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Interactive comment on "The application of terrestrial laser scanner and photogrammetry in measuring erosion and deposition processes in humid badlands in the Central Spanish Pyrenees" *by* E. Nadal-Romero et al.

Anonymous Referee #2

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General comments

This is an interesting paper on geomorphodynamic processes in badlands that uses comparatively new 3D measurement methods. The latest development in easy to use and inexpensive structure-from-motion photogrammetry (sic!) has dramatically increased the potential for spatially continuous high-resolution elevation measurements. Although photogrammetric methods have been used in erosion research for several decades, they had until recently mostly been applied to smaller-scale/lower resolution

studies (e.g. large landslides) or to quantification of the retreat of individual linear erosion forms with clearly defined edges such as gullies. Centimeter-scale changes of surface heights, such as observed within gullies or in badlands, had been difficult to quantify with sufficient accuracy and precision or extremely time-consuming until TLS and SfM techniques became more widely accessible. Thus, this paper addresses interesting and highly topical new possibilities for badland research.

Having said that, I feel that the paper in the current state fails to exploit its full potential and indeed does not do what the abstract promises and the conclusions state: it does not actually "compare" the two methods, and it does not "use the combination" of them "to maximize their advantages". It just presents the results obtained with both methods without actually analyzing or discussing their differences – a deficiency which is unjustified and unnecessary in my opinion, but rather easy to remedy. This is my main criticism, and I think it imperative that the paper be improved in this respect before publication. This requires some additional analysis and improved error assessment. Another aspect that needs improvement is the insufficient literature review on (SfM) photogrammetry in geomorphology. In particular, I would suggest that the authors consider the following issues:

Specific comments

Throughout the paper (check all instances including chapter headings): The term "photogrammetry" is too general and not specific enough in this context. "Close range photogrammetry" is an established term which has always been used in the literature for stereoscopic photogrammetric analysis of high-resolution terrestrial images (with object distances normally even closer than yours). The method you use – structure from motion or SfM – is also based on photogrammetric principles, but uses another approach in reconstructing the geometry of camera orientation, as well as using a large amount of multiple overlapping images rather than just pairs of images. You must absolutely not publish a paper using this method without even mentioning its name! This is misleading, as your method does not employ traditional softcopy photogrammetry. I

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would suggest to use the term “SfM photogrammetry” instead – see (and cite!) Westoby et al. 2012 in Geomorphology.

p 341 L 2-4: can you really conclude that studies on badland erosion have increased? Or would any topic you research in a digital database such as ISI Web of Knowledge show an increase during the last 30 years due to increased digitalization of literature. . .?

p 341 L 16-17: the TLS does not measure points of a spatial mesh – the mesh is only created from the points afterwards

p 341 L 23-26: Sentence: The surveys encourage its applications?

Section 1.3: Some of the literature cited in this section seems to me rather arbitrarily chosen; the literature review not is too well conducted. E.g., is a conference proceedings paper of 2004 (Bitelli) the best choice for showing that “today, this tool offers new possibilities”, when there exist more recent and substantial papers in geomorphological and photogrammetric journals? And is the study by Farenzena et al., a rather unknown conference proceedings paper, really a good choice for documenting the importance of photogrammetry as a tool in archaeology? There are many more substantial and comprehensive papers better suited for this purpose, e.g. in the Journal of Archaeological Science or Archaeometry.

Also; there is no difference made in this section (as in the rest of the paper) between traditional photogrammetric methods and the new SfM methods (see my initial comment above). This is, however, really important, as with the advent of SfM we have seen a large increase of studies using 3D elevation models in geomorphology. It is not true (p 342 L 11-13) that “to date few studies have taken advantage of the possibilities offered by geomorphology [?? why by g.?] to generate terrain models” – instead, there has a surge of new publications on this during the last 2-3 years. It is essential that the authors improve the literature review in this respect, as their statements here are clearly outdated, and that they make clear where they speak of photogrammetry in

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general or SfM techniques in particular. Apart from the review paper by Westoby (see above) this section misses other important works and authors on photogrammetry in geomorphology, the work by Jim Chandler (e.g. ESPL or Photogrammetric Record) and Fonstad et al. 2013 (ESPL).

Section 2.1: As this paper is to be published in SOIL, could you provide a little more details of the soils/substrate in your badlands?

p 343 L 14: sentence garbled?

p 343 L 22-23: sentence in brackets garbled

p 344 L 8-10: rearrange or split sentence for clear structure in north slope and south slope – unclear

Section 2.3: the explanation of the (SfM) photogrammetry method is not very well done and very superficial. This section needs a clearer explanation of the basic principles of the method and less vague statements. Which settings have you used for deriving the point clouds? And what do these settings mean – e.g. which parameter changes when you chose “high quality” rather than “medium quality” for dense point cloud generation? P 345 L 2-3 is much too vague. Also:

p 344 L 22: better than what?

p 344 L 22-24: in. . .slopes? Why plural – you have one north-facing and one south facing slope? And why “in” – you take images “of”, not “in”.

p 344 L 25: the 12 MP are a characteristic of the camera; better added above in line 21

p 344 L 23-24: You state that you have taken 17 and 15 images respectively – always the same number and positions for all monitoring dates? And – more importantly – why so few images? This seems a critical point to me – the main difference of SfM compared to traditional photogrammetry is that it heavily relies on the redundancy of

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image information. A large number of images is imperative for good results. From the number and distribution of images taken at your study sites, is looks more like a set-up for traditional terrestrial photogrammetry than SfM. Why have you taken so few images? From what I have read about and done with SfM, a much large number (50-100) would have been suitable for these areas, and I would expect that your results suffer from this deficiency (much more than from too low resolution, as suggested in p352, L 20).

P 345 L 5-6: of course the resolution depends on the measuring distance! Your model cannot possibly get finer than the image resolution and this directly depends on the measuring distance.

p 345 L 13: It is unclear with which method you measured the ground control points ("targets") – the TLS itself does not measure absolute coordinates. Does it have a total station or DGPS integrated?

p 345 L 16: It seems a bit biased to compare the errors of the TLS with errors measured with the same device by the same (co-)author. . .

p 345 L 19: are the 0.025 m given here the estimated error of the GCPs? The whole section is missing a clear indication of error values of the photogrammetric restitution as reported by the software; please add.

Section 3: The most important issue in this section is the complete lack of an analysis that actually compares the two methods. There is only one very qualitative and vague statement (p 348 L 9-13) about "really similar results" and "remarkable differences", but I do not know how these statements are supported. I don't think the figures in Tables 2 and 3 justify such an assessment. Why have you not analysed the difference between the TLS and SfM models for each period in DoDs (DEMs of difference?) Rather than comparing just one value each for mean or StD, this will give you a spatial distribution of differences between the models and indicate for example if there is a general offset between the TLS and SfM surface, or a better representation of small rills in one of

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them etc.

Section 4: The accuracies of the two methods need to be better discussed in this section. How do the mean values of erosion in Tables 2 and 3 relate to the respective absolute accuracies of the 3-D model? E.g., if the estimated orientation error of the SfM model is 0.025 m RMSE (see comment regarding p 345 L 19); what does this mean for a computed mean value of 0.001 m for period 2 – and for all other values in Table 2-3? The absolute orientation error then is higher than the mean modelled surface elevation change in nearly all periods...

The question of error assessment does of course apply to the TLS data, as well. See for example in Figure 7: in the first model, there is an increase of elevation nearly all over the interrill areas, with no change in the rills – how should this be possible? Is this not a systematic offset within the range of TLS accuracy?

p 348 L 15: Can you prove the subcentimeter accuracy?

Section 3 and 4: In both sections the patterns of erosion and deposition visible in the models are in my opinion not well enough presented and discussed. Can you indicate examples of the processes you mention (e.g. rill development, mud flow etc) in the figures? The Mud and debris flow you describe in p 349 L 10-24 as typical for north slopes are actually much better to see in the south slope figures!

p 349 L 28 – p 350 L 1: wrong numbers or units! It should read 2 mm, 38 mm and 56 mm

p 350 L 10-15: repetition from Section 1.1. You ought not to repeat arguments from an introduction in a discussion section...

p350 L 26-27: At present, I think this statement is not supported by your analysis...

p350 L 28: quality in which respect? I think the main problem is the low number of images! With respect to this, I would be careful with the statement in P 351 L 4 – this recommendation somewhat contradicts your choice of SfM as a method.

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P 351 L 5-6 and L 15: which images do you talk about? TLS does not primarily provide imagery but 3-D coordinates. Do you mean the image taken be the camera integrated in the TLS? Or do you mean the surface models (sic) computed from the TLS point clouds?

P 351 L 6-11: here for the first time the problem of sight shadowing (not just shadowing) is mentioned – this ought to be mentioned before in the methods section. It can also be seen in Figures 5, where it is difficult to differentiate the holes from the blue negative values.

P 351 L 20: This statement (differences less than 3 cm) is not useful as a general statement, as it is highly dependent on the case study setup and may differ with image resolution, object distance, study are size etc.

P 352 L 19-20: is this "could" past tense or subjunctive? In any case; I do not understand it. . . in what way does a higher resolution solve which problems?

P 352 L 20-222: sentence unclear/partly garbled

Fig 3: The number of picture stations does not correspond to the numbers given in the text (p 344 L 23-24). Also, there is only one TLS station indicated, but the text gives plural (p 343 L 25: "from the different scan stations")

Fig 5-8: all sub-figures need to be labelled clearly for periods! The legend/color bar is far too small and absolutely illegible. The blue background is confusing as it makes holes in the data (Fig 5) look like negative changes

Technical corrections

check use of "i.e." in section 1.2. and throughout the paper – it is often misused in place of "e.g.". I.e. (id est) means "that is" while e.g. (exempli gratia) means "for example"

p 340 L 17: wrong year for Walling

p341 L 11: Barnhart and Crosby

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p 343 L 16: . . .”are 3200 and 560m^2 respectively”

Table 1 caption: “periods” (plural)

Fig 1: Spell out rainfall simulation, topographic surveys, dendrochronology (?)

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