

***Interactive comment on* “Estimation of hydrological drought recovery based on GRACE water storage deficit” by Alka Singh et al.**

Anonymous Referee #2

Received and published: 16 March 2020

Summary:

The presented work shows an integrated precipitation approach to determine the recovery period and required precipitation to refill water storages and thus to overcome a hydrological drought. Thus, historical integrated precipitation is linked to total water storage anomalies (TWSA) by GRACE to combine and validate their precipitation-based methodology to an existing storage deficit methodology. Furthermore, three scenarios of precipitation forecast are provided to identify the best estimated time of recovery. They found that the recovery period of integrated precipitation is in good agreement with the recovery period from TWSA, especially in regions where integrated precipitation and total water storage changes showed a strong linear relationship. I think that this work discusses an important topic to have a better understanding of drought

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evolution and to use this information possibly in water management. The methodology and findings are of good scientific quality and significance, but yet I have general and specific concerns, especially regarding to presentation quality, that are listed below. Thus, I recommend major revision, but believe that the manuscript could be published after addressing/clarifying my comments.

General comments

1. Until the first results were shown, it was not clear if the precipitation or the GRACE approach is the main contribution of the paper. This is important for abstract, introduction, conclusion and maybe should also be more consistent with the title and structure of the data and methods chapter. For example, [Page1 Line14] says the main goal is the combination of GRACE and precipitation, while [Page1 Line21] let assume that the author's main point is the precipitation approach and GRACE is only used as validation.

2. More clarification is needed about the drought definitions. Do you place your approach more in the context of hydrological drought or drought in general? The manuscript should be consistent according to the drought definitions. Be also clear about other drought categories of parameters, e.g.: [Page 1 Line32] meteorological drought is not only described by precipitation, also evapotranspiration. [Page1 Line34] soil moisture, precipitation, and runoff and not all hydrological parameters. For example, precipitation is a meteorological parameter.

3. Why are mascons used instead of spherical harmonics, the mascon solutions are underlying by constraints. Does the cap size of 3 x 3 degree of mascon solution then not represent a similar spatial resolution as the spherical harmonic GRACE resolution?

4. [Page3 Line103] Which method is used to regrid the data? Is there a precipitation data set with an 0.5 degree resolution? I ask myself if the downscaling from 2.5 to 0.5 degree has a significant impact.

5. [Page3 Line110] Why are the TWSA smoothed with an averaging filter? Does their

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noise have a significant impact on the results?

6. [Page4 Line129-136] The linkage between integrated precipitation and GRACE is an important aspect for the validation so it should be explained more detailed. The paragraph is (probably) based on the water balance equation, which should at least be mentioned but better also shown. The assumptions that were decided to describe the relationship about evapotranspiration/runoff should be added here and it also should get clear how the precipitation is integrated in time. So for example, is it integrated continuously for each month to the previous months or is there an integration period of 3 months that is running over all months etc.?

7. [Page4 Lines144-147 and Lines158-162] It was not clear how the required precipitation is linked to the regression coefficients. It would great if the linkage for the example of a coefficient lower/higher/equal 1 in the first paragraph is clearly explained. Secondly, how do we then get the surplus required-precipitation? Is it derived by removing cdPA from dTWSA?

8. Figure 4, as well as some other figures, is analyzed too shortly (e.g. [Page5 Line181]) or, for example, only part a) of a), and b) is described. The figures provide much more information, especially about spatial differences. So, the figures should be described more in detail, which I prefer because they contain interesting findings, or removed/added to supplementary.

9. [Page5 Line188] It is not clear how the sub-seasonal signal is computed and where the number of 0 to 3 months of reconstruction is resulting from. The final hindcast is 2 years, so how did the authors manage the 0-3 months restriction of the sub-seasonal signal?

10. [Page7 Line247] The definition of severe drought was not exactly set. What is the definition or to which definition is it referred?

11. [Page7 Line253] Based on which principles are the differences of recovery months

divided into the different classes? How were the classes determined? It leads also to confusion in Figure 9. Without reading the caption it seems as if the difference is very small everywhere (from 1 to 4 months), but the number does not represent the “difference in months”, rather the “class number of difference in months”.

12. [Page9 Line333] Could you please discuss that the recovery period derived from precipitation is also underlying certain assumptions (e.g. about evapotranspiration)?

Specific comments

I would recommend to work through the manuscript again to remove grammatical/syntactic errors. Some examples: - [Page1 Line30] Missing commas, ‘the’, and ‘and/or’ (should also be checked: and/or is needed before last item of a list), suggestion: ‘... developing parts of the world, for example, the 2011 East Africa drought or the 2018 dry corridors of central America (REF).’ - [Page2 Line56] have/has and “the” too much, suggestion: ‘... is independent of other drought indices and has global spatial coverage.’ - [Page2 Line69] singular/plural, citing brackets, suggestion: ‘... reviewed different kinds of drought and their prediction methods based on statistical, dynamical, and hybrid methods. Panet et al. (2013) were ...’ - [Page3 Line91] add date of last access for websites - [Page4 Line146] be consistent with required precipitation/required-precipitation - [Page 5 Line 181] be consistent with figure/Figure and section/Section - [Page5 Line190] estimated precipitation → reconstructed precipitation - [Page5 Line202] be consistent with climatology/annual signal

References that should be added: - [Page2 Line59] Reference for global gridded assessments - [Page2 Line62] Reference for increasing frequency of drought - [Page3 Line98] Reference for cubic convolution interpolation

[Page2 Line77] Please explain why only terrestrial water storage can be used instead of, for example, in-situ groundwater data.

[Page2 Line81] It could be added that you focus on sub-decadal drought because there

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are only about 15 years of GRACE data.

[Page2 Line83] GPCP was not introduced yet.

[Page3 Line114] “Here, we define ‘recovery’ as a return to the climatological storage state for a given month.” This is not totally clear to me, does it mean that the deviation from current dTWSA to the climatology itself in a specific month, which is referred to as severity in Thomas et al. (2014), is already the recovery?

[Page3 Line123] state of drought → severity of drought?

[Page4 Line125] Could you mark the three recovery periods in Figure 1, please? It seems as if the recovery periods are longer than 1.5, 1 and 0.5 years.

[Page5 Line167] ... are statistically analyzed using the methods of ...

[Page5 Line184] The annual signal and linear trend extracted by signal decomposition ...

[Page5 Line187] How was the number 10-14 months for autoregression chosen?

[Page5 Line200] worst → worse

[Page5 Line201], [Page7 Line271], and [Page7 Line283] etc.: ‘In these regions...’, ‘this region’, and ‘monsoon regions’ be precise which regions

[Page5 Line202] robust → dominant

[Page6 Line211] Where (reference) is it defined that one sigma represents a wet year and three sigma an exceptionally wet year?

[Page6 Line220] providing a minimum and maximum baseline?

[Page6 Line232] “In Figure7, observed precipitation (red dashed line) and absolute required precipitation (blue line) ...” This was already said.

Figure 7: This was quite hard to analyze. I would recommend to enlarge the subfigures

or put them in a different order (e.g. 4 x 1).

[Page6 Line241] some drought → drought

[Page6 Line241] Remove ‘it is a random selection of the month for’

[Page7 Line254] blue → red?

[Page7 Line256] Is with 80% the total global land area or the masked global land area meant?

4.2.2 Different precipitation scenario → Precipitation scenarios

[Page7 Line 265] ‘We stimulated one-month (February 2016)recovery period ...’ Not clear what is meant

[Page8 Line288] Better more precise: Here we define drought severity and duration using ...

5 Discussion: Refer to section if different aspects/findings are discussed. [Page8 Line298] soil water column → water colum

[Page8 Line 299] Position of sentence in paragraph awkward in the previous context.

[Page9 Line327] Also shown in Figure 11 ...

[Page9 Line342] 1) the independence from other drought indices → more precise, which independencies?

All Figures: Please check figure references in the text, some of the references have been mixed up. Make sure that all figure captions and title really describe what is shown (compared to what) e.g. Figure 4 fraction of a), b), and c) to what? Total of all. . . or Figure 9 validation of what by what? And consider changing colorbars, since some figure might better be represented in a different way, e.g. Figure 9 discrete colorbar.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2019->

590, 2019.

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