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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.

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Dear editor, dear reviewers, We are pleased to submit a revised version of the manuscript. First of all we want to thank for your effort in improving the work. Recommendations about the methodology, and about the form to transmit the main ideas of the paper have resulted extremely useful. We have followed by far the majority of them, and we think that they helped to prepare a better manuscript, easier to be read and more robust from a methodological point of view. Below, we provide a point-by-

point answer to all the comments raised from the review, and the changes that we have introduced in this revised version. Despite it is required a separate answer to both reviews, we provide the same document to both reviewers to facilitate them a fast assessment of all changes introduced in the manuscript.

Looking forward to hear your kind reply,

Estela Nadal-Romero and co-authors.

Anonymous Referee 1 General Comments

1. Photoreconstruction survey and its error assessment Concerning this comment, these new paragraphs have been included in the introduction section (1.3. New remote-sensing techniques: Terrestrial Laser Scanner and SfM photogrametry): "The digital photogrammetry has generated an improvement in topographic methods, due to a better accessibility to a wider variety of users, its low cost, and also because the increased automation of the photogrammetric routines (Fonstad et al., 2013). Recently, Structure for Motion (SfM) techniques, developed by the computer vision community, were adapted to generate high resolution and quality DTM. Classical (Stereoscopic) photogrammetry is based on 3D reconstruction models by superimposing two images of the same area from different perspectives. SfM is based on the reconstruction of the 3-dimensional geometry from the matching of multiples images generated from different points of view. Pictures can be taken at different scales, and the position, orientation and distortion can be no-known. SfM differs from stereoscopic photogrammetry, because it uses image matching algorithms to recover randomly acquired images and to detect points in common elements. The biggest difference between both methods is the need to use GCP for the 3D model resolution. In classical photogrammetry, the collinearity is solved after the introduction of the GCPs; in SfM, collinearity is solved from the common elements of the images. So, if there are errors in the measurement s of the GCPs, they are propagated to the final result (Fonstad et al., 2013). Through SfM, the final quality of the point cloud is based on a high number of common points

(> 1000) that have been automatically generated."

2. Comparison between both techniques taking the LiDAR survey as the reference. It has been the main concern in our manuscript. We are conscious that it was a weak point in our manuscript. So we have carried out a new analysis including the comparison of the methods. Two new comparison figures have been included together with a point cloud with RGB colours (real colours from the camera coupled in the TLS) of the slopes in the different survey days (Figures 9 and 10 and Table 4). Thereby, in section 3.3. Joint analysis these lines have been added: "Figures 9 and 10 showed a direct comparison of DEMs between techniques considering LiDAR (TLS) as the reference. Differences have been calculated for the first and last acquisition dates (23/07/13 and 23/07/14). Big differences occurred in small areas, where small vegetation patches were present (almost all vegetation was eliminated from the point clouds, but some influence can be appreciated in the exterior limits of the selected slopes). Small differences were observed in "deep" concavities (yellow colours in the comparison figures), because in these areas the SfM was not able to accurately reproduce a precise topography. Other errors were usually located in ridges, and the areas behind them, from the TLS perspective, showing one of the main TLS limitations: with only one point of view, some areas are hidden. Differences were bigger in north-facing slopes in both surveys (also the highest standard deviation were recorded)."

Specific comments:

3. Tittle. We have changed the tittle. The application of terrestrial laser scanner and SfM photogrammetry in measuring erosion and deposition processes in two opposite slopes in a humid badland areas (in the Central Spanish Pyrenees)

4. Abstract. We have changed in the abstract and in the manuscript "geomatic" and we have used "remote sensing techniques".

1.2. Review, line 26: Gauging stations. We consider that gauging stations are invasive in most of the case, due to the construction of the gauging station and due to the

building of the different canals to measure the water level. In the case of the deployment of ground control points in our study case, these points are outside (in the limit) of the study area, so we are not disturbing the different slopes.

1.3. Page 341, Line 27: term "Photogrammetry". The different reviewers coincided in that the term photogrammetry is not correct, so we have deleted it and we have used Structure for Motion photogrammetry (SfM).

1.3. page 342, line 10:We have made a wide revision in SfM photogrammetry and LiDAR studies. Different references have been included in the text (see the end of the comments and manuscript (last lines in 1.3 section)

1.3. page 342, line 11:Previous photogrammetric studies in badland areas have been included in these lines.

2.2. page 344, line 13:TLS does not enable a consistent distribution of the acquired information. Yes. It is a limitation for all remote sensing techniques. But we want to remark that for the TLS it is an important issue. Indeed, the high number of points obtained for low distances to the TLS in comparison to these obtained for large distances, is one limitation for these devices. This has encouraged minimizing scan distances when possible (Heritage and Hetherington, 2007). In the contrary, SfM technique, does not show this high dependence on distance due to the multiple points of view of the surveyed area (Smith and Vericat, 2015) being this one of the main advantages when we compare to TLS.

2.3. page 344, line 22: We have changed these sentences to avoid a misunderstanding: "Structure-from-Motion photogrammetry allows the creation of 3D models from multiple overlapping images taken at distinct triangulation angles. In this case, we used the FUJIFILM Finepix x 100 camera, with a focal length of 23 mm (equivalent to a fixed lens of 35 mm), with a resolution of 12 MP (4288 x 2848 pixels), which provided better 3D reconstruction than classical photogrammetry (James and Robson, 2012)."

2.3. page 344, line 23: The number of pictures could be a problem in our study case. However, we consider that the increase in the number of pictures could induce different problems as the lighting of the different pictures. This way, in different point cloud generation tests in Agisoft software, when considering a higher number of pictures, large errors were observed in some areas (topographic features that did not exist as very abrupt peaks or sinks), which were related to illumination changes. Also we know that distance is a problem. So in future fieldwork, we will try to take into account the distance and the picture number as a factor. We consider that is really important to obtain different images from all possible point of views. However, the number of pictures necessary could vary in each study, and we consider that it is really difficult to determine a minimum number of pictures (3 would be the minimum to generate a 3D model). So we consider that the number will depend on the occlusion, topography (complexity) and scale. A number between 10 and 100 is adequate to medium and high scales, when the study area was well represented in the image geometry. A different point that should be addressed is the constraint of computer memory. In our analyses it was a big problem because we cannot analysed a big number of pictures. We have used the software Agisoft and our computer only have a memory of 12 Gb. However, there are different studies (e.g. Micheletti, Chandler and Lane, 2015b) that have carried out the analyses in similar areas and at the same scale, and they have obtained good models with 13 pictures.

2.3. page 345, line 6: In SfM, the resolution does not depend so importantly on the measuring distance as in TLS; the point distribution within the area does not vary significantly and in general is quite similar for the whole study site. Concerning this issue, these lines have been included in 2.3. section: “High resolution of original images offers better texture and resolution to find keypoints in the photoset. Similarly, decreasing the distance between the camera and the feature of interest is related to increasing the spatial resolution of the photograph and will enhance the spatial density and resolution of the final point cloud (Westoby et al. 2012).”

2.4. page 345. Direct comparison of DEMs between techniques. As we said before, we have carried out a direct comparison of DEMs between techniques considering LiDAR as the reference (Figures 9 and 10 and Table 4). Comparison of 3D cloud is the best way to generate DEMs of difference to quantify volumetric change in temporal frequencies between successive topographic surveys (Williams, RD, 2012). In such a way, two new figures, one for north-facing slope and one for the south-facing slope, have been included. In these figures, considering as reference the LiDAR DEM, differences have been calculated for the first and last acquisition dates (23/07/13 and 23/07/14). The observed differences between DEMs are (new Table 4):

24/07/2013 24/07/2014 North-facing slopes (TLS-SfM) [m] -0.013 $\pm$ 0.0308 -0.0201$\pm$ 0.0326 South- facing slope (TLS-SfM) [m] -0.002 $\pm$ 0.0202 -0.006 $\pm$ 0.0141

These results showed the differences that existed between both methods. Additionally, when considering the figures that show these differences (the two new figures), it is possible to observe that larger differences occur in limit areas, where small vegetation patches were present (most of the vegetation was eliminated from the point clouds). Lower errors were observed in “deep” concavities (yellow colours in the comparison figures), because in these areas the SfM was not able to accurately reproduce a precise topography. Other errors were usually located in ridges and these areas behind them from the TLS perspective, showing one of the main TLS limitations; with one point of view, some areas were hidden. Thereby in the limits of these ridges we observed deviations between SfM and the DEM originated with the TLS. Considering the Std Dev in these comparisons and also the standard deviation obtained in the calculations of the transformation matrixes from the targets coordinates (data processing section), which ranged between 0.025 m and 0.015 m, the colour scales of the erosion maps was set with a “zero band” (white colour) around zero $\pm$ 0.025 m.

3.1. We think that we cannot provide a sediment yield estimation for the slope as the balance of positive or negative differences. We have estimated an erosion rate for the slope areas for one year (according with the topographic differences). We consider centimetre differences significant due to the intense and fast geomorphological dynamic in these humid badlands. The precision should be enough for centimetre precision. We have installed again a new turbidimeter at the outlet of the catchment so in near future studies we can compare both methodologies in different study periods with higher precision (assuming the turbidimeter error assessment too).

3.3. page 348. We have carried out the comparison between both techniques, as explained before. Thereby, those differences could be explained due to the difficulty of SfM to detect small erosion processes (in our opinion and experience). This is especially evident for Period 3, the less active period in both slopes. In this period the small amount of total rainfall and low rainfall intensities were registered (Table 1), and small differences were observed in the north-facing slope. Additionally, in the erosion maps no big landslides or rills formation were observed during this period. Thereby, Period 3 differences represent an example of such deviation with erosion processes in the centrimetric scale. Nevertheless, some deviations were observed in the south-facing slope in mean differences from the expected behaviour for the low "erosive" period. In this case, for Period 3, the observed positive differences may explain erosion processes, no detected by SfM neither by the TLS, but with an accumulation in the lower part of the surveyed area, properly observed. Probably, the deviation in the north-facing slope with a higher importance was the one observed for the annual period. Considering the mean deviation obtained in the DEM comparison between TLS and SfM, this error may be understood. Despite the difference deviations observed, clearly erosion maps of both techniques present quite good agreement in the eroded areas, accumulation areas and even more important in the order of magnitude observed in both of them. This encourages considering both techniques applicable in such kind of studies with the advantages and disadvantages presented in this manuscript. Hereby, it could be concluded that both techniques were not precise enough to observe small differences that happened in periods with moderate erosions processes, but they show enough precision to describe erosion processes on small study areas at annual scale in really high dynamics humid badlands.

4.1. Page 348. Line 15. We have changed "subcentimeter accuracy". We have considered centimetre accuracy.

4.1. page 349, line 9: Yes, we completely agree with the reviewer opinion, and such assertion has been included in the final manuscript version in the discussion section.

4.2. Page 350. Line 26. We have added more literature about the accuracy of SfM in different studies, and also new results have been included in this section

4.3. page 351, line 1: The dependence of the 3-D model from SfM, firstly depends on the software reconstruction mode, if low-resolution modes are selected, poor 3D models are created. When high-resolution mode is selected, the spatial resolution is improved. We have not analysed the number of points for a given cell, because we have not worked with rasterized information. Working and comparing only 3D point clouds ensure that the resolution of the obtained clouds is not lost, because otherwise, in some areas (closer to the acquisition points) we would have lost some information. In spite of that, a small number of pictures have been used for generating the point clouds, as can be observed in Figure 3, and considering the sharp topography of the study site which makes extremely difficult photo acquisition, perspectives diverge at least 90° (between extreme positions).

As can be appreciated in the new figures, included in the manuscript, we have only compared these areas without vegetation presence, to avoid such influence. Additionally (and fortunately for our analysis) in the slopes, due to the high geomorphological dynamics vegetation cannot growth.

Also the referred above lines, now states: "The comparison between both methods (Figures 9 and 10 and table 4) showed that results were similar in both cases, although significant differences can be observed in small points.

Our study demonstrated that SfM delivers good accuracy and is really useful for field application in geomorphological and soil erosion studies, for observing changes in the centimeter scale (depending on the working distance)In our case, the quality of the images should be improved in order to obtain better accuracy, paying especial attention to illumination changes during the acquisition of the images, which have been observed as an important error-causing interference. The number of pictures could be a problem to be solved together with the computer memory (a large memory is needed to process a large number of high quality pictures). Nevertheless, if the image acquisitions locations are well established and the image overlapping is done well, the number of needed images is not very high (5–10 pictures). Micheletti et al. (2015) carried out an analyses in similar areas and at the same scale, and they obtained good and valid models with 13 pictures."

4.3. page 351, line 16: We have included in Table 4 (now Table 5) and in the text brief information on the cost and time-requirements of both technologies in this study area.

5. page 352, line 20: We could obtain higher resolution pictures making photos at lower distance in small areas and then adding them to the dataset. However, for the present study we don't have it, but we can consider that in future study. Nevertheless, this statement makes reference to a general possibility of reducing errors that could be accomplished by using higher resolution cameras or making pictures at closer distances.

Table 3: We consider relevant centimetre differences. We are conscious that millimetre differences are really difficult to analyse. We have realize that changes in the month or 3-months scale are quite difficult to observe, unless erosion processes (mudflows, landslides, rill or gully development. . .) are big enough (above several cm of difference) to ensure that are captured by the techniques.

Table 4. We have included detail data about the cost and times of both methods.

Figure 1. We have considered GIS and remote sensing together. LiDAR was separated because its novelty in recent years.

FIGURES 5-8. We have improved the quality of these figures, with letters and explanations for each figure (dates, software). We have improved the legend and labels. We have used the common colour scale for such kind of maps as suggested by reviewers, (blue, and red with white transition). We have not consider to include arrows in the figure because we think that it could be difficult the reading. However, we have added two new figures with the comparison of both methods at annual scale, and we have included coloured point clouds of the slopes for one of the acquisition dates to provide more information on the study site characteristics to potential readers.

Figures captions (new figure captions): Figure 5 (6,7,8): Erosion maps for the analysed periods in North (South)-facing slope for TLS (SfM) technique. Differences have been calculated with Cloud Compare software.

Technical corrections.

4.2. pag. 351, line 1: We have changed lighting conditions. References. We have included additional references as reviewers have mentioned in the different points.

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Gallart, F., Marignani, M., Pérez-Gallego, N., Santi, E., and Maccherini, S.: Thirty years of studies on badlands, from physical to vegetational approaches. A succinct review, Catena, 106, 4-11.

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Martínez, S., Ortiz, J., and Gil, M. L.: Geometric documentation of historical pavements using automated digital photogrammetry and high-density reconstruction algorithms, Journal of Archaelogical Science, 53, 1-11. 2015.

Michetti, N., Chandler, J.H., and Lane, S.N.: Investigating the geomorphological potential of freely available and accessible structure-from-motion photogrammetry using a smartphone, Earth Surface Processes and Landforms, 40, 473-486, 2014.

Nadel, D., Filim S., Rosenberg, D., Miller, V.: Prehistoric bedrock features: Recent advances in 3D characterization and geometrical analyses, Journal of Archaeological Science, 53, 331-344, 2015.

Smith, M.W., and Vericat, D.: From experimental plots to experimental landscapes: topography, erosion and deposition in sub-humid badlands from Structure-from-Motion photogrammetry. Earth Surf. Process. Landforms, 2015.

Prokop, A.: Assessing the applicability of terrestrial laser scanning for spatial snow depth measurements, Cold Regions Science and Technology ,54, 155–163, 2008.

Westoby, M.J., Brasington, J., Glasser, N.F., Hambrey, M.J., and Reynolds, J.M.:

“Structure-from-Motion” photogrammetry: A low-cost, effective tool for geoscience application, Geomorphology, 179, 300-314, 2012.

Anonymous Referee 2

First of all, we would like to thank the reviewer the first comment on our paper and the comment about the difficulties to apply this kind of methods in such dynamics humid badlands. Thank you very much. We have improved the manuscript in this new version. We have carried out additional analysis to improve error assessment. As suggested by reviewers, we have included a comparison of both methods. And finally we have included a wider literature review on SfM photogrammetry in geomorphology.

Specific comments

1. We have changed in the manuscript the term “photogrammetry”. We use Structure for Motion photogrammetry (SfM).

2. p 341 L 2-4: It is true that due to the increased digitalization of literature, these data could be confused. However we think that badland studies have increased in the last decades. You can check the review carried out in 2013 by Gallart et al. and published in Catena. They indicated, after the analysis of a list of about 450 texts written since 1982 (when the important book Badlands Erosion and Piping, Bryan and Yair), that badland researches have increased in Scientific literature.

3. p 341 L 16-17: Yes, you are right, so we have removed the word “mesh”.

4. p 341 L 23-26: We have changed surveys by “. . .data already obtained with TLS. . .

5. Section 1.3: We have included a large number of references (See list at the end of comments 1), also improving the whole section, including an explanation between SfM and traditional photograpetric methods as follows:

“The digital photogrammetry has generated an improvement in topographic methods, due to a better accessibility to a wider variety of users, its low cost, and also because the increased automation of the photogrammetric routines (Fonstad et al., 2013). Recently, Structure for Motion (SfM) techniques, developed by the computer vision community, were adapted to generate high resolution and quality DTM. Classical (Stereoscopic) photogrammetry is based on 3D reconstruction models by superimposing two images of the same area from different perspectives. SfM is based on the reconstruction of the 3-dimensional geometry from the matching of multiples images generated from different points of view. Pictures can be taken at different scales, and the position, orientation and distortion can be no-known. SfM differs from stereoscopic photogrammetry, because it uses image matching algorithms to recover randomly acquired images and to detect points in common elements.

The biggest difference between both methods is the need to use GCP for the 3D model resolution. In classical photogrammetry, the collinearity is solved after the introduction of the GCPs; in SfM, collinearity is solved from the common elements of the images. So, if there are errors in the measurement s of the GCPs, they are propagated to the final result (Fonstad et al., 2013). Through SfM, the final quality of the point cloud is based on a high number of common points (> 1000) that have been automatically generated."

6. Section2.1. We have included more details of the substrate in the study area.

7. Page 343. L. 14. We have improved the sentence and now it states: "These slopes were chosen based on two criteria: (1) according to the different geomorphological processes that can be observed on the dry slope (south-facing) and on the more humid one (north-facing), and (2) according to the differences in the surveyed areas and on the working distances for data acquisition with both methods (TLS and SfM)."

8. Page 343. Line 22-23. We have improved the sentence. Now it states: "The device used in the present study is a long-range TLS (RIEGL LPM-321) (see Revuelto et al., 2014 for checking the technical characteristics of the TLS and the procedure used for scanning and for the post-processing information)."

9. Page 344. Lines 8-10. We have changed these sentences. Now it states: "In this study, for the north-facing slope the average resolution in point cloud acquisition was 625 points/m2 (0.04 m linear distance between points), and the angular scanning resolution was 0.027°. On the south-facing slope the resolution was, 1,890 points/m2 (0.023 m) and the angular scanning resolution was 0.054°."

10. Section 2.3. We have slightly improved the explanation of the SfM photogrammetry method. Nevertheless we do not want to do a deep analysis of the generation process. We consider that are technical details which are high dependent on the software considered. Thereby we have introduced the details on the software only as users. Additionally, in the section which we consider more interesting for erosion community, the setup characteristics for the image acquisition is deeply described (Figure 3).

11. Page 344. L. 22. We have changed this sentence. Now it states: "which provided better 3D reconstruction than classical photogrammetry (James and Robson, 2012)"

12. Page 344. L. 22-24. We have changed this sentence following the reviewer's recommendations of plurals. .

13. Page 344. L. 25. We have changed this sentence following the recommendation.

14. Page 344. Lines 23-24. Yes, we have taken always the same number of photos and in the same positions. Why? We consider that is really important to obtain different images from all possible point of views. However, the number of pictures necessary could vary in each study, and we consider that it is really difficult to determine a minimum number of pictures (3 would be the minimum to generate a 3D model). So we consider that the number will depend on the occlusion, topography (complexity) and scale. A number between 10 and 100 is adequate to medium and high scales, when the study area was well represented in the image geometry. A different point that should be addressed is the constraint of computer memory. In our analyses it was a big problem because we cannot analysed a big number of pictures. We have used the

software Agisoft and our computer only have a memory of 12 Gb. However, there are different studies (e.g. Micheletti, Chandler and Lane, 2015b) that have carried out the analyses in similar areas and at the same scale, and they have obtained good models with 13 pictures. Due to your comments and the results in future surveys we will try to increase the number of images and in this way we can test the results and check if the models improve due to the number of images.

15. Page 345. Line 5-6. Yes. Thank you very much for your comment. We will try to improve the resolution and number of images and distance in future studies. Also this sentence now states: "...decreasing the distance between the camera and the feature of interest is related to increasing the spatial resolution of the photograph and will enhance the spatial density and resolution of the final point cloud (Westoby et al., 2012)."

16. Page 345. Line 13. Measuring ground control points with a DGPS or a total station, being quite accurate methods, increase uncertainties too. The expected errors on a global coordinate acquisition must be considered in the coordinate transformation process, which in planimetry may reach 10 cm. Hereby, in order to not include these possible deviations, no global coordinates have been considered. In such a way, the coordinates of ground control points in the coordinate system of TLS (not absolute coordinates, because the TLS do not has integrated GPS antenna) have been used for giving values to SfM point clouds. Reflectors placed in ground control points were selected in Agisoft software and their coordinates, directly obtained from the TLS, were introduced in this software. This way, the text now states: "Based on the target coordinates, a transformation matrix to a common coordinate system (which is named project coordinate system)using Riprofile 1.6.2 software is generated for the TLS point cloud. [....], the point cloud obtained from SfM photogrammetry is transformed onto the same coordinate system by a transformation matrix calculated in Agisoft Photoscan using the TLS-recorded target coordinates with standard deviation below 0.025 m.

17. Page 345. Line 16. We have included new references about TLS errors with same

device (Prokop, 2008). We consider this is important, even if one of the co-authors of this manuscript is cited, because this demonstrates, that this aspect is in accordance to other studies.

18. Page 345. Line 19. This value is the standard deviation in target coordinates positions when applying the translation-rotation matrix that transforms point cloud generated in Agisoft to the coordinate system of the TLS. Please, see response 15 to reviewer 1. In this point, it is discussed this error put in contrast to differences observed between DEM comparison of TLS and SfM.

19. Section 3. We have analysed the differences between the TLS and SfM model for the initial and final period. Two new figures have been created and added to the manuscript. Please, see response 3.3. page 348. to reviewer 1 and the new figures (Figures 8 and 9) added in the manuscript.

20. Section 4. We absolutely agree with reviewer opinion in this point: errors reported (standard deviations through the paper) in tables 2 and 3, makes that the absolute accuracies, needed to support such mean differences, are not enough. Thereby, we consider these differences as a tendency about what it happens in the slopes. For us, after the revision of our work, it is clear that both techniques are suitable for observing and measuring differences above two-three cm, but for smaller differences, the uncertainties of the method, are really difficult to measure. The error mentioned by the reviewer about old figure 7, was due to a deviation in the colour scale selection. We agree in this point with the reviewer, it seemed a systematic offset error. It has been corrected in the new TLS south-facing slope figure in the final manuscript version, with the improved blue-red colour scale.

21. Page 348. Line 15. We have changed "subcentimetre" accuracy to centimetre accuracy, which fits better with the obtained results.

22. Section 3 and 4. We have improved the processes presented and discussed, considering these suggestion. We have also added some photos to provide more

information on the study sites characteristics. Rill development is better observed in the south-facing slope due to the topographic characteristic of the selected slope. However, in the north-facing slope rill development is also observed (as you can see in the TLS figures).

23. Page 349. Line 28 and Page 350 line 1. These numbers are doing reference to the values presented on Table 2 and 3, and are correct (also the units).

24. Page 350. We consider that these erosion rates data have to be included. First in the introduction showing the high erosion rates recorded in badland areas and second in the discussion where we showed our data in comparison with other erosion rates recorded with different methods.

25. Page 350. Line 26-27. With the new analysis and new data we consider that we have provided more analysis to support this statement. Additionally this sentence now states: "Our study demonstrated that SfM delivers good accuracy and is really useful for field application in geomorphological and soil erosion studies, for observing changes in the centimeter scale (depending on the working distance)."

26. Page 350. Line 28. Page 351. Line 4. In SfM the highest number of photographs is desired for obtaining a higher point cloud resolution or quality of the generated DEM. This higher quality would be directly related with the capacity of the method for observing little differences in the terrain. It would be interesting too, to obtain pictures at different distances, to test if the distance is a really important factor in SfM, and in that case our models could be improved. In our study, due to illumination problems (terrain shadowing effects and also clouds presence or not in the different image acquisitions), large errors were observed in the point cloud generation process when considering pictures with different illumination. This made compulsory to discard these pictures and finally only consider these with the same illumination. This originated the relatively low number of images considered in this study.

27. P 351 L 5-6 and L 15: We have checked this sentence. We mean the surface model

computed from the TLS point clouds, not images of course. This has been corrected in the text.

28. Page 351. Lines 6-11. This is maybe the main limitation of TLS application and hereby has been included in method sections this sentence: TLS automatically obtains 3D point clouds, but with a main limitation, we have only work from a single scan position; if other scanning positions are not defined, it is quite expensive in time, problems in the sight shadowing would be present. "….However due to time restrictions we have worked with one single scan position causing the shadowing effect of terrain (the so-called sight shadowing), which do not enable to retrieve data from different areas of the site originating missing information. This missing information due to terrain curvature observed in some areas with the TLS (north-slope), is avoided with SfM photogrammetry because different points of view of the study area were easily acquired (see differences in Figures 9 and 10). Nevertheless, in the presented analyses, and data and also in the images that show point cloud differences, these shadow areas have been removed in SfM photogrammetry to consider exactly the same area with both methods.

29. Page 351. Line 20. We have deleted this statement to avoid misunderstanding.

30. Page 352. Line 19-20. It is a subjunctive tense. We consider that if we increased the images resolution our model would be improved too.

31. Page 352. Line 22. We have changed this sentence.

32. Figure 3. We have checked and improved these small mistakes.

33. Figure 5-8. We have improved the figures, changes the legend and labels Figures have been changed as suggested by reviewers, and a new scale more appropriate for such kind of maps has been included. Nevertheless some resolution has been lost, because we have realize that a transition band around zero (± 2.5cm). Please see comment 15 of reviewer 1, where these figures have been explained. Unfortunately

the software used in the study does not enable to change the background colour. Nevertheless, we consider that with the colour bar between red and blue with a white transition these accumulation areas are appropriately recognized.

34. Technical corrections a. We have changed i.e. for e.g. b. Page 340. Line 17. We have corrected the year for Walling. c. Page 341. Line 11. We have changed and corrected Barnhat and Crosby. d. Page 343. Line 16. We have changed this sentence. e. Table 1. Caption. We have changed "periods". f. Figure 1. We have changed the names in the X axis.

Anonymous Referee 3

We are really thankful to the nice comments and suggestion from anonymous reviewer 3. Most of them coincide with these suggested by the other reviewers and thereby in the previous response can be found most of these changes.

The paper now exploits better the obtained information, having been improved results and discussion sections being included new relevant references. A new comparison between both methods has been included for the annual period in the two slopes, doing the manuscript more robust, especially in the comparison between the two techniques.

1. We have included more references to discuss the advantages of the different techniques for this specific application. We have remarked the characteristics of humid badland areas topography to show the differences with other environments where these techniques have been applied.

2. Following the reviewer recommendation, we have changed the abstract to focus the study.

3. We have changed the term photogrammetry using Structure from Motion photogrammetry (SfM). Also we have differentiated between "traditional" photogrammetry and SfM to highlight new opportunities in data acquisition of SfM,

4. We have changed the sentence from previous manuscript version "P345 L6" . After

Reading different literature we have checked that distance is really important. However, we consider that the effect of distance is higher using TLS. So now it states: "The spatial resolution of the generated point clouds depends on the quality of the model processed with the images obtained with the camera. In this study, we used higher resolution modes, which provided a spatial resolution of 970 points/m2 for the north-facing slope and 2800 points/m2 for the south-facing slope. High resolution of original images offered better texture and resolution to find keypoints in the photoset. Similarly, decreasing the distance between the camera and the feature of interest is related to increasing the spatial resolution of the photograph and will enhance the spatial density and resolution of the final point cloud (Westoby et al., 2012)."

5. We have included the comparison between both techniques. Please see 3.3 Joint analysis section and the new figures included. Now it is stated: "Figures 9 and 10 showed a direct comparison of DEMs between techniques considering LiDAR (TLS) as the reference. Differences have been calculated for the first and last acquisition dates (23/07/13 and 23/07/14). Big differences occurred in small areas, where small vegetation patches were present (almost all vegetation was eliminated from the point clouds, but some influence can be appreciated in the exterior limits of the selected slopes). Small differences were observed in "deep" concavities (yellow colours in the comparison figures), because in these areas the SfM was not able to accurately reproduce a precise topography. Other errors were usually located in ridges, and the areas behind them, from the TLS perspective, showing one of the main TLS limitations: with only one point of view, some areas are hidden. Average differences (Table 4) were bigger in north-facing slopes in both surveys (also the highest standard deviation were recorded)."

6. Figures 5-8. We have improved the figures, labels and legend following reviewers recommendations.

We have tried to improve and go much into the analysis of geomorphological process understanding.

Finally, we remain at the disposal of the Managing Editor and the Anonymous Referees in terms of making additional changes and improvements to the manuscript. Thank you for your assistance and advice on how to improve our manuscript.

Yours faithfully,

Estela Nadal-Romero and co-authors

Please also note the supplement to this comment:
http://www.soil-discuss.net/2/C295/2015/soild-2-C295-2015-supplement.pdf

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Interactive comment on SOIL Discuss., 2, 337, 2015.