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Reply on RC3

Dung Trung Vu et al.

Author comment on "Satellite observations reveal 13 years of reservoir filling strategies, operating rules, and hydrological alterations in the Upper Mekong River basin" by Dung Trung Vu et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-360-AC3, 2022

General comment

Dung Trung Vu and co-authors used Landsat data to derive water area, elevation, and storage series of ten major reservoirs on the main stem of the Lancang River basin. In addition, the authors used a hydrological model to simulate the inflow of the reservoirs and discussed the impact of reservoir filling and operation on the discharge of the Lancang-Mekong River. The authors did provide some suggestions on how to use remote sensing data to obtain reservoir storage changes and combine them with hydrological models to examine the impact of reservoirs. However, the novelty of this study lies in the incremental contributions that are not enough to be considered for publication in the prestigious journal of HESS. In particular, this study falls short of assessing the accuracy and precision of the results. Limitations of this method could impede the application of this approach to other areas. Therefore, I recommend rejection of this manuscript.

Response: Thank you for taking the time to review our work and provide many thorough comments. We agree that there are opportunities for improving the quality of this work, but we respectfully disagree with the overall evaluation. First, it is true that our methodological approach lies on the advancement of previous works (in particular, Gao et al., 2012 and Zhang et al., 2014), but we do not claim that the novelty of this work lies in its methodological contribution. Instead, the novelty of this study lies in three knowledge gaps that we address, that is, (1) lack of water level and storage time series for the Lancang dams, (2) filling strategies of these dams, and (3) event attribution analysis on droughts and pluvials (please refer to lines 63-87). This is why—we believe—the research is relevant to the special issue on Socio-hydrology and transboundary rivers. Second, the accuracy and precision of the results can be further evaluated by banking on a few additional datasets, as explained below. Finally, we disagree that our methodological approach cannot be applied to other areas, since (1) all datasets have global coverage, (2) both data and code are publicly available, and (3) we contributed an algorithm for improving the water surface estimation of Landsat images—something that makes them more usable, especially in regions affected by cloud cover.

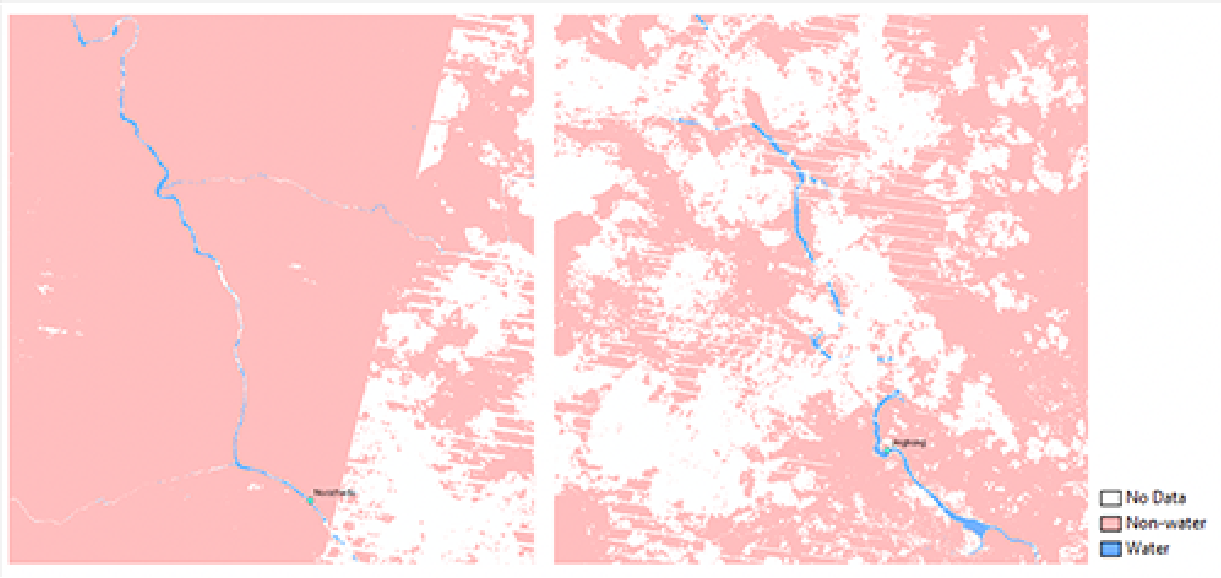
Comments

1. The water surface area extraction algorithm needs substantial improvement. There are already many decent global water surface area datasets with spatial and temporal

resolutions that fully meet the requirements of the study and their algorithms are relatively advanced (Pekel et al. 2016; Pickens et al. 2020). These data can at least be used as input data to generate Water Layers instead of simply using NDWI with a fixed threshold.

Response: The key benefit of using the Pekel et al. (2016) or Pickens et al. (2020) method is that these algorithms provide a global product on water surface area with a probability of occurrence of water for every grid cell based on long-term Landsat record. Based on this long-term record of Landsat data during cloudless days (and without the challenging issues of speckle and shadows), these products essentially inform the user of the probability of a given grid cell being water at a given time of the year, which is particularly useful if there are clouds present---thus the issue of cloud cover can be mitigated. There have been many studies that have improved water area classification for reservoirs by building on such studies by Pekel et al. (2016) or Pickens et al. (2020). For example, Zhao and Gao (2018), uses Pekel's dataset (which has recently been updated to 2020), to improve water classification during cloudy or challenging situations common in Southeast Asia. Regardless of what specific water area classification method is used (e.g., index-based such as NDWI, MNDWI), the key source of uncertainty in water area estimation using visible sensors (Landsat) will always be that of cloud cover and, when the various methods are compared, we have found NDWI to perform more robustly in Asian climates. Please refer to our previous studies (e.g., Biswas et al. 2021a,b).

In our study, we are following exactly a similar procedure, one that builds not only on an index classification but also on the prior probability of water occurrence (please refer to lines 213-226 and Figure 5). Thus, our method is already inclusive of the Pekel et al.'s dataset concept and is not a pure index-based classification—this ensures that our water surface area estimates are robust during cloud cover situations. Moreover, the reviewer should note that, in our experience, Pekel et al.'s dataset suffers from a few problems, despite the use of a long-term Landsat record, even during cloudy days and for smaller water bodies and in steep terrain (please refer to the figure below). For example, we have frequently found Pekel's data-based water classification (such as Zhao and Gao, 2018) to perform poorly in patches for reservoirs in Mekong, requiring therefore additional sensors and more creative methods, which our study has incorporated. Finally, our study employs k-means clustering as the final filter to further improve water area estimation (see Figure 6). In sum, our water surface area is a robust approach involving three layers of improvement---prior probability, index classification, and k-means clustering.



Water extent of Nuozhado (left) and Jinghong (right) reservoirs extracted from Landsat observations in September 2009 by the European Commission's Joint Research Centre (Pekel et al., 2016). Water detection results are affected by clouds and other disturbances such as the no-data stripes in Landsat 7.

Water extent of Nuozhado (left) and Jinghong (right) reservoirs extracted from Landsat observations in September 2009 (downloaded from the dataset of Pickens et al. (2020)). Water detection results are heavily affected by clouds and other disturbances such as the no-data stripes in Landsat 7.

2. The author's introduction of the input data is not clear enough. Different levels of input Landsat data (TOA reflectance/surface reflectance/DN) may yield different water body index results, so the level of input data needs to be explicitly shown.

Response: For the Landsat data, we used the Landsat Collection 1 Level-2 (Surface Reflectance) downloaded from the USGS website (https://earthexplorer.usgs.gov/). This is because we are doing a retrospective analysis and not developing an operational tool that *needs near real-time data. (In fact, no study should really use TOA reflectance unless it is for some kind of real-time data assimilation or if fast updates are needed.) We will clarify this point.*

Also, the type of Jason data needs to be shown and the processing of extracting the water body elevations from the altimetry data needs to be introduced since whether and which waveform retracking algorithm used should largely affect the results. Without really showing the waveform retracking algorithm and specific thresholds for the classic pulse limited radar altimeters, these results are highly unconvincing.

Response: For the radar altimetry, we used the data provided in the G-REALM repository (https://ipad.fas.usda.gov/cropexplorer/global_reservoir/), which is based on the analysis of Jason-2 and 3 altimetry data. This is a well-known dataset, described in Birkett et al. (2010a, 2010b). We agree that this information should have been provided (and we will do it in the revised manuscript), but that does not mean that the results are "highly unconvincing"—since our analysis includes both Landsat-derived and altimetry-converted water surface area.

3. More data are needed for assessing the water area/elevation/storage results. The authors used Jason-2 and Jason-3 altimetry data to evaluate the water elevations derived from Landsat data in the Xiaowan and Nuozadu reservoirs. However, the time span and sampling of the altimetry data is relatively low at the two reservoirs. For example, altimetry-based water levels for the Nuozadu Reservoir from 2017 to 2020 are missing. Therefore, more validation data should be supplemented, such as water surface elevations derived from Sentinel-3 and ICESat/ICESat-2 data. In addition, the accuracy and precision of satellite altimetry data need to be supported by validation results.

Response: Thanks for your suggestion. G-REALM has recently released a few new datasets, so we will bank on them to extend the validation. In particular, we can extend the time span of water level (obtained from Sentinel 3A) for Nuozadu (released last month), and add a validation for Huangdeng (2009 – 2020), and Jinghong (2019-2020 only)—the latter obtained from Sentinel 3B and released two weeks ago. As for the accuracy and precision of the satellite altimetry data, we note that extensive validations were carried out in Birkett et al. (2010a, 2010b) with gauged data. Finally, thank you for suggesting the use of IceSat-2 for further validating our results. However, IceSat-2 has a 91 day repeat and is therefore not useful for understanding or improving reservoir dynamics or operations for the study region.

4. The accuracy of the water surface area/elevation/storage results needs to be described in detail. There are no statistical metrics in the manuscript to characterize the accuracy and uncertainty of the results. For example, CC and RMSE can be used to describe the consistency between Landsat-derived elevations and altimetry-derived elevations.

Response: Thank you for raising this point. We will include a quantitative comparison of Landsat-derived elevations and altimetry-derived elevations.

5. The temporal resolution of the study results needs to be substantially improved. As can be seen from the presented graphs, the water elevations of the reservoirs change rapidly from June to October, and the monthly water elevation and storage series may not accurately depict the real operation of the reservoirs.

Response: The temporal resolution is sufficient for studying the reservoir dynamics of many Asian reservoirs subject to the Monsoon. That is because many reservoirs will typically begin filling sometime during the monsoon season (June-July) and drain from November onwards as part of flood control and irrigation requirements (with hydropower needs controlling the rate at times). This is a point demonstrated in Biswas et al. (2021a), *who used an entirety of 35 years of Landsat data to show that we can understand reservoir storage dynamics for 1,598 reservoirs with confidence to track the gradual increase/decrease of active storage as well as inter-annual variability.*

To prove that monthly time step is sufficient for our study, we will provide the comparison between our Landsat-derived water level/storage and Sentinel-1/2-derived water level/storage, which can have a frequency of 6 days (Sentinel-1A and B have a frequency of 12 days and interleave to each other), but only available from 2014 and 2015 onwards.

6. The advancement of the study results is not shown compared to the hydrological model results. It can be seen from Figure S5 that the reservoir water storages from the satellite observations and the VIC-Res model simulations are very similar. Therefore, what is the necessity for performing this study that used remote sensing data?

Response: It is indeed good news that a macro-scale hydrological model can accurately reproduce hydrological and water management processes in the Lancang. However, it is necessary to consider two key elements. First, for basins like the Lancang (for which streamflow and water management data are not publicly available), we need data to setup and validate hydrological models—hence the need for this research, as explained in line 424-433. Second, the accuracy of models simulating water reservoir dynamics can be improved by banking on data providing information on storage dynamics, filling strategies, and rule curves. In our case, for example, the storage data (inferred from satellite data) are used by VIC-Res to solve the mass balance of each reservoir—this is a point we will expand on, as explained to reviewer #2, comment no. 3. In sum, we believe that the information provided by hydrological models and satellite data is complementary, not interchangeable.

7. The authors used model simulated inflow (Q) and evaporation loss (E) to calculate the fraction of inflow volume retained by the reservoir (θ). Unfortunately, the authors did not give the method and input data used to obtain E and the share of E in.

Response: In our study, evaporation losses from the reservoir surface are modelled with the Penman equation for all cells belonging to the impoundment—a functionality available in the VIC-Res software (Dang et al., 2020). In the Penman equation, solar radiation and surface wind data were derived from the Global Meterological Forcing Dataset (Sheffield et al., 2006). We will clarify this point in the revised manuscript and show the share of E in the mass balance. Finally, we note that the evaporation values for humid basin reservoirs of South and Southeast Asia rarely makes a difference in improving outflow estimation. This has been shown in Bonnema et al. (2017).

8. For the 2019-2020 drought event, the authors argue that the Lancang dams did not change their operating patterns and stored about 46% of the estimated natural flow during the wet season, and the operations "contributed to downstream droughts and pluvials". However, from another point of view, the reservoirs could retain a fixed percentage of water when inflow decreases, which reduces the storage increment and increases the outflow compared with retaining water to a certain elevation (a commonly used operating rule). Therefore, it cannot simply be considered that "dam operations contributed to downstream droughts and pluvials".

Response: In our analysis, we simply followed the data, which indicate that water has been withheld during the drought. Naturally, this is not the only cause for the downstream drought, so this is why we use the verb "contributed" instead of "caused". We also acknowledge that there is uncertainty in our analysis (please refer to our response to reviewer #2, comment no. 6), so we will make sure this point is reflected in the manuscript.

9. The authors overstate the impact of new reservoirs on downstream water discharge. According to the authors' calculation, Nuozhadu (21749 Mm3) and Xiaowan (14645 Mm3) reached steady-state operations in about two years by retaining from 15% to 23% of the annual inflow volume. And the newly building reservoir, Tuoba (1039 Mm3), has less than one-tenth of the capacity of Xiaowan or Nuozhadu. But the authors claimed that downstream countries should expect a temporary, yet substantial, decrease of water availability if the same filling strategies were to be implemented. This does not seem to have a solid basis.

Response: We disagree with this comment, simply because it is not based on what we wrote. In the Discussion (line 405-414) we wrote that "China is already building a new dam (Tuoba; 1039 Mm3) and planning the construction of ten additional ones (MRC, 2020)", so it is the filling of multiple additional dams that could cause "a temporary, yet substantial, decrease of water availability". Please note that all these dams are rather large: e.g., Ru Mei (13,385 Mm3), Ban Da (12,902 Mm3), Gu Xue (10,127 Mm3); taken together, they have a total storage capacity of about 64,950 Mm3 (Schmitt et al. 2019). We will make sure this point is crystal clear.

10. The Authors need to pay attention to the citations. For example, the authors did not cite related literature in their initial references to NDVI, NDWI, and MNDWI. Also, the authors did not show specific sources of remote sensing (Landsat/Jason) or other data (CHIRPS-2.0) they used and cite them properly in the text or the supplement content.

Response: In line 180 we introduce the spectral indices (i.e., NDVI, NDWI, and MNDW) and refer to Table S4, which contains the name, formula, and references for each of them. The specific sources of remote sensing (STRM-DEM/Landsat/Jason) or other data (CHIRPS-2.0) with the links to access were stated in the code and data availability section (page 23).

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