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Interactive comment on "Quantifying sediment mass redistribution from joint time-lapse gravimetry and photogrammetry surveys" *by* Maxime Mouyen et al.

Anonymous Referee #2

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The paper presents a study of river induced mass transports from micro-gravimetry compared to volume changes inferred from photogrammetry. While I cannot assess weaknesses in the geometrical approach, the gravimetry part and its interpretation lacks serious shortcomings.

Gravity changes measured at 3 epochs are presented, consisting of gravity surveys with one relative gravimeter referred to point (AG06) observed with the absolute gravimeter (AG) FG5-224. However, the third epoch in 2017 has no reliable reference as the AG measurement failed. Instead, simply a mean value of three epochs was assumed, which is inadequate for the following reasons: a) Figure 5 shows sig-

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Discussion paper

nificant annual variations due to changes in the water storage, with a large uncertainty documented by the discrepancy of two selected models. Figure 3 documents AG observations in the range of 7 μGal from 2014 to 2016 which serve as a reference, where the first one was acquired in the beginning of the year (~Feb, not further specified in the paper), while the other two were measured in Nov (presumably in temporal proximity of the relative surveys, which should be documented). b) As shown with Figure 5 a significant gravity decrease has to be considered from November to March. Although a "strong annual periodicity in this area" (L114) was stated by the authors, this variability was not taken into account when approximating the missing absolute gravity reference value for 2017. c) With Figure 4 a clear vertical uplift of ~25 mm is documented for AG06 for the period 2015-2017 which corresponds to a gravity change of -5(!) μGal, assuming the ratio of -2 μGal/cm used by the authors (L153). The other AG surveys at AG06 since 2006 (L88) are neither documented nor used in this study, although a significant contribution must be expected for the extrapolation of the missing 2017 value. The assumption of the 2017 reference value seems therefore highly questionable. Furthermore, no uncertainty estimate is provided, and the uncertainty estimates for the individual FG5 observations in Fig. 3 doesn't seem to include systematic effects.

Although a vertical uplift is documented for point AG06, no monitoring of the field points BA01-09 is performed, e.g. by spirit leveling. Therefore it is impossible to discriminate between the effects of a possible vertical uplift (as for point AG06) and the impact of (local) mass changes.

The relative gravity measurements were performed with only one relative gravimeter. For surveys in the microgal level, the control of the instrument is essential, both for the instrumental drift as well as for eventual steps due to transportation and handling and is usually realized by parallel observation with a second gravimeter. The measurement scheme is not documented, only the reference to AG06 is mentioned. Textbooks on gravimetry document several schemes to control relative surveys which were not applied nor mentioned in the paper. It is not true, that "Inferring this drift requires to regularly re-measure a base station where absolute gravity is known (AG06 in this case)" (L123). Drift and eventual steps can be analyzed and separated without any knowledge of the absolute gravity value, assumed a proper measurement scheme was chosen. Further, a strict temporal regime is necessary to obtain reliable and reproducible measurements in the microgal range, which cannot be achieved by just observing the scatter of the readings. A variability of the observation time between 15 to 23 minutes (L121) will most likely include a change of the instrumental drift during movement and during rest, which degrades the obtained values systematically. Finally, the corrections due to ambient temperature variations are rather unusual and should be referred specifically to CG5#167, as documented in Fores et al. (2016).

The computation of the gravitational mass effects is not clear. While Figure 1 is showing a point mass approach, which is inadequate for the problem, later (L238) the prism approach of Nagy is mentioned. It should be clearly documented, which method the study is following. Although rectangular prisms are still widely used it should be checked whether more efficient and innovative methods, e.g. based on polyhedra, could be applied, see e.g. Petrovic(1996) or Tsoulis (2012) and references therein.

The estimate of a density distribution lacks serious shortcomings. First, gravitational effects due to the landslide cannot be separated from changes in the sedimentation in the river bed. It is very likely that the documented gravity change between epochs 2015 and 2016 is caused mainly by the landslide, not by mass changes in the river bed. This is supported by the volume changes inferred from the photogrammetric approach. Therefore the estimate of a density distribution(!) by a least squares approach (which is basic and doesn't need to be documented in a schematic way used for matrix computation) is highly unreliable. Observation equations and correct uncertainty estimates are missing. Only the error of the a posteriori unit weight is given instead of the covariances of the estimated parameters (and their significance!). The ill-posed problem of the inversion of gravity changes with respect to mass variations is not sufficiently well addressed, see e.g. Prutkin and Casten (2009) and references therein.

The explanation of gravity changes due to vertical displacements (L150) is unacceptable. Not the distance to the "Earth's center of mass" is relevant, but the complex relation between the position of the sensor relative to the surrounding masses and their (re-)distribution.

Finally, the gravitational effect of the dolosses placed near to gravity site BA02 is unclear. Since the close proximity to the measurement point just a volume estimate as documented in Appendix A which is insufficient. Instead, an integration over the volume of these disturbing mass elements is necessary.

In conclusion, the results of the gravimetric part of the study are neither based on a solid observational basis nor are they interpreted in a proper way. Therefore I cannot recommend the contribution in its present form for publication.

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