for me to follow the manuscript. In addition (this may have more to with my background than what is most suitable for HESS), I am more accustomed to Ït' than SM for soil moisture, and R (surface runoff) could easily be confused for respiration (although honestly I am not sure if there is a more widely used abbreviation for runoff).

Reply: Thank you for your suggestions. We agree that using abbreviations such as LUE, PAR, GPP and ET would be better for the readers. We have revised some variable abbreviations to make them easier for readers. For instance, in the revised version, we have used Qs to stand for surface runoff. We have used θ to represent soil moisture. Furthermore, we have also summarized all abbreviations in the supplementary material.

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