

#	Remarks to author by	Author's original responses to HESS Discussion	Authors' responses
a) Editor			
1	<p>Editor decision: Reconsider after major revisions (further review by editor and referees) by Anke Hildebrandt</p> <p>Dear Hansini Gardiya Weligamage and co-authors,</p> <p>two reviewers have provided feedback on your manuscript. Both think that the paper is suitable for HESS as such, but they have also suggested major changes. I have also read your manuscript and agree with this assessment. The manuscript has the potential to make a relevant contribution, but more and substantial work is required to bring it to a mature stage. This relates to the depth of motivation for the significance of the proposed signatures as well as the interpretation of discrepancies between the compared time series.</p> <p>I will therefore decide on major revisions before reassessing whether the manuscript is suitable for publication.</p> <p>In your response, you have already agreed to make some changes, but you have also disagreed with some of the suggestions. While I concede that not all of the reviewers' suggestions need to be followed to the letter in</p>		<p>Dear Anke Hildebrandt, Thank you for considering our manuscript as suitable for HESS, subject to revisions.</p> <p>We appreciate your feedback as well as the feedback from both reviewers.</p> <p>We have carefully considered all the points made and revised the manuscript accordingly.</p> <p>Below we summarise the responses to your key concerns.</p> <p>1. Depth of motivation for the significance of the proposed signatures</p> <p>We agree on depth of motivation was not clearly expressed in our original manuscript and therefore, we improved the introduction in the revised manuscript as we mentioned at row #2</p> <p>2. The interpretation of discrepancies between the compared time series.</p> <p>We acknowledge the lack of interpretation in the original manuscript regarding the discrepancies between remotely sensed AET and flux tower AET. We have rewritten Sections 4.2 and 4.3 of the Discussion. These subsections have now been substantially improved to incorporate more detailed interpretation and explanation.</p> <p>3. Reconsider reviewer 1's comment 2.</p> <p>Thank you for this suggestion. We think you referred to Reviewer 1's first detailed comment following their general overview,</p>

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	<p>the review process, I believe that the suggestions made by the reviewers were all very well-founded. Please consider not only editorial/technical comments, but also those that are more substantive in nature and would require restructuring of the manuscript. It is precisely these comments that can greatly improve it.</p> <p>For example, I encourage you to reconsider reviewer 1's comment 2.</p> <p>Please go through the reviewers' comments once more carefully.</p> <p>Please also note the additional comments that follow at the end of this email.</p> <p>I will resubmit the manuscript for review. To assist in this process, please provide a step-by-step response and indicate where and how their comments have resulted in changes to the manuscript, and provide a version of the manuscript with highlighted changes. I look forward to receiving the new version of your manuscript.</p> <p>Kind regards, Anke Hildebrandt</p>		<p>which questioned whether our motivation is about using new statistics for evaluation or whether it was to evaluate remotely sensed data (labelled C1, now listed as Comment #6 in our response document).</p> <p>We considered that comment and made two key changes:</p> <ul style="list-style-type: none"> revised the manuscript title as “Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures” improved the introduction section to clearly articulate the motivation of this manuscript. (Please refer to #6 for the exact responses) <p>4. Please go through the reviewers' comments once more carefully.</p> <p>Thank you for this suggestion. We carefully considered both reviewers' comments again and responded accordingly</p> <p>5. Please also note the additional comments that follow at the end of this email.</p> <p>Thank you for this note. Please refer to #2 and #3 for our responses</p> <p>We hope that the revisions made have improved the manuscript and that it is now suitable for further consideration for publication in HESS.</p>
Additional comments			
2	<p>The blueprint paper by McMillan et al. (2020), which is a review of existing hydrological signatures, explored in depth the significance of streamflow signatures for e.g., ecological or watershed processes. The current paper lacks this background and therefore sounds</p>		<p>Thank you for identifying that our original manuscript lacked sufficient background on hydrological signatures including AET signatures and their associated behaviours.</p>

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	<p>somewhat arbitrary in its current form. I strongly encourage you to explain in more detail why the signatures are meaningful and what "behaviors" (as indicated in the title) they refer to.</p>		<p>In response, we have revised Section 1 (Introduction) to provide additional context on streamflow signatures and to explain the underlying behaviours inherent in AET signatures, as follows:</p> <p>(Please note that the blue texts within quotation marks below are the newly added contents, while the red texts are the removed contents in the revised manuscript. Also, the line numbers refer to the revised manuscript with track changes.)</p> <p>L28-34: “Hydrological signatures are statistical metrics used to quantify hydrological behaviours in catchments and can be used to compare hydrological behaviour across space and time (Addor et al., 2018; McMillan, 2021) and to assess the behavioural fidelity of hydrological model simulations against observations (Gupta et al., 2008). This concept of hydrological signatures to quantify hydrological behaviour was initiated in the ecohydrology (e.g., Poff et al., 1997; Richter, 1996) to assess changes in flow regimes. Since then, their application has expanded across diverse hydrological domains because of its superiority in characterising underlying hydrological processes encoded in streamflow data, which are governed by watershed characteristics, and hydroclimate, rather than being just a statistical metrics (McMillan, 2021). ...”</p> <p>L46-57: “Although there has been a wide range of hydrological signatures defined for streamflow (McMillan, 2021; Olden & Poff, 2003; Safeeq & Hunsaker, 2016), signatures directly calculated based on other hydrological variables are rare, with some notable exceptions of studies that used the soil moisture and groundwater signatures (e.g., Araki et al., 2022; Heudorfer et al., 2019). Building on this foundation, this study aims to systematically define, compile, and test a list of actual evapotranspiration (AET) signatures. These AET signatures are intended to uncover underlying processes, such as hydrological</p>

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			<p>and ecohydrological processes embedded within AET dynamics, which, to our knowledge, have not previously been done. However, we acknowledge that there are existing literature that investigates various aspects of AET and quantifying it in different study areas, examining at different spatial scales such as in-situ level (e.g., Rungee et al., 2019), grid level (i.e., remote sensing, e.g., Zhang et al., 2010), catchment level (e.g., Avanzi et al., 2020), and regional level (e.g., Gardiya Weligamage et al., 2023). ”</p>
3	<p>I do not understand why only Australian data is used as an example to compare signatures. Why not use a global data set?</p>		<p>Thank you for raising this valid concern regarding our use of only Australian data, rather than a global dataset for comparing AET signatures.</p> <p>We agree that applying the methodology to a global dataset would be a valuable extension and would support broader generalisation.</p> <p>However, one reason we did not undertake this is that the global dataset is quite outdated (mostly ends in 2015) but will soon be significantly updated (according to the Fluxnet website). Thus, we feel a global study would be best timed immediately after this new development.</p> <p>Further, this study was undertaken at the end of a PhD which was otherwise focussed on Australia. Aside from the effort of manually compiling a global dataset (which is a difficult prospect at the end of a PhD), the Australia-only focus also meant that we could leverage our familiarity with geographic context, local processes and data sources</p> <p>This limitation of not using a global dataset is acknowledged in Section 4.4 (Limitations and Future Studies) as both a concern and a direction for future research as below:</p>

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			<p>L474-494: “This study serves as a proof of concept for one potential application of the proposed AET signatures in evaluating remotely sensed AET products. Our companion study, Gardiya Weligamage et al. (2025) demonstrates another application, using AET signatures to diagnose deficiencies in hydrological models. While this study is limited to Australian sites, which geographically constrains the global applicability of the findings, it establishes a foundation for the broader development and use of AET signatures. Moreover, we consider this regional focus more appropriate for a proof of concept, particularly given the findings of McMillan et al. (2023), who reported difficulties in examining signatures and underlying behaviours across large samples that include catchments affected by unusual hydroclimate or data errors. A further limitation is that there are likely other aspects of evapotranspiration dynamics that we have not characterised, and we invite future studies to contribute ideas to broaden this initial set, in much the same way as has occurred for streamflow signatures (see Gnann et al. 2021). Our findings encourage the use and expansion of AET signatures over other regions and continents. As a starting point for the study of AET signatures, future studies could further refine or adapt these signatures to better capture AET behaviours and enhance their use in hydrological model calibration and evaluation to represent AET processes more realistically.”</p>
4	<p>Comment on section 2.1 "Proposed signatures"</p> <p>The presentation of this section is unclear and difficult to navigate. The equations are collected in Table 1, but the explanations are in the main text. At the same time, the symbols used in Table 1 require a reference to the text, so the reader now has to go back and forth between the text and Table 1. Please incorporate the equations shown in Table 1 into the text. This will keep everything in the same</p>		<p>Thank you for your suggestion to incorporate equations presented in Table 1 into the text to improve navigation through Section 2.1.</p> <p>We have revised Section 2.1 by explicitly using bold text for each signature name and including corresponding equation within the text. (Please refer to page 3 & 4, L 91, 92, 95, 96, 103, 108, and 113)</p>

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	place and improve readability. Be sure to structure the text to make it easier to separate each signature.		Also, a clear spacing has been inserted between paragraphs for each temporal scale (i.e., annual, seasonal, monthly, etc) to easily identify each signature within each category.
b) Reviewer 1 (Citation: https://doi.org/10.5194/hess-2024-373-RC1)			
General comment			
5	<p>The study uses different statistical metrics (referred as hydrologic signatures) like annual median, coefficient of variations (at different timescales) and use them to compare evapotranspiration derived using two remotely sensed products (MODIS and CMRSET) with observations from 17 flux tower sites across Australia.</p> <p>While this study reports important biases in remote sensing products with observations, it severely lacks in the interpretation of the comparisons and the application of different metrics. As a result, I would recommend a major revision for the manuscript to be publishable in HESS.</p>	<p>Thank you for your constructive comments on our manuscript.</p> <p>We find your suggestions are valuable for strengthening the manuscript.</p> <p>We are happy to improve the manuscript in response to the comments you made below.</p> <p>We hope you would agree that the revisions will improve the interpretation of aspects of the study that you identified as a problem.</p> <p>Below we provide detailed responses to each of your comments.</p> <p>Please note that the red texts within the quotation marks in authors' responses below indicates suggested revisions to the text in the revised manuscript.</p>	<p>Further to our earlier comments, we would like to specifically highlight the following responses:</p> <ol style="list-style-type: none"> 1) to better reflect the assessment of remotely sensed actual evapotranspiration (AET) deficiencies, we changed the title to: “Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures” and slightly revised the abstract. 2) We have improved the discussion section by incorporating your suggestions regarding interpretation of results and their application, as outlined in your detailed comments. <p>We hope the revisions made in response to your feedback, as well as those from the other reviewer and the editor, have significantly improved the manuscript. Below we provide detailed responses to each of your comments.</p> <p>Please note that the blue texts within quotation marks below are the newly added contents, while the red texts are the removed contents in the revised manuscript. Also, the line numbers refer to the revised manuscript with track changes.</p>
Comments			

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6	<p>C1: Line 44 – 45: I would disagree with this statement. Understanding changes in AET is a well-researched (and ongoing) subject. I don't think the right motivation for this paper is that statistical metrics like (annual median, coefficient of variations) have not been used to study AET before. Rather I suggest authors motivation should be on comparing and interpreting the remotely sensed evaporation estimates with Flux tower data, the reasons which can lead to discrepancy between them and the use of hydrologic signatures in understanding those biases.</p>	<p>1) We understand on your disagreement on the statement in L 44-45 as it could imply complete negligence of AET dynamics in research. Therefore, we suggest revising the sentence replacing the “This lack of attention of AET signatures is surprising ...” with “This is a worthy research focus given the importance of AET in the overall water cycle, comprising around 60% of the global terrestrial hydrological cycle”</p> <p>2) Regarding your statement that characterising AET signatures should not be the motivation of our manuscript, we politely disagree.</p> <p>We are not claiming that statistical metrics have not been used to study AET. We argue that within the hydrological signature space, AET signatures have not yet been systematically defined and collated to quantify different aspects of AET dynamics as mentioned in L40-44 in the original manuscript.</p> <p>Therefore, the motivation of this study is to characterise a list of statistical metrics (i.e., AET signatures) to quantify AET dynamics as mentioned in L68-70.</p>	<p>Thank you for this comment. We understand your point of the comment.</p> <p>Therefore, we decided to change the manuscript title to reflect our study as:</p> <p>“Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures”</p> <p>Also, the abstract was slightly revised to focus on the application of AET signatures as</p> <p>L14-17: “AET signatures can assist in tasks such as evaluating remotely sensed products, diagnosing deficiencies in hydrological models, and improving understanding of hydrological processes, such as the role of AET in driving hydrological drought. This study focuses on first of these three applications. To achieve this, the study proposes eight AET signatures defined at various temporal scales from daily to annual. We demonstrate the value of AET signatures by using them to assess two remotely sensed AET (AET_{RS}) products are assessed against flux tower AET (AET_{Fluxtower}) at seventeen FluxNET sites in Australia.”</p> <p>In addition, we think we had not clearly articulated the motivation of this manuscript, so the manuscript seems to be appeared similar to any other studies which investigated AET. And the editor is also agreeing on this regard.</p> <p>Therefore, the introduction was revised as follows: L46-60: “Although there has been a wide range of hydrological signatures defined for streamflow (McMillan, 2021; Olden & Poff, 2003; Safeeq & Hunsaker, 2016), signatures directly calculated based on other hydrological variables processes are rare, with some notable exceptions of studies that used the soil</p>

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		<p>We then applied those characterised AET signatures to one of their potential uses, which is assessing the quality of remotely sensed AET products as mentioned in L70-72.</p> <p>3) We agree that our application of AET signatures to assess the quality of remotely sensed AET is not reflected in the manuscript title.</p> <p>Therefore, we suggest the following title “Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures”</p>	<p>moisture and groundwater signatures (e.g., Araki et al., 2022; Heudorfer et al., 2019). Building on this foundation Therefore, in this study aims to systematically define, compile, and test we are concerned with a list of signatures of actual evapotranspiration (AET) signatures. These AET signatures are intended to uncover which underlying processes, such as hydrological and ecohydrological processes embedded within AET dynamics, which, to our knowledge, have not previously been done. researched to our knowledge. This lack of attention to AET signatures is surprising given the importance of AET in the overall water cycle, comprising around 60% of the global terrestrial hydrological cycle. While there is This complements existing literature that investigated ing various aspects of AET and quantifying it AET in different study areas, examining at different spatial scales such as in-situ level (e.g., Rungee et al., 2019), grid level (i.e., remote sensing, e.g., Zhang et al., 2010), catchment level (e.g., Avanzi et al., 2020), and regional level (e.g., Gardiya Weligamage et al., 2023). systematic and comprehensive studies focusing on AET signatures remain elusive. Moreover, some studies have used streamflow-based signatures such as total runoff ratio (e.g., McMillan et al., 2014; Safeeq & Hunsaker, 2016), streamflow seasonality (e.g., Wrede et al., 2015), and diurnal cycles in streamflow (e.g., Schwab et al., 2016; Wondzell et al., 2010) to examine AET processes, although these signatures are only indirectly related to those AET processes.”</p>
7	C2: Line 170-174: It will be useful to also have Morton's equation to estimate potential evaporation written here.	<p>Yes, we agree.</p> <p>We will include the equation.</p>	The equation is included in L187 in the revised manuscript.
8	C3: Figure 3b: There should be some discussion/explanation about why coefficient of variation (interannual variability) is high in dry regions irrespective of dataset. Does it relate to the interannual variability in rainfall/net radiation/PET over these sites?	<p>Yes, we agree that this needs to be discussed.</p> <p>In our opinion, AET in dry regions is typically more variable due to high rainfall variability. In addition, PET</p>	<p>The revised discussion Section 4.2 is as follows</p> <p>L372-379: “...However, the CV_{annual} across flux tower sites was low across the majority of sites (range of 0-0.2 at 14 out of 17 sites), regardless of their aridity index. This finding is consistent with the relatively constant annual AET variability over time, as</p>

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		<p>is generally high, particularly in hot arid environments. Generally, evaporation from soil contributes more to AET than transpiration from vegetation in hot arid environments. Moreover, vegetation tends to be opportunistic during rainfall events and remains dormant during dry periods. Therefore, these factors collectively influence the variability of AET in hot dry regions.</p> <p>We will discuss this with reference to literature as appropriate.</p>	<p>reported by Gardiya Weligamage et al. (2023). The three exceptions were flux tower sites in dry regions such as Calperum, Sturt Plains, and Ridgefield, which exhibited comparatively higher CV_{annual} (ranging from 0.3-0.5). This is likely driven by high interannual rainfall variability (Liu et al., 2024; Wang et al., 2017) and high PET (Pan et al., 2021) in dry regions. In such regions, evaporation from soil contributes more to AET than transpiration from vegetation in hot arid environments; moreover, vegetation tends to be opportunistic during rainfall events and remains dormant during dry periods (Ratzmann et al., 2016). Therefore, these factors collectively influence the high variability of AET in hot dry regions..."</p>
9	<p>C4: In addition to coefficient of variation at inter-annual scale, maybe it will be helpful to also compare absolute deviations at annual scale, report it and keep it in supplement.</p>	<p>Sorry, we politely decline your comment for the reasons outlined below. However, we remain open to further consideration if you can elaborate on your reasons to make this comment.</p> <p>As mentioned above in #2, our motivation in this manuscript is to introduce a new list of signatures (i.e., AET signatures) to the hydrological signature space to characterise AET dynamics. So, this manuscript shows how useful these AET signatures can be by comparing remotely sensed AET with flux towers. Therefore, we would prefer to focus on AET signatures.</p> <p>The comparison of absolute deviations does not add extra</p>	<p>Author's response remains the same. Please refer to the original response.</p> <p>Only the reference row numbers in the response table and the revised manuscript with track changes have been updated, and these have been highlighted below for your reference.</p> <p>As mentioned above in #6...</p>

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		<p>information relevant to the utility of AET signatures.</p> <p>Moreover, the absolute deviation of AET at the annual scale does not allow capturing variability across sites. Instead, it is limited to site specific comparison of variability between remote sensing and flux tower AET. We have outlined this reason in the original manuscript (Section 2.1 L83-85).</p> <p>Therefore, we do not think that reporting absolute deviations would provide additional insights into the interannual variability.</p> <p>However, we would be happy to consider this if you could explain what additional information this would add to the AET signature list.</p>	<p>(Section 2.1 L92-94 in the revised manuscript with track changes).</p>
10	<p>C5: Line 213: I am confused about what is meant by CMRSET shows minimal bias? Do you mean spatial variability in lag-12 auto-correlations are low?</p>	<p>Yes, we agree that the sentence may be unclear.</p> <p>By 'minimal bias', we intended to convey that CMRSET tended to both overestimate and underestimate flux tower periodicity, without showing a clear pattern of over- or under-estimation.</p> <p>To make the sentence clearer, we suggest a revise text as below.</p>	<p>Author's response remains the same. Please refer to the original response.</p> <p>Further to our original response, the revised text under Section 3.2 is as follows:</p> <p>L246 - 249: “Across all sites, tThe $P_{12\text{month}}$ of CMRSET monthly AET does not systematically over- or underestimate flux tower $P_{12\text{month}}$. However, there is a considerable scatter meaning some sites showing significant overestimation and others significant underestimation of CMRSET $P_{12\text{month}}$ to flux tower $P_{12\text{month}}$ shows significant scatter but minimal bias.”</p>

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		<p>“Across all sites, the $P_{12month}$ of CMRSET monthly AET does not systematically over- or underestimate flux tower $P_{12month}$. However, there is a considerable scatter meaning some sites showing significant overestimation and others significant underestimation of CMRSET $P_{12month}$ to flux tower $P_{12month}$.”</p>	
11	<p>C6: Figure 4: This is an important figure which depicts the difference in seasonality and phase lags in season peaks between remotely sensed data and flux tower observations. But there is no interpretation about what does this imply? My intuition is that this may likely relate to the vegetation parameterizations and surface water stress in remote-sensing derived AET products. However, it is clear that aridity index (defined at long timescales) does not explain these variations either with flux-towers or the remotely sensed data. I suggest authors to look at periodicity and phase lags in surface water-stress if they explain these effects.</p>	<p>Yes, we agree that seasonal scale AET signatures need to be discussed further.</p> <p>As you mentioned, this may be related to the parameterization of vegetation and surface water stress in remote sensing AET products.</p> <p>We will discuss this with reference to literature as appropriate. Regarding the latter part of this comment, we agree that looking into phase lags and water stress are important. That is why we included the signatures on water stress and asynchronicity between AET and PET as described in L93-110 and Figure 5b & 5c. Also, we do not see any comment from you regarding those two signatures. Therefore, we assume this addresses your comment. But we would be happy to discuss this further during the later stage of review.</p>	<p>Further to our original response, the seasonal scale AET signatures were discussed under Section 4.3. We have added quite a long block of text in response to this comment - see line 411-471. We particularly note the following quotes from this text, which are the most relevant to answering the concern of the reviewer:</p> <p>L 429-432: “The close alignment of TSP with $AET_{Fluxtower}$ is likely because the CMRSET model was calibrated only to flux tower sites in Australia (Guerschman et al., 2022), in contrast to MODIS, which is globally calibrated and thus has less Australian focus (Mu et al., 2011). Our findings concur with Guerschman et al. (2022), who reported that the calibrated CMRSET model performs better than MODIS AET (i.e., MOD16A2).”</p> <p>L441-456 : “However, none of the information above supports explaining the differences in periodicity and offsets in seasonal peaks between AET_{RS} and $AET_{Fluxtower}$ shown in Figure 4. We assume that these discrepancies may be attributed to vegetation and surface water stress parameterisation in AET_{RS} algorithms. However, significant uncertainties related to water stress parameterisation are unlikely, as our assessment using water stress signature showed that water stress is fairly predicted by AET_{RS}, except for wet, tropical flux tower sites. This exception in the wet tropics could be due to uncertainties associated with the PET (recall that Morton’s Wet Environment PET was used in</p>

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			<p>Water Stress signature), which may not be directly comparable to AET_{RS}. Given this, vegetation parameterisation likely plays a vital role in these observed inconsistencies in $P_{12month}$, and TSP. This could be due to uncertainties associated with Enhanced Vegetation Index (EVI) and Global Vegetation Moisture Index (GVMI) in CMRSET and in Leaf Area Index (LAI) /Fraction of Photosynthetically Active Radiation (FPAR) in MODIS. Mu et al. (2011) discussed overestimation of LAI as a potential source of overestimation in MODIS AET. Moreover, MODIS AET applies the same set of biophysical parameters for each biome type globally (Mu et al., 2011). Since Australia has distinct biome types, MODIS AET could introduce uncertainties due to differences in plant biophysics. Gan et al., (2018) also reported MODIS AET underestimates flux tower AET at non-forested sites (e.g., Dry River, Howard Springs, Sturt Plains), but overestimates at forested sites (e.g., Tumbarumba, and Wombat State Forests). Consequently, combined uncertainties and limitations could contribute to the seasonality issues in CMRSET and MODIS AET. Therefore, caution should be exercised when extracting seasonal information from both MODIS AET and CMRSET.”</p> <p>Regarding the latter part of this comment, we agree that looking into phase lags and water stress are important. That is why we included the signatures on water stress and asynchronicity between AET and PET as described in L106-121 in Section 2.1 and Figure 5b & 5c. Also, we do not see any comment from you regarding those two signatures. Therefore, we assume this addresses your comment. But we would be happy to discuss this further during the later stage of review.</p>
12	C7: Similar to C3, there shall be some discussion/explanation of why coefficient of variation (at monthly scale) shows a variation with aridity.	Yes, we agree that this needs to be discussed.	<p>The revised discussion under Section 4.2 is as follows</p> <p>L382-398: “Signatures that capture short-term temporal dynamics of AET, such as $CV_{monthly}$, $P_{12month}$, and TSP exhibited</p>

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		<p>Similar to our response to your comment C3, we will discuss this with reference to literature as appropriate.</p>	<p>wide scatter across observed flux tower sites, with no clear relationship to aridity. This decoupling is likely due to the fact that AET dynamics at shorter temporal scales are strongly influenced by local geographic, biophysical, and hydroclimatic conditions such as vegetation dynamics, soil properties, soil moisture dynamics, and inter annual rainfall variability that are not well represented by broad, long-term climate classification like aridity index. van Dijke et al. (2020) reported a strong correlation between leaf area index (LAI) and latent energy (LE) in savanna and arid grassland ecosystems across FluxNet sites, including Ozflux sites. They explained that in these environments, soil water deficiency and high evaporative demand lead to a significant increase in LE even with small increases in LAI. For the evergreen broadleaf forested ecosystem, a positive correlation was also observed between LAI and energy fluxes, attributed to evaporation from canopy interception, which accounts for up to 30% of total evapotranspiration. While their study suggests that both of these vegetation types exhibit a clear relationship with energy fluxes, our analysis indicates that AET signature patterns, especially on monthly and seasonal scales, cannot be easily explained by classifying based on vegetation cover alone.”</p>
13	<p>C8: I don't think signature 8 (Index of AET responsiveness to a rainfall event) is a robust metrics. The results presented in figure 6 don't support it either. The response of AET to rainfall will be affected by many confounding factors like water availability, energy availability, land-cover type and seasonality. For e.g, a summer time or winter time rainfall can have very different effects on AET due to differences in net radiation (energy availability). The cloud radiative effects associated with rainfall will also be different across seasons. The presence/absence of</p>	<p>Yes, we agree that responsiveness to rainfall can vary depending on antecedent conditions. However, this does not automatically disqualify it as something worth reporting.</p> <p>This paper focuses on signatures that report discrepancies in AET dynamics, regardless of their underlying causes.</p> <p>While we agree that discussing the potential causes of these</p>	<p>We would like to improve our original response to this comment.</p> <p>Yes, we agree that responsiveness to rainfall can vary depending on antecedent conditions. And as we mentioned in the original manuscript under Section 2.1, for the purpose of demonstration, we selected rainfall events and respective AET under a subjective threshold and within a window period. Hence, we obtained all the rainfall and AET timeseries pairs that satisfied the condition. However, we can use this signature by subsetting the rainfall and AET timeseries based on their climatic regions, based on seasons, based on vegetation groups for further insights.</p>

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	<p>vegetation can also significantly alter surface water-stress conditions through water-channelling mechanisms like root systems. A better way to diagnose this effect could perhaps be to first link changes in rainfall to antecedent hydrologic condition like surface water-stress and then look at their response to AET.</p>	<p>discrepancies is valuable, the primary aim of this manuscript is not just to explain differences between remote sensing and flux tower AET. Instead, our motivation is to define and present AET signatures.</p> <p>Even if discrepancies arise from different ways, that does not disqualify the AET signature of being reportable.</p>	<p>Therefore, we revised the discussion Section 4.2 as follows:</p> <p>L399-406: “At the event scale, most flux towers did not show a discernible correlation between rainfall events and subsequent AET events. Therefore, on first impression, the ‘index of AET responsiveness to a rainfall event’ signature does not appear to add significant value in this AET signature analysis. However, we could subset event scale rainfall and AET timeseries data by climatic regions, season, or vegetation group to gain more detailed insights. MoreoverHowever, we employed this event-scale signature to evaluate commonly used conceptual rainfall-runoff model performances in a companion paper Gardiya Weligamage et al. (2025), and the models were found to be very biased in this signature, showing simulated AET that was too responsive to precipitation. Therefore, this event-scale signature also adds value in constraining models or exploring model deficiency.”</p>
14	<p>C9: For each figure, there should be some quantitative measure of consistency like Rsquared or RMSE with respect to observations for both MODIS and CMRSET. This would help assess which dataset performs better for each hydrologic signature.</p>	<p>Yes, we agree.</p> <p>Thank you for your suggestion. We will update the AET signature figures with a quantitative measure for both MODIS and CMRSET signatures.</p>	<p>We updated AET signature figures, including NSE_{MODIS} and NSE_{CMRSET}.</p> <p>We did not use R² because it is insensitive to bias, nor RMSE because it does not contextualise the errors against the variability in the sample. The NSE does both of these things.</p>
15	<p>C10: It may be useful to analyse if the biases between flux tower observations and remote sensing derived estimates shows a variation with vegetation type for different hydrologic signatures.</p>	<p>Yes, we agree.</p> <p>We will include a discussion on this, for example by contrasting results across forests, savanna, and grassland ecosystems.</p>	<p>Yes, we agree.</p> <p>However, we could not identify clear differences in AET signatures between flux tower and remotely sensed AET based on vegetation type. Nevertheless, this point is addressed in the Discussion under Section 4.2.</p> <p>L382-398: “Signatures that capture short-term temporal dynamics of AET, such as $CV_{monthly}$, $P_{12month}$, and TSP exhibited wide scatter across observed flux tower sites, with no clear relationship to aridity. This decoupling is likely due to the fact</p>

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			<p>that AET dynamics at shorter temporal scales are strongly influenced by local geographic, biophysical, and hydroclimatic conditions such as vegetation dynamics, soil properties, soil moisture dynamics, and inter annual rainfall variability that are not well represented by broad, long-term climate classification like aridity index. van Dijke et al. (2020) reported a strong correlation between leaf area index (LAI) and latent energy (LE) in savanna and arid grassland ecosystems across FluxNet sites, including Ozflux sites. They explained that in these environments, soil water deficiency and high evaporative demand lead to a significant increase in LE even with small increases in LAI. For the evergreen broadleaf forested ecosystem, a positive correlation was also observed between LAI and energy fluxes, attributed to evaporation from canopy interception, which accounts for up to 30% of total evapotranspiration. While their study suggests that both of these vegetation types exhibit a clear relationship with energy fluxes, our analysis indicates that AET signature patterns, especially on monthly and seasonal scales, cannot be easily explained by classifying based on vegetation cover alone.”</p>
16	<p>C11: Section 4.2: This section is more of a repetition/summary of results rather than insights.</p>	<p>Yes, we agree.</p> <p>In line with the other reviewer suggestion, we will improve this section with this comment, which was also supported by the other reviewer who highlighted the same point with some suggestions for the improvements.</p> <p>We plan to improve this section by expanding the AET signature results related to flux tower AET, which already discussed under this section, comparing them with other studies</p>	<p>Yes we agree.</p> <p>The Section 4.2 was revised, including insights as follows:</p> <p>L365-408: “Ozflux observations are recognised for their high quality, with minimal data gaps and errors. Isaac et al. (2017) reported that around 80% of Ozflux sites achieved an energy balance closure ratio exceeding 0.8, indicating robust flux measurements. Moreover, these flux tower sites cover a diverse range of vegetation types, including tropical and temperate grasslands, tropical savannas, Mediterranean and temperate woodlands, and both temperate and tropical forests (Guerschman et al., 2022).</p> <p>Given these high-quality data and broader ecological coverage, this study confirms various anticipated AET behaviours at flux tower sites in Australia across different temporal scales. For</p>

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		<p>that have examined AET in Australia. Additionally, we will include a discussion on the reliability of flux tower data and their quality assurance techniques.</p>	<p>example, the \overline{AET}_{annual} increased as the aridity index decreased as expected, indicating that less arid flux towers have a higher \overline{AET}_{annual}, whereas more arid flux towers have a lower \overline{AET}_{annual}. However, the CV_{annual} across flux tower sites was low across the majority of sites (range of 0-0.2 at 14 out of 17 sites), regardless of their aridity index. This finding is consistent with the relatively constant annual AET variability over time, as reported by Gardiya Weligamage et al. (2023). The three exceptions were flux tower sites in dry regions such as Calperum, Sturt Plains, and Ridgefield, which exhibited comparatively higher CV_{annual} (ranging from 0.3-0.5). This is likely driven by high interannual rainfall variability (Liu et al., 2024; Wang et al., 2017) and high PET (Pan et al., 2021) in dry regions. In such regions, evaporation from soil contributes more to AET than transpiration from vegetation in hot arid environments; moreover, vegetation tends to be opportunistic during rainfall events and remains dormant during dry periods (Ratzmann et al., 2016). Therefore, these factors collectively influence the high variability of AET in hot dry regions. Signatures that capture short-term temporal dynamics of AET, such as $CV_{monthly}$, $P_{12month}$, and TSP, exhibited wide scatter across observed flux tower sites, with no clear relationship to aridity. This decoupling is likely due to the fact that AET dynamics at shorter temporal scales are strongly influenced by local geographic, biophysical, and hydroclimatic conditions such as vegetation dynamics, soil properties, soil moisture dynamics, and inter annual rainfall variability that are not well represented by broad, long-term climate classification like aridity index. Van Dijke et al. (2020) reported a strong correlation between leaf area index (LAI) and latent energy (LE) in savanna and arid grassland ecosystems across FluxNet sites, including Ozflux sites. They explained that in these environments, soil water deficiency and high evaporative demand lead to a significant increase in LE even with small increases in LAI. For the evergreen broadleaf forested ecosystem, a positive correlation was also observed</p>

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			<p>between LAI and energy fluxes, attributed to evaporation from canopy interception, which accounts for up to 30% of total evapotranspiration. While their study suggests that both of these vegetation types exhibit a clear relationship with energy fluxes, our analysis indicates that AET signature patterns, especially on monthly and seasonal scales, cannot be easily explained by classifying based on vegetation cover alone.</p> <p>At the event scale, most flux towers did not show a discernible correlation between rainfall events and subsequent AET events. Therefore, on first impression, the '<i>AET responsiveness to a rainfall event</i>' signature does not appear to add significant value in this AET signature analysis. However, we could subset event scale rainfall and AET timeseries data by climatic regions, season, or vegetation group to gain more detailed insights.</p> <p>Moreover, we employed this event-scale signature to evaluate commonly used conceptual rainfall-runoff model performances in a companion paper Gardiya Weligamage et al. (2025), and the models were found to be very biased in this signature, showing simulated AET that was too responsive to precipitation.</p> <p>Therefore, this event-scale signature also adds value in constraining models or exploring model deficiency. Furthermore, this event-scale signature is particularly noteworthy, as it highlights a distinct aspect of AET dynamics not previously quantified. As McMillan (2020) confirmed, no signature (even an indirect AET behaviour explanation using hydrological signatures) was previously identified for assessing AET at the event scale."</p>
17	C12: Line 334 – 335: This is not demonstrated in the manuscript rather argued qualitatively. Refer to comment C9.	<p>Yes, we agree.</p> <p>As responded to the C9, we will include a quantitative measure for CMRSET and MODIS signatures, as it will help assess the dataset performances quantitatively.</p>	<p>We revised the text under Section 4.3, referring to NSE_{MODIS} and NSE_{CMRSET}.</p> <p>L424-431: "For example, challenges were more pronounced with the MODIS AET, which exhibited offsets in TSP ($NSE_{MODIS} = -1.44$, see Figure 4b), while being overly periodic but with scatter compared to flux tower data. This suggests that globally developed MODIS AET often failed to reflect AET dynamics at</p>

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			seasonal scale in diverse Australian environment. Conversely, the regionally developed CMRSET product tended to align comparatively better with the <i>TSP</i> observed by flux towers ($NSE_{CMRSET} = 0.52$, see Figure 4b) but with larger scatter. The close alignment of <i>TSP</i> with $AET_{Fluxtower}$ is likely because the CMRSET model was calibrated only to flux tower sites in Australia (Guerschman et al., 2022), in contrast to MODIS, which is globally calibrated and thus has less Australian focus (Mu et al., 2011)"
18	C13: Line 351: The current version of the study compares hydrological signatures but does not provide comprehensive insights into AET dynamics.	Thank you for this comment. We hope that, with the additional discussion as suggested in your comments C3, C7, C10, C11, as well as reviewer 2's suggestions, the revised manuscript will offer more comprehensive insights into AET dynamics.	Thank you for this comment. We hope that, with the additional discussion as suggested in your comments C3, C7, C10, C11, as well as reviewer 2's suggestions, the revised manuscript will offer more insights into AET dynamics. In addition, we replaced the word 'comprehensive insights' with 'key insights' to avoid a strong statement (L498).
Minor			
19	Line 19: AET_{Rs} instead of RS_{AET} to be consistent.	Yes, we agree. Thanks for noticing. We will correct.	Corrected (Please refer to L20).
20	Line 213: suggest to change "minimal" to "reduced"	We will change the sentence in response to the C5 above.	We revised the sentence in response to comment #10 as follows: L246-249: "Across all sites, t The $P_{12month}$ of CMRSET monthly AET does not systematically over- or underestimate flux tower $P_{12month}$. However, there is a considerable scatter meaning some sites showing significant overestimation and others significant underestimation of CMRSET $P_{12month}$ to flux tower $P_{12month}$ shows significant scatter but minimal bias. "
21	Figure 7: Legend missing for MODIS AET	Yes, we agree. Thank you for noticing. We will include the missing legend.	Included the missing legend in Figure 7.

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22	For all the figures it may be helpful to have a legend depicting color scale of aridity index (humid – blue, arid – red) or an arrow beside the colormap.	Yes, we agree. Thank you for this suggestion. We will indicate the aridity index on the signature figures.	Indicated the aridity index values on the legend.
c) Reviewer 2 (citation: https://doi.org/10.5194/hess-2024-373-RC2)			
General comments			
23	<p>The paper introduces actual evapotranspiration signatures at different temporal scales (annual, seasonal, monthly, and event-based), similar to hydrological signatures, for example. The signatures include among others interannual variability, the timing of seasonal peaks, water stress, and responsiveness to rainfall events. The authors use them to compare actual evapotranspiration data from 17 Australian flux towers with data from two different remote sensing products. They conclude that CMRSET performed better than MODIS 16A2GFv061 in matching flux tower data and highlight the utility of signatures in selecting appropriate remote sensing products.</p> <p>The manuscript is generally well-written, facilitating the clear understanding of the authors' main points. The authors present an existing approach of defining specific signatures in a new context (actual evapotranspiration). The signatures are similar to those used in the hydrological context. Three applications of these signatures are mentioned, and the authors test one of them (comparing flux tower data with remote</p>	<p>Thank you for your thoughtful and constructive comments on our manuscript. We greatly appreciate the time and effort you have taken to review our work.</p> <p>We find your suggestions are valuable for strengthening the manuscript, especially the discussion section.</p> <p>Below we provide detailed responses to each of your comments</p> <p>Please note that the red texts within the quotation marks in authors' responses below indicates suggested revisions to the text in the revised manuscript.</p>	<p>Thank you for your thoughtful and constructive comments on our manuscript. We greatly appreciate the time and effort you have taken to review our work.</p> <p>We find your suggestions are valuable for strengthening the manuscript, especially the discussion section.</p> <p>Below we provide detailed responses to each of your comments.</p> <p>Please note that the blue texts within quotation marks below are the newly added contents, while the red texts are the removed contents in the revised manuscript. In addition, the line numbers refer to the revised manuscript with track changes.</p>

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	<p>sensing products) to demonstrate applicability. While the idea is promising and the application useful, the study lacks depth in presenting the results, especially in the discussion section. There is more potential in the comparison of the signatures of flux tower with those of remote sensing products that should be explored further.</p> <p>Two three points I would like to point out:</p>		
24	<p>- The results section frequently contains interpretations, which should be moved to the discussion section This would allow for a more detailed and in-depth exploration of the signatures in the discussion.</p>	<p>Thank you for highlighting that we have done some interpretations under the results section and pointing out those instances under comments 15, 19, 20, and 21.</p> <p>We agree to move interpretations contained in the Results section to the Discussion to provide a more detailed and in-depth discussion.</p>	<p>Following your suggestion, we removed interpretations from the results section, as you pointed out, for example, under comments #37,41,42, and 43, and incorporated them into the discussion section.</p>
25	<p>- The discussion section lacks depth and further evaluation of the results. Additionally, it would benefit from better contextualization within the existing literature, as there are very few references cited. Some of the points mentioned in the introduction could be expanded upon. I elaborate on this in the main comments.</p>	<p>Thank you for highlighting the need for an in-depth and detailed evaluation of the results, incorporating existing literature within the Discussion, as well as for your detailed suggestions under the main comments 22 to 24.</p> <p>In line with our responses to those comments, we agree to strengthen the Discussion section by</p> <ol style="list-style-type: none"> 1) comparing our approach with other methods and discussing literature that has applied 	<p>Incorporating this comment, along with your detailed suggestion under the main comments #44 to #46, and reviewer 1's feedback, we have substantially revised the Discussion section. Please refer to Section 4 in the revised manuscript for updated content.</p>

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		<p>signatures in other disciplines and with different variables.</p> <p>2) expanding on the advantages of using signatures over traditional performance metrics such as KGE and NSE.</p> <p>3) including a discussion about literature, which compared visual inspections and signatures as we did here.</p> <p>4) comparing flux tower AET signatures with other studies that have examined AET in Australia.</p> <p>5) discussing the reliability of flux tower data and their quality assurance techniques.</p>	
26	<p>The title reflects one of the three potential applications of AET signatures mentioned in the manuscript, however, it does not really align with the application being tested (comparison of remote sensing and flux tower data). I suggest removing “for improved behavioral insights” from the title and including the comparison aspect instead.</p>	<p>Yes, we agree.</p> <p>we suggest modifying the manuscript title to “Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures”</p>	<p>We modified the manuscript title to “Assessing deficiencies in remotely sensed actual evapotranspiration (AET): introducing AET signatures”</p>
Specific comments			
27	<p>L. 32: Add the literature reference.</p>	<p>Yes, we agree.</p> <p>We will add relevant literature.</p>	<p>Literature was added.</p> <p>L37-39: “In modelling, the use of signatures contrasts with commonly used aggregate metrics (e.g., Nash Sutcliffe</p>

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			Efficiency (NSE) or Kling Gupta Efficiency (KGE)), which condense the information of coherence/discrepancy between two timeseries down to a single number (Kiraz et al., 2023; McMillan, 2021).”
28	L. 36: Araki et al., 2022 is not a modelling study. They apply signatures to observed time series. McMillan, 2021 is a review paper including both modelling and observed data.	Yes, we agree. We will change the sentence as follows “In practice, signatures have been widely used to quantify dynamics in hydrological variables and in modelling studies (Araki et al., 2022; Kiraz et al., 2023; McMillan, 2021; Westerberg et al., 2011), while their linking to specific hydrological processes remains an open research question, with a key challenge being the interactions among different processes to produce emergent patterns in observed data (McMillan, 2020). ”	We revised the text as follows: L42-45: “In practice, signatures have been widely used to quantify dynamics in hydrological variables and in modelling studies (Araki et al., 2022; Kiraz et al., 2023; McMillan, 2021; Westerberg et al., 2011), while their linking to specific hydrological processes remains an open research question, with a key challenge being the interactions among different processes to produce emergent patterns in observed data (McMillan, 2020). ”
29	Figure 1: Do the colors of the locations indicate the aridity index as in figure 2? It should be explained here, too, and a legend included.	Yes, we agree. We will update the figure with aridity index information	We have updated Figure 1 by indicating aridity index information in the legend and explained it in the Figure 1 caption. Please refer to L155.
30	L. 40: “hydrological processes” should be replaced with “hydrological variables” or similar, because streamflow, soil moisture and groundwater are not processes. 4)	Yes, we agree. We will revise the sentence replacing ‘processes’ with ‘variables’.	We replaced “hydrological processes” with “hydrological variables” in the revised manuscript L47.
31	L. 44: I wonder if “surprising” is appropriate here. In general, signatures are simply one of many methods to analyze data. Some of the suggested signatures have been previously used (e.g. median) to analyze data, though they were not refer to by that term. While I think	Yes, we agree. We will replace the phrase “This lack of attention of AET signatures is surprising ...” with “This is a worthy research focus given the importance	We have improved the text, incorporating your suggestion, rather than our suggested change in the original response, as follows: L 49-57: “Building on this foundation Therefore, in this study aims to systematically define, compile, and test we are concerned with a list of signatures of actual evapotranspiration

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	it's valuable that you introduce and test AET signatures, I would suggest placing less emphasis on the "surprising" aspect.	of AET in the overall water cycle, comprising around 60% of the global terrestrial hydrological cycle"	<p>(AET) signatures. These AET signatures are intended to uncover which underlying processes, such as hydrological and ecohydrological processes embedded within AET dynamics, which, to our knowledge, have not previously been done. researched to our knowledge. This lack of attention to AET signatures is surprising given the importance of AET in the overall water cycle, comprising around 60% of the global terrestrial hydrological cycle. While This complements existing there is literature that investigated ing various aspects of AET and quantifying itAET in different study areas, examining at different spatial scales, such as in-situ level (e.g., Rungee et al., 2019), grid level (i.e., remote sensing, e.g., Zhang et al., 2010), catchment level (e.g., Avanzi et al., 2020), and regional level (e.g., Gardiya Weligamage et al., 2023). systematic and comprehensive studies focusing on AET signatures remain elusive."</p>
32	L. 78: Refer to table 1.	<p>Yes, we agree.</p> <p>We will revise the sentence referring to table 1.</p>	<p>We revised the sentence as follows: L87: "We propose eight signatures to quantify AET behaviour, as outlined in Table 1."</p>
33	L. 96: I suggest removing "these" for better readability.	<p>Yes, we agree.</p> <p>We will make the change.</p>	Removed the word.
34	L. 102: The asynchronicity signature is not completely clear to me. Since you are working with monthly timeseries here, you are looking at differences in the yearly cycles of AET, aren't you? Since you normalize the curves you are not interested in the "height/amplitude" of the signal but are looking at the timing? What is the advantage of this signature over something like lagged correlation? Wouldn't it be helpful to use a signature, where you receive for example also	<p>Thank you for your comment and your careful consideration of this signature. We also spent considerable time thinking through this signature during its formulation.</p> <p>Indeed, lagged correlation can be a useful measure, but since we don't know the appropriate lag up-front, we need to report it as a signature in its own right. Presumably, this would involve testing correlation over</p>	Author's response remains the same. Please refer to the original response.

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	the magnitude of the shift, i.e. the phase shift between two signals?	several lags and reporting the best one. In case the “best” correlation is well-defined and high, the lag signature would be meaningful, but otherwise, it might give a false impression about the laggedness. Also, we would end up with two separate signatures (lag; and correlation for that lag) that need to be considered together. We feel this adds undesirable complexity, given no other signatures are like this. In contrast, the existing signature measures similar information but with a single metric.	
35	Table 1: You could name signature 8 only “AET responsiveness to rainfall event” without the “index of”.	Yes, we agree. We will make the change.	We made the change in Table 1, in relevant texts, and in Figure 6.
36	L. 200: I agree that the spatial footprint plays a role in AET signatures. However, does a sensitivity of a flux tower to the position within the landscape relate to the deviation between $AET_{Fluxtower}$ and AET_{RS} with aridity? You mentioned that RS underestimate AET_{annual} for less aridity. If I understand this correctly, this would imply that all flux towers in dry areas were placed in locations that lead to an underestimation and wetter areas in locations that lead to an overestimation. Or is it that in dry regions the landscape is often less heterogeneous as in wet regions? It would be interesting if you could expand on this a bit more in the discussion.	Thank you for this comment. We can see why the reviewer has said this. In the original manuscript, our description of these results and how they vary with the aridity was confusing. In order to improve the clarity, we will update the manuscript, replacing the text from L193-200 as follows. “The comparison of \overline{AET}_{annual} between flux tower and RS products shows that all sites, except for three sites in the tropical northern Queensland (i.e., Robson Creek, Cow Bay and Cape Tribulation), the	We can see why the reviewer has said this. In the original manuscript, our description of these results and how they vary with the aridity was confusing. In order to improve the clarity, we revised the manuscript as follows. L220-225: “The comparison of \overline{AET}_{annual} between flux tower and RS products shows that all sites, except for three sites in the tropical northern Queensland (i.e., Robson Creek, Cow Bay and Cape Tribulation), the RS \overline{AET}_{annual} aligns relatively close to the one-to-one line with flux tower \overline{AET}_{annual} , although some scatter and slight underestimation are evident. In contrast, for the three tropical northern Queensland sites, there is a strong overestimation of RS \overline{AET}_{annual} , despite differences in aridity among these sites.”

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		<p>RS \overline{AET}_{annual} aligns relatively close to the one-to-one line with flux tower \overline{AET}_{annual}, although some scatter and slight underestimation are evident. In contrast, for the three tropical northern Queensland sites, there is a strong overestimation of RS \overline{AET}_{annual}, despite differences in aridity among these sites.</p> <p>”</p> <p>Given that we have clarified this as a geographic issue related to hydroclimate, rather than a general issue across all sites, we presume this comment then perhaps less relevant now. However, a discussion on the RS AET signatures in such geographic regions is worth the discussion.</p>	<p>Given that we have clarified this as a geographic issue related to hydroclimate, rather than a general issue across all sites, we presume this comment then perhaps less relevant now.</p> <p>This is now discussed under Section 4.3.</p> <p>L457-468: “At the annual scale, RS \overline{AET}_{annual} largely matched with the flux tower \overline{AET}_{annual}, although some scatter and slight underestimation were observed. However, a notable overestimation of RS \overline{AET}_{annual} was shown at 3 tropical study sites in northern Queensland, namely Robson Creek, Cow Bay and Cape Tribulation. This discrepancy may reflect geographic and hydroclimatic influences specific to these coastal rainforest environments. This includes steep spatial gradients in wetness that may not be well characterised by gridded data, as supported by Guerschman et al. (2022) who also noted the near coast and strong orographic precipitation gradient in the Cow Bay and Cape Tribulation area. This highlights the need for caution when interpreting remotely sensed annual AET in similar settings. In the comparison of CMRSET and MODIS AET, Mohammadi et al. (2015) showed that MODIS AET tends to underestimate in arid floodplains in Australia, similar to several other studies (e.g., Kim et al., 2012; Tang et al., 2015), together suggesting that the underestimation may be due to limitations in MODIS AET in estimating land cover changes and water cover fraction. This finding is in line with our results at most flux tower sites. However, our study shows that both the AET_{RS} underestimate compared to flux tower AET. This could be due to the difference in spatial footprints between AET_{RS} and $AET_{Fluxtower}$.”</p>
37	L. 203: The remaining sentence after “implying” is interpretation and should be moved to discussion.	<p>Yes, we agree.</p> <p>We will move this interpretation to the discussion section</p>	<p>The content in L203 in the original manuscript was moved to the Discussion Section 4.3 in the revised manuscript as follows:</p> <p>L468-471: “In addition, all CV_{annual} showed underestimation (negative bias) relative to flux towers, implying relatively poor year-to-year variability in MODIS AET and CMRSET compared</p>

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			to actual interannual variability as seen in flux tower data. This may also be due to uncertainties and limitations associated with vegetation parameterisation in AET _{RS} algorithms. ”
38	Figure 2: x-axis is years not months. The legend is very small and CMRSET and MODIS are hard to differentiate in the plots.	Yes, we agree. We will revise Figure 2 accordingly.	We revised Figure 2, including a big legend and increasing CMRSET and MODIS timeseries line thicknesses.
39	I miss some sentences on figure 2 except for the introduction at the beginning of the results section. Maybe you can point out some things you want to demonstrate with these plots.	Yes, we agree. The reason for including a concise description of Figure 2 in the original manuscript is that we thoroughly discuss the major visual inspections in each example flux tower in the Discussion Section 4.1. However, we will extend the text in the Results section to highlight the important points shown in Figure 2.	We extended the text in the Results section to highlight the important points shown in Figure 2 as follows: L211-216: “These timeseries plots highlight some aspects of AET that can be observed through visual inspections, such as AET variability, periodicity, and asynchronicity between AET and PET. For example, notable variability is observed in both AET _{Fluxtower} , AET _{RS} at Wombat State Forest and Howard Springs. In Gingin, seasonal variations in AET _{Fluxtower} appear to be offset from PET, indicating asynchronicity. In Robson Creek, lower temporal variability in AET _{Fluxtower} , is observed compared to AET _{RS} . These kinds of dynamics can be systematically examined and quantified using AET signature results.”
40	Figure 3 and 4 (and others): I suggest adding an R ² or similar to give some quantification of the correlation between signatures of flux towers and remote sensing. A legend for the aridity index is missing. It is a bit cumbersome to look it up in table 1.	Yes, we agree. We will include a quantitative measure for signature comparison and a legend for aridity index for figures.	We included NSE _{MODIS} and NSE _{CMRSET} for each AET signature comparison figure, and a legend was included for aridity index. We did not use R ² because it is insensitive to bias, nor RMSE because it does not contextualise the errors against the variability in the sample. The NSE does both of these things.
41	L. 219: “This results...” interpretation -> discussion	Yes, we agree.	We deleted these interpretations from the results section and discussed them under the Discussion section.
42	L. 241: “...perhaps suggesting...” interpretation -> discussion	We will move these to the Discussion.	
43	L. 250: “...perhaps suggesting...” interpretation -> discussion		
44	L. 283: In this section, I would expect a more thorough discussion of the method introduced. Table 3 is a nice summary comparing visual dynamics with signature results, but it is barely	Yes, we agree. Thank you for your thoughtful comment and the suggestions to expand Section 4.1.	Incorporating your suggestions, Section 4.1 was revised as follows.

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	<p>touched upon in the text. If evaluating a new method or an existing method in a new context, I would expect some comparisons of how this method is performing as opposed to other methods from your own results but also how it compares to literature. For example, you mention in the introduction that signatures are being used in other disciplines or with other variables. Are there studies that show how this improved over using NSE/KGE? Are there studies that do a similar comparison as you did with visual inspection vs. signatures? What is the advantage/disadvantage of the signatures over other methods? What are the strengths/weaknesses? ...</p>	<p>We agree that this section could be strengthened by comparing our approach with other methods and discussing literature that has applied signatures in other disciplines and with different variables.</p> <p>As you suggested, we can also expand on the advantages of using signatures over traditional performance metrics such as KGE and NSE. While we have touched on this, it could certainly be elaborated further using literature. Additionally, we can include a discussion about literature, which compared visual inspections and signatures as we did here.</p>	<p>L333-364: “Table 3 provides examples of how observed dynamics in AET, such as variability, seasonality, and the relationship between AET and PET, can be translated into measurable indicators using AET signatures. These signatures enable more objective comparisons between AET_{RS} and AET_{Fluxtower}, while also offering insights into the underlying processes within a given region.</p> <p>This capacity for nuanced characterisation in AET signatures contrasts with traditional fit/performance metrics such as NSE and KGE. As mentioned in the introduction, these commonly used performance metrics are often applied to quantify hydrological model performances, but may obscure specific behavioural information (McMillan, 2021; Wagener & Gupta, 2005). For example, the NSE calculated using monthly MODIS and CMRSET AET at some flux tower sites showed negative values, indicating bad predictive skills, whereas the KGE calculated using both the AET_{RS} tended to show some predictive skills relative to flux tower observations. However, both of these conventional performance metrics fail to identify which aspects of AET in remote sensing products have led to poor prediction of AET_{Fluxtower}. For example, as per table 3, at the arid Calperum site, MODIS AET exhibited an earlier seasonal peak in AET compared to the flux tower, an insight captured by the <i>TSP</i> signature that is unavailable using NSE or KGE. Similarly, at the wet tropical Robson Creek, AET_{RS} products showed slightly greater monthly variability than flux tower observations, again reflected by <i>CV_{monthly}</i> signature but not clear in conventional metrics. Even though the subcomponents of KGE, such as the ratio of standard deviation, the ratio of mean, and the Pearson correlation coefficient, provided valuable information about the ability of these two AET_{RS} products to capture AET dynamics compared to AET_{Fluxtower}, the final KGE value obscures this information.</p>

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			<p>Given that AET signatures capture more behavioural information than traditional performance metrics, they can also be used in other applications, such as hydrological modelling for more realistic outcomes, in a similar way to using other hydrological signatures. For example, Huynh et al. (2021) incorporated hydrological signatures into the calibration of a conceptual distributed hydrological model and found improved flash flood predictions, achieving higher NSE and KGE scores compared to models calibrated without signatures. Kiraz et al. (2023) developed a signature-based performance metric that strongly correlated with NSE and KGE, while also enabling calibration and evaluation of regionalised ungauged catchments. Using the AET signatures developed above, Gardiya Weligamage et al. (2025) demonstrated that incorporating AET timeseries data with streamflow information into calibration generally yields improvements in overall model performance, as indicated by NSE and KGE values. Their signature-based assessment of calibration to traditional AET metrics revealed that only the monthly variability and AET synchronicity with PET were enhanced in such calibration (relative to streamflow-only calibration).</p> <p>While these signatures have many inherent strengths, challenges could remain in applying them, particularly in large sample studies, due to data errors associated with flux tower measurements, particularly in extreme climates (McMillan et al., 2023). Therefore, readers should have a prior understanding when regionalising and interpreting any hydrological behaviours using signatures.”</p>
45	L. 297: This is a nice introduction to pick out one or two concrete examples from above to illustrate how NSE/KGE do not deliver as much detail as the signatures. It would help in supporting the drawn conclusions later on.	<p>Yes, we agree.</p> <p>We will include some examples from signatures to show how NSE and KGE are poor in delivering aspects of AET.</p>	<p>A few examples of changes in AET dynamics, as captured by AET signatures, were included to illustrate the limitations of NSE and KGE in the revised manuscript, under Section 4.1.</p> <p>L341-346: “However, both of these conventional performance metrics fail to identify which aspects of AET in remote sensing products have led to poor prediction of AET_{Fluxtower}. For example,</p>

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			as per table 3, at the arid Calperum site, MODIS AET exhibited an earlier seasonal peak in AET compared to the flux tower, an insight captured by the <i>TSP</i> signature that is unavailable using NSE or KGE. Similarly, at the wet tropical Robson Creek, AET _{RS} products showed slightly greater monthly variability than flux tower observations, again reflected by <i>CV_{monthly}</i> signature but not clear in conventional metrics.”
46	L. 303: This section sounds more like a listing of the results. From the header I would expect more on the AET behavior. What do you learn from the signatures on AET behavior? How do your results compare to other studies that looked at AET in Australia? How reliable are the flux tower data? Were they tested for energy balance closure? ...	<p>Yes, we agree.</p> <p>We will improve this Discussion section by</p> <ol style="list-style-type: none"> 1) Expanding the AET signature results related to flux tower AET. 2) Comparing results of flux tower AET signatures with other studies that have examined AET in Australia. 3) Discussing the reliability of flux tower data and their quality assurance techniques. 	<p>Incorporating your suggestions, Section 4.2 was revised as follows:</p> <p>L366-408: “Ozflux observations are recognised for their high quality, with minimal data gaps and errors. Isaac et al. (2017) reported that around 80% of Ozflux sites achieved an energy balance closure ratio exceeding 0.8, indicating robust flux measurements. Moreover, these flux tower sites cover a diverse range of vegetation types, including tropical and temperate grasslands, tropical savannas, Mediterranean and temperate woodlands, and both temperate and tropical forests (Guerschman et al., 2022). Given these high-quality data and broader ecological coverage, this study confirms various anticipated AET behaviours at flux tower sites in Australia across different temporal scales. For example, the \overline{AET}_{annual} increased as the aridity index decreased as expected, indicating that less arid flux towers have a higher \overline{AET}_{annual}, whereas more arid flux towers have a lower \overline{AET}_{annual}. However, the <i>CV_{annual}</i> across flux tower sites was low across the majority of sites (range of 0-0.2 at 14 out of 17 sites), regardless of their aridity index. This finding is consistent with the relatively constant annual AET variability over time, as reported by Gardiya Weligamage et al. (2023). The three exceptions were flux tower sites in dry regions such as Calperum, Sturt Plains, and Ridgefield, which exhibited comparatively higher <i>CV_{annual}</i> (ranging from 0.3-0.5). This is likely driven by high interannual rainfall variability (Liu et al., 2024; Wang et al., 2017) and high PET (Pan et al., 2021) in dry</p>

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			<p>regions. In such regions, evaporation from soil contributes more to AET than transpiration from vegetation in hot arid environments; moreover, vegetation tends to be opportunistic during rainfall events and remains dormant during dry periods (Ratzmann et al., 2016). Therefore, these factors collectively influence the high variability of AET in hot dry regions. Signatures that capture short-term temporal dynamics of AET, such as $CV_{monthly}$, $P_{12month}$, and TSP exhibited wide scatter across observed flux tower sites, with no clear relationship to aridity. This decoupling is likely due to the fact that AET dynamics at shorter temporal scales are strongly influenced by local geographic, biophysical, and hydroclimatic conditions such as vegetation dynamics, soil properties, soil moisture dynamics, and inter annual rainfall variability that are not well represented by broad, long-term climate classification like aridity index. van Dijke et al. (2020) reported a strong correlation between leaf area index (LAI) and latent energy (LE) in savanna and arid grassland ecosystems across FluxNet sites, including Ozflux sites. They explained that in these environments, soil water deficiency and high evaporative demand lead to a significant increase in LE even with small increases in LAI. For the evergreen broadleaf forested ecosystem, a positive correlation was also observed between LAI and energy fluxes, attributed to evaporation from canopy interception, which accounts for up to 30% of total evapotranspiration. While their study suggests that both of these vegetation types exhibit a clear relationship with energy fluxes, our analysis indicates that AET signature patterns, especially on monthly and seasonal scales, cannot be easily explained by classifying based on vegetation cover alone. At the event scale, most flux towers did not show a discernible correlation between rainfall events and subsequent AET events. Therefore, on first impression, the '<i>AET responsiveness to a rainfall event</i>' signature does not appear to add significant value in this AET signature analysis. However, we could subset event scale rainfall and AET timeseries data by climatic regions, season, or vegetation group</p>

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			<p>to gain more detailed insights. Moreover, we employed this event-scale signature to evaluate commonly used conceptual rainfall-runoff model performances in a companion paper, Gardiya Weligamage et al. (2025), and the models were found to be very biased in this signature, showing simulated AET that was too responsive to precipitation. Therefore, this event-scale signature also adds value in constraining models or exploring model deficiency. Furthermore, this event-scale signature is particularly noteworthy, as it highlights a distinct aspect of AET dynamics not previously quantified. As McMillan (2020) confirmed, no signature (even an indirect AET behaviour explanation using hydrological signatures) was previously identified for assessing AET at the event scale.”</p>
47	L. 360: MODIS and CMRSET miss units (probably mm) and a short readme as in the flux tower data would help.	<p>Yes, we agree.</p> <p>Thanks for looking into the Zenodo data repository.</p> <p>We will make changes accordingly.</p>	<p>We added the readme files for MODIS and CMRSET in the Zenodo repository.</p> <p>Updated the data availability link (https://doi.org/10.5281/zenodo.14226801) in the manuscript (L505).</p>
48	L. 338: You conclude that both MODIS AET and CMRSET have issues with seasonality, right (offset in MODIS AET and scatter in CMRSET)? What could be reasons for this?	<p>Thank you for this comment.</p> <p>We will certainly discuss this further in the revised manuscript. This may be related to the parameterization of vegetation and surface water stress in remote sensing AET products.</p>	<p>This was discussed under Section 4.3.</p> <p>L423-456: “At the seasonal scale, notable discrepancy was observed between AET_{RS} and $AET_{Fluxtower}$, in terms of $P_{12month}$, and TSP. For example, challenges were more pronounced with the MODIS AET, which exhibited offsets in TSP ($NSE_{MODIS} = -1.44$, see Figure 4b), while being overly periodic but with scatter compared to flux tower data. This suggests that globally developed MODIS AET often failed to reflect AET dynamics at seasonal scale in diverse Australian environment. Conversely, the regionally developed CMRSET product tended to align comparatively better with the TSP observed by flux towers ($NSE_{CMRSET} = 0.52$, see Figure 4b) but with larger scatter. The close alignment of TSP with $AET_{Fluxtower}$ is likely because the CMRSET model was calibrated only to flux tower sites in Australia (Guerschman et al., 2022), in contrast to MODIS, which is globally calibrated and thus has less Australian focus</p>

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			<p>(Mu et al., 2011). Our findings concur with Guerschman et al. (2022), who reported that the calibrated CMRSET model performs better than MODIS AET (i.e., MOD16A2). However, Guerschman et al. (2022) also noted that CMRSET captures less of seasonal variability at tropical sites and shows weaker correlation with flux tower AET in arid regions compared to temperate areas. They further explained that the seasonality in tropical and temperate regions is effectively captured by PET, which leads to higher correlation between $AET_{Fluxtower}$ and CMRSET in those regions than in arid sites. Our results also agree on that higher correlation (r) between both CMRSET (median $r=0.69$) and MODIS AET (median $r = 0.77$) with flux tower AET. Furthermore, our <i>AAP</i> signature shows that both the AET_{RS} and $AET_{Fluxtower}$ with mostly synchronous relationship with PET at flux tower sites in temperate (i.e., flux towers at northern Australia) and tropical regions (i.e., flux towers at northern Queensland).</p> <p>However, none of the information above supports explaining the differences in periodicity and offsets in seasonal peaks between AET_{RS} and $AET_{Fluxtower}$ shown in Figure 4. We assume that these discrepancies may be attributed to vegetation and surface water stress parameterisation in AET_{RS} algorithms. However, significant uncertainties related to water stress parameterisation are unlikely, as our assessment using water stress signature showed that water stress is fairly predicted by AET_{RS}, except for wet, tropical flux tower sites. This exception in the wet tropics could be due to uncertainties associated with the PET (recall that Morton's Wet Environment PET was used in Water Stress signature), which may not be directly comparable to AET_{RS}. Given this, vegetation parameterisation likely plays a vital role in these observed inconsistencies in $P_{12month}$, and TSP. This could be due to uncertainties associated with Enhanced Vegetation Index (EVI) and Global Vegetation Moisture Index (GVMI) in CMRSET and in Leaf Area Index (LAI) /Fraction of Photosynthetically Active Radiation (FPAR) in MODIS. Mu et</p>

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			al. (2011) discussed overestimation of LAI as a potential source of overestimation in MODIS AET. Moreover, MODIS AET applies the same set of biophysical parameters for each biome type globally (Mu et al., 2011). Since Australia has distinct biome types, MODIS AET could introduce uncertainties due to differences in plant biophysics. Gan et al., (2018) also reported MODIS AET underestimates flux tower AET at non-forested sites (e.g., Dry River, Howard Springs, Sturt Plains), but overestimates at forested sites (e.g., Tumbarumba, and Wombat State Forests). Consequently, combined uncertainties and limitations could contribute to the seasonality issues in CMRSET and MODIS AET. Therefore, caution should be exercised when extracting seasonal information from both MODIS AET and CMRSET.”
		Technical corrections	
49	L. 18: AET _{RS} ?	Yes, we agree.	Done. L20 in the revised manuscript
50	L. 28: “across space AND TIME”	Thank you for identifying technical errors.	Done. L 29 in the revised manuscript
51	L. 84: Parentheses and “&” should be “...such as Clausen and Biggs (2000)”	We will correct them in the revised manuscript.	Done. L94 in the revised manuscript
52	L. 134: “measurements” or “measurement device”/”measurement equipment”		Done. L144: “... with eddy covariance measurements,..”
53	L. 155: The abbreviations are not used anywhere in the manuscript again, so no need to introduce them here.		Deleted. (L166-167)
54	L. 195: “m” instead of “meters”		The respective text was revised. Therefore, the original text was deleted.
55	L. 208: Here it is “autocorrelation” and in figure 4a “auto-correlation”.		Corrected the subfigure 4a to “autocorrelation”
56	L. 356: “before they are adopted”		Corrected. L504 in the revised manuscript.