Legend

Reviewers' comments

Authors' responses

Direct quotes from the revised manuscript

Reply to Reviewers' comments (Reviewer#1)

Reviewer #1: This is the review for the paper titled "An in-situ daily dataset for benchmarking temporal variability of groundwater recharge" by Malakar et al. The authors estimated groundwater recharge per unit specific yield (RpSy) at the 485 groundwater monitoring wells across the United States. They adopted the water table fluctuation method on the daily groundwater table time-series. Here are my major comments:

I like the way the authors represented groundwater monitoring well data in this manuscript. They performed analysis using daily time-scale data.

Response: We thank Dr. Bhanja for his time reviewing our manuscript and providing detailed comments and suggestions. Point-by-point replies to the comments or suggestions made can be found below.

Reviewer #1: The authors mentioned that the RpSy concept was introduced to reduce errors associated with the recharge estimation arising from the uncertainties in the specific yield (Sy) data. RpSy is nothing but the dh – the change in water table. I think this may not provide the representative values of change in recharge rates. For example, groundwater recharge signature in alluvium will differ a lot from the hard rock areas with a similar change in water table. I think the authors can reduce emphasizing RpSy as a central point of this manuscript, rather, focus more on creating the unique database.

Response: We thank Dr. Bhanja for this comment. In this manuscript, our objective is to benchmark temporal variations at gauging locations, not to spatially compare recharge variations using RpSy. We would like to underscore that estimation of RpSy cannot merely be considered as the change in water table (dh). After a recharge event, the groundwater table may rise and then recede. Calculating recharge simply by taking the dh between the start of the recharge event and a point further along the recession period could yield a small or even negative recharge estimate. In our approach to calculating recharge using the Water Table Fluctuation (WTF) method, we determine the recharge by evaluating ΔH, which is the difference in water table height between two consecutive time steps adjusting for what the height at the current time step would be if it were receding according to the rate defined by the master recession curve (MRC). Notably, the time steps is 1 day in our case, which is much shorter than the duration of a recharge event. An MRC predicts the characteristic rate of change of water-table level as a function of the H. To summarise, ΔH is not simply the vertical distance between two temporal points; rather, it incorporates the characteristic rate of change of the water table level in its calculation. Thus, our aim is to build this unique RpSy database; even without incorporating Sy, the data presented remains valuable.

Following the reviewer's comment, we clarified this in the text:

It is to be noted that the WTF based groundwater recharge incorporating MRC is not merely the difference in water table height between two time points. For instance, after a recharge event, the groundwater table may rise and then recede. Calculating recharge simply by taking the difference in water table height between the start of the recharge event and a point further along the recession period could yield a small or even negative recharge estimate. In our approach to calculating recharge using the WTF method, we determine the recharge by evaluating the difference in groundwater table height between the current and next time step, adjusting for what the height at the current time step would be if it were receding according to the rate defined by the MRC. This variable, ΔH, is evaluated between two consecutive time steps, 1 day in our case. Notably, the time step is much shorter than the duration of a recharge event. **[Page: 3, Line: 100-108]**

Reviewer #1: Section 3.1 and Figure 3: Correlation between RpSy and USGS-based groundwater recharge show less than 0.5 values across the majority of the mid-western, dryland areas. I understand USGS-based recharge estimates using the water budget approach, can the mismatch show bias in precipitation or any other data? The magnitude mismatch is understandable, the patterns should match unless uncertainties present in the data. Authors may consider using other recharge data for comparison in those areas.

Response: Thank you for your insightful comment regarding the correlation between RpSy and USGS-based groundwater recharge in the mid-western, dryland areas, particularly to potential biases in precipitation or other data sources.

We agree that the observed correlation values below 0.5 in these regions call for further scrutiny. One likely explanation for the mismatch could be the inherent differences in the methodologies used to derive RpSy and USGS-based recharge. While the USGS-based recharge estimates employ a water-budget approach, which primarily reflects precipitation and surface runoff inputs at a coarser resolution, the RpSy data are derived from the water table fluctuation (WTF) method, which captures localized recharge responses at a point-scale. This scale mismatch can lead to differing recharge estimates, especially in regions with significant heterogeneity in soil moisture, precipitation patterns, and land use.

Additionally, it is conjectured that the relatively poor performance at several wells in the mid-western states is attributable to the uniform distribution of county-scaled groundwater-sourced irrigation water use data in the assessment of USGS recharge (Reitz et al., 2017a). In contrast, wells selected for RpSy derivation are expected to be not influenced by irrigation. An additional source of mismatch could be linked to the USGS product neglecting the change of storage in the water balance approach and the inherent uncertainties in their model structure (Reitz et al., 2017a). It is to be noted that RpSy essentially captures the recharge flux reaching the groundwater table, while the recharge estimate in USGS product's is the water flux leaking below the root zone. These two fluxes can be different, especially in settings where significant moisture deficit exists in the soil column between the root zone and the groundwater table.

As you rightly pointed out, biases in precipitation data may contribute to the observed differences in patterns. For example, the USGS dataset reflects precipitation data at a gridded resolution, while the RpSy estimates reflect local recharge conditions that may be more sensitive to spatial and temporal variability in rainfall. In dryland areas, where precipitation events are often sporadic and intense, such differences in temporal and spatial resolution could significantly impact recharge estimates. In fact, there could be biases in the USGS data from ET estimates used therein as well.

We also acknowledge the suggestion to explore other recharge datasets for comparison. Notably, the current analysis focuses on the developed benchmark data, which is first of its kind in providing an observational data-based recharge equivalent at a daily resolution. The comparison with the USGS product is not a direct validation but rather done to highlight the alignment and disagreement with an established product. We have noted that in the conclusion section, that the RpSy dataset can be used to validate temporal consistency of other recharge estimates, derived from empirical methods, physically-based land surface models, or integrated hydrologic models.

Following the reviewer's concern, we have modified the existing text in the manuscript:

It is conjectured that the relatively poor performance at several wells in the mid-western states is attributable to the uniform distribution of county-scaled groundwater-sourced irrigation water use data in the assessment of USGS recharge (Reitz et al., 2017a). In contrast, wells selected for RpSy derivation are expected to be not influenced by irrigation. The disagreement also could be due to the scale mismatch between the RpSy, which provides recharge equivalent estimates at a point scale (near the wells), and the gridded USGS product. Biases in precipitation and evapotranspiration data used in the USGS product can also contribute to this disagreement. An additional source of mismatch could be linked to the USGS product neglecting the change of storage in the water balance approach and the inherent uncertainties in their model structure (Reitz et al., 2017a). It is to be noted that RpSy essentially captures the recharge flux reaching the groundwater table, while the recharge estimate in USGS product's is the water flux leaking below the root zone. These two fluxes can be different, especially in settings where significant moisture deficit exists in the soil column between the root zone and the groundwater table. **[Page: 7, Line: 203-113]**

Reference:

Reitz, M., Sanford, W. E., Senay, G. B., and Cazenas, J.: Annual Estimates of Recharge, Quick-Flow Runoff, and Evapotranspiration for the Contiguous U.S. Using Empirical Regression Equations, J. Am. Water Resour. Assoc., 53, 961–983, https://doi.org/10.1111/1752-1688.12546, 2017a.

Reviewer #1: Figure 4a and 4c look similar to me and they are not reflecting the patterns observed in Figure 4b and 4d. Please revisit the figures.

Response: We thank Dr. Bhanja for this perceptive note. In response to the reviewer's comment, we acknowledge that during the production of the combined figure, we mistakenly pasted identical Figures in 4a and 4c, which indeed resulted in a lack of alignment with the patterns observed in Figures 4b and 4d. We sincerely appreciate the reviewer for pointing out this oversight. Following your feedback, we have corrected the figure accordingly. The corrected Figure 4 is incorporated in the manuscript.

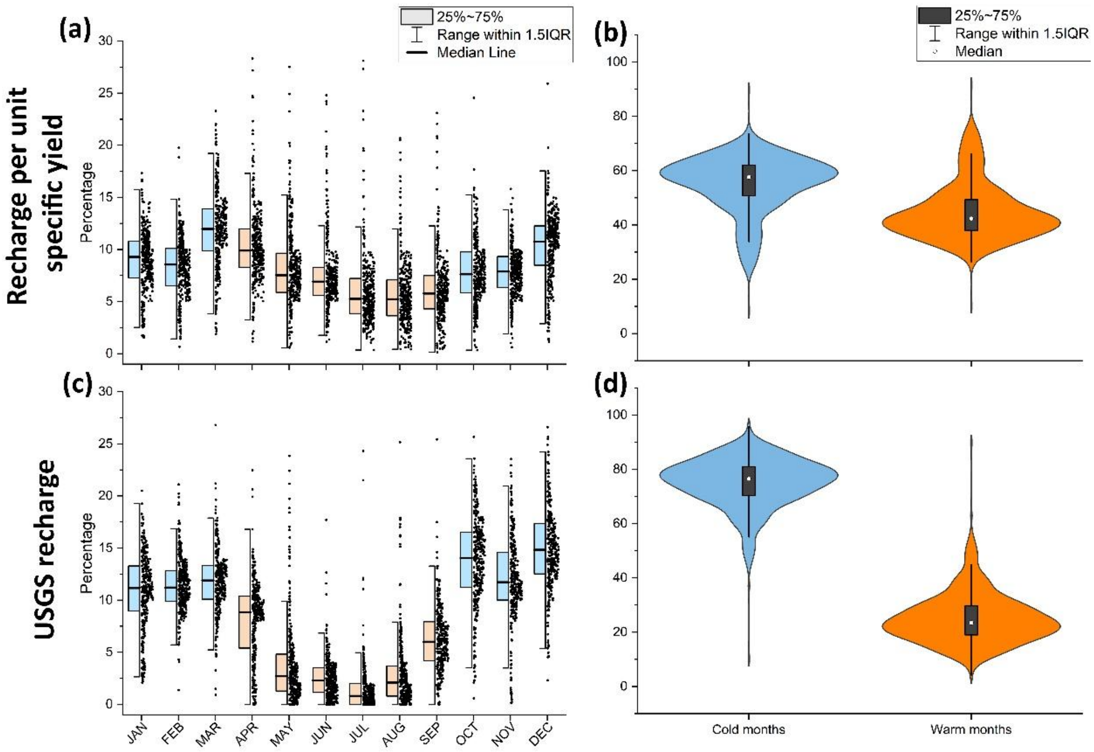

Figure 4: Fraction of recharge in different months and seasons (i.e., Cold seasons (Oct to Mar), Warm-season (Apr to Sept)) relative to the total recharge(/equivalents) for RpSy (top, a and b) and USGS (bottom, c, and d) recharge products. In this plot, USGS recharge data for the grids with RpSy estimates are used. IQR indicates the interquartile range.