Reply on comments by Referee #2

Referee:

The paper “Sediment transport in Indian rivers high enough to impact satellite gravimetry” by Klemme et al. examines how sediment transport can affect trends in gravity fields observed by the GRACE satellites in several river basins in India. This is an important study as accounting for sediment transport can directly affect how we interpret GRACE derived terrestrial water storage changes. The paper is concise and well written. But the manuscript is too focused on impacts on trends. I think the manuscript can be improved substantially if the authors can add some analyses on sediment data.

Response:

We thank the reviewer for their work on our manuscript and appreciate their constructive feedback. We are happy to incorporate their suggestions and improve the manuscript. Our detailed response can be found in the following.

Referee:

My major comments are:

As the most important data for this study, sediment data are not well analyzed and presented, making it difficult to assess the quality of the research. At minimum, there should be an analysis on seasonal and interannual variability of sediment data and their correlations with precipitation and GRACE EWH in each basin. There is a figure on seasonal variation of sediments but it is buried in the Supplementary file.

In addition, an analysis on how temporal variability of sediments varies from one basin to another would be helpful to understand their climate and environmental controls. If sediments eventually end up at the Bay of Bengal, do sediment data collected at the Bay of Bengal show higher seasonal maximum and lagged correlations with sediments at each basin? These analyses will establish the basis for the need to consider the impact of sediment loss on gravity changes. To accompany these analyses, I suggest a paneled figure that shows time series of sediments, GRACE EWH and precipitation data for each of the basins and for all basin average.

Response:

We agree that the presentation of sediment data within our study is important. Unfortunately, the current data availability does not allow for a detailed discussion of seasonal or interannual variability within the catchments. We have shifted the discussion of data seasonality to the main manuscript and included statements on the differences between individual catchments. We need to highlight however, that the seasonality in sediment discharge is based on seasonality in the river’s water discharge rather than sediment measurements.

Referee:

Seasonality (i.e., monthly mean) needs to be removed from the GRACE EWH time series before computing any trends. Strong seasonality as in GRACE data may affect computing long-term trends. Related to this issue, seasonal cycles should be removed from Figs.4-6 to make the differences in trends more discernable. Seasonal variations can be shown in the figure suggested above.

Response:

Based on the reviewer's comment, we performed a more detailed trend analysis to decipher the impact of seasonality on the linear trend. For this, we utilized a dynamic linear model, allowing for variable seasonality and interannual trends. We then derived a median average trend from the best twelve model results. All derived trends, within their uncertainties, agree with the linear trends used in the study. Relative differences are within 5 % and absolute differences are smaller than 0.1 cm yr^{-1}. We proceed to use the linear trends in the study, but include results from this model analysis in the supplement. In the main manuscript, we state: *»Linear least-squares optimizations of the generated monthly time-series yield the local TWS trends. […] A more detailed trend analysis is included in the supplemental material.«*

For the correction figures, we have decided to move the figure for the full study area to the supplement and instead replace it by a trend comparison as the reviewer suggested below. We hope, this will help to convey the information the reviewer found hard to discern in the initial figures. For the other two correction figures, we decided to leave the seasonality in the data, as it helps convey an understanding of the dimension in change of the trend compared to the natural TWS seasonality.

Referee:

At the end of reading section 3.3, those numbers no longer register with me. Since all the numbers are provided in tables, there is no need to state them in the text. Instead, the manuscript should highlight the largest impacts or patterns of impacts that may be interesting to readers. A scatter plot showing TWS trends without correction for sediments vs those with the corrections would be useful for identifying patterns and for accompanying the manuscript.

Response:

We have limited the numbers provided in the text to the most essential ones and include a comparison plot of the TWS data as suggested.

Referee:

Given the coarse scale of GRACE data and the lack of detailed sediment data, section 3.3.4. is flimsy. If included, the authors need to show their calculations and provide justification for assumptions made in Lines 184-187 and line 188-192.

Response:

We understand where the reviewer is coming from. This section is included to illustrate the impact of sediment discharge on the floodplains, where the main groundwater depletion is taking place. Given the scarcity in data, it can only be a rough estimate. We have re-phrased the section. It is now titled *»Impact within floodplain regions«* and we state that *»To estimate the impact of sediment discharge on gravity data of groundwater depletion, we are interested in erosion within the Indo-Gangetic floodplain, where the strongest gravity decrease is observed. Generally, the estimation of the sediment impact in river lowlands and floodplains is more complicated than in mountain regions due to sedimentary redistribution within the catchments. While some sediment might be eroded in regions of excessive agriculture (Galy el at., 2007; Garzanti et al., 2011), there might also be regions of sediment storage and river accretion. Wasson et al. (2003) estimated the fraction of Ganges sediment discharge that was eroded from floodplain regions to be < 10 %. As an upper estimate, we assume these 10 % of*

Ganges sediment to be eroded directly within the floodplain section that yields the strongest GRACE gravity reduction (part of the Ganges catchment in 76°E to 79°E and 28°N to 30°N). For this area, the sediment loss would represent a mass loss of roughly 0.9 kg m^{-2} yr^{-1} and would explain at most 2 % of the observed TWS decrease in this region (5.4 cm yr^{-1}). Most likely, floodplain sediment is eroded more homogeneously from the catchment, reducing the impact to less than 1 % of the observed gravity decrease. Thus, despite high sediment discharge in by Indian rivers, the impact of sediment mass loss on TWS trends in the floodplains is comparatively small.«

Referee:

Minor comment:

Fig.1. The white color for high elevation is invisible.

Response:

We changed the colour scheme accordingly. The Figure has been moved to the Supplement.

Referee:

Line 56: the clause after whereat needs to be revised for clarity.

Response:

We deleted the clause, since this information is now conveyed in the new seasonality section.

Referee:

Line 120: EWH increase and EWH decrease may be replaced by “high EWH values” and “low EWH values”, respectively.

Response:

We decided to leave this as is, since it is in fact the time of increasing EWH values (positive slope) and decreasing EWH values (negative slope) rather than high and low values that is referred to.

Referee:

Figs.4&5 contain references to σ-environment which is not explained anywhere else in the manuscript.

Response:

In the revised manuscript we specify that the σ-environment refers to the standard deviation stated in Table 3.

Referee:

Line 10-14: The sentence is too long and difficult to understand. Please revise.
Line 20: e.g. is not correctly used here. Replace “on e.g.” with “such as”
Line 23: explain it -> explained it
Line 36: annual -> interannual?
Line 138: please delete “, with”.
Line 150: reduction in GRACE EWH ->decreasing trend in GRACE EWH?

Response:

These points were changed accordingly.