Reviewer comments

Author comments

Major comments

1) The reading flow is not easy to follow, due to (a) long descriptions of methods, which could be greatly shortened (in addition, a general scheme at the beginning of section 4 would certainly be very useful to explain your processing chain from L3B or L1B images), (b) part of the description of the results included in the figure legends, (c) (too) many descriptive figures (I think a better selection of figures should be made. For example, figures 5 do not add much to understanding and can be placed in the supplementary material. Figures 4 and 6 illustrate the same effect), (d) the method section also includes results.

(a) We have shortened the method description and restructured it according to the suggestions of Reviewer 2, moving the description of the orthorectification error into a separate section and the analysis of stable pairs into the supplement. However, we would like to emphasize that a clear description of the applied method allows to more easily reproduce the processing steps that were taken.

(b) We do believe it is important that figure captions re-iterate and emphasize key findings and results. This will greatly enhance the context and readability of figures. Acknowledging your feedback, we have shortened figure captions in the result section including the previous Figure 12 (now Figure 10) and Figure 15 (now Figure 14).

(c) Previous Figures 5 and 7 have been moved to the supplementary material. We kept Figures 4 and 6 (now 4 and 5). Yes, they illustrate the same effect, but one figure is conceptional, the other shows real data and we feel it is important to demonstrate this to the reader. In accordance with Reviewer 2, we have added a sketch of the acquisition geometry to Figure 5 that allows to better link the figures.

(d) We have moved our analysis of the stable pair across the Siguas site to the supplementary material, and we agree that these are results. These show an experimental analysis to quantify the orthorectification error and do not match well with the presented results. This has further shortened the method section, and the section is now easier to follow.

2) The validation of the results is not really quantitative. Statistics should at least be provided to show the improvement of the different steps, for all sets of images. Here, a single histogram is shown for a correlation between 2 images (Figure 14). Why not extract a statistic (SD for example) from this histogram and compare it for the different steps for all pairs?

In addition, you could provide more quantitative validation by comparing your results with field measurements, which exist at least on the Siguas landslide (Lacroix et al., 2019).

To add a more quantitative assessment of our analysis, we have replaced the histograms shown in the initial manuscript by a scatter plot that shows the IQR across stable terrain where the landslide area was masked. This plot shows the offset before and after the application of the polynomial fit for all correlation pairs (n= 88 at the Siguas landslide and n=106 for Del Medio). We kept the histogram representation of the disparities before and after the correction, because it shows the shift of the entire distribution, but added them as a third column to the previous Figures 11 (now 9) and S5.

We have looked at the field measurements at the Siguas landslide, but we do not think that they complement our manuscript in a meaningful way because:

(a) the data presented by Lacroix et al., 2019 were acquired between November 2015 and May 2017. Earliest PlanetScope data is available from late 2016, so there is a temporal overlap of merely a few months.
(b) the current manuscript focuses on data acquired by the newer PlanetScope PSB.SD instruments which were not in orbit at the time the field measurements were taken. To compare velocity estimates to the GNSS data, we would have to work with data acquired by the older Dove-C (PS2) instruments, which were decommissioned in April 2022. Even though these data also suffer from orthorectification errors, a validation of will not be fully transferable to the newer sensors.
(c) In extending our quantitative analysis to include all pairs, and basing our assessment on the displacement over stable terrain, we adopt a validation approach widely recognized and utilized in other studies, such as Lacroix et al. 2023 and thus consider this as a robust alternative to field data comparisons.

3) The authors use 2 different processing approaches to extract displacement fields, using L3B or L1B images. I think there is a lack of clear discussion on which of these 2 approaches is more efficient. This discussion should be based on a more quantitative assessment of the errors on each of the processed pairs (see my previous comment). For me, this discussion should also include a systematic analysis (for all pairs) of subframe misalignment errors. The authors claim that they are reduced in the latest acquisitions. Could the author clarify why they have come to this conclusion, and when this improvement was made?

We have added a new section to the discussion titled “Comparison of L1B and L3B approaches”, evaluating the different methods. We have not included a systematic analysis of sub-frame misalignment. Scenes with severe striping were excluded from the analyses presented in our manuscript. We have looked at generating robust methods to differentiate subtle and largely unpredictable striping patterns with smooth transitions from other co-registration errors in a quantitative way, but this is difficult due to the wide range of effects and errors. We cannot pinpoint a date when the improvement of the subframe misalignment was made, however, we observe that severe striping, as visible in Figure 3 D or Supplementary Figure S1, is most common among acquisitions made by the earliest PSB.SD Doves in the beginning of 2020.

Detailed comments

L15: "geoscientific": I would rather say "geomorphic".

Changed.

L36-37: "landslides are prone to orthorectification errors": It would be useful to quantify this orthorectification error. I suggest reviewing all the uncertainties associated with the use of PlanetScope data for landslide studies (Bradley et al. 2019; Mazzanti et al. 2020; Dille et al., 2021; Amici et al., 2022; Lacroix et al., 2023, ...).

We acknowledge the importance of quantifying orthorectification errors in landslide studies. Our detailed justification of why landslides are susceptible to orthorectification errors is presented in Section 3.1.1. The studies that are listed by the reviewer mostly do not consider the influence of orthorectification errors on their uncertainties, so we do not think a review of the presented uncertainties is very suitable to support that statement. We are aware that landslides with minor elevation changes compared to Siguas and Del Medio landslides will show a much lower impact from orthorectification errors. In the revised manuscript, we have therefore specified that landslides orthorectification errors are common for landslides with relief that have significantly altered the landscape over time:

Before: … landslides are prone to orthorectification errors …

Now: … landslides that have significantly altered the landscape over time are prone to orthorectification errors …

L75: It would be interesting if you also mentioned that monitoring already exists on the Siguas landslides, which could be used to validate your results (Lacroix et al., 2019). See my main comment no. 1.

See our reply to main comment no. 2.

2.1: Are there independent estimates of the speed of the Del Medio landslide?

No, unfortunately not, but we are in the process of setting up GNSS stations in the area.

Figure 1: As things stand, the black and blue lines mentioned in the legend are difficult to see. Is there any real point in showing the road network?

We have changed the catchment divide between the Central Andes and the foreland region to white. We keep the road network in the figure, because it shows important aspects of the infrastructural network and allows to identify the geographic location of the landslides.

L110: "NIR measurements are stored at the green pixels of the RGB Bayer-mask (Planet, 2022a). "This is not clear. Besides, is there any point in knowing this information? In general, I think authors should simplify their text to make it easier to read (see my main comment No. 1).

We have removed that sentence.

L114: "NIR band is captured at a different time": Can you specify what the timeframe is?

When the consecutive frame is captured, so approximately 1-2 seconds. We have replaced "different time" with "a few seconds later" to make that clear.

Figure 3: This is a nice figure to show the different errors. I would simply reverse the order of the legend so that it corresponds to the order of the sub-figures: (1) DEM error (A), (2) striping errors (B, C, D), (3) overall shifts between scenes (C, A), (4) stereoscopic errors (D).

We re-organised Figure 3 to fit the order in which the different errors are presented in the text: (1) orthorectification error, (2) stereoscopic effects, (3) global shift and ramp errors, (4) stripes. We also picked new examples that highlight each error individually.

L155-156: It should be noted that the error associated with a global offset is classically corrected for slow slide studies using PlanetScope, which significantly reduces the errors (see also my comment on the uncertainty associated with PlanetScope images of slow slides l36-37).

We added that in the section on previous approaches improving the co-registration accuracy:

Lines 191-194: The proposed mitigation strategies include registering PlanetScope scenes to high-resolution reference imagery (Dille et al., 2021), subtracting the median displacement estimated over stable terrain (Lacroix et al., 2023), both of which efficiently remove global shifts, and the fitting of polynomials (Kääb et al., 2017, 2019; Feng et al., 2019).

L240: L1B images are also available in clipped format.

To the best of our knowledge, they are not. We have been in contact with the Planet Support particularly about this issue and they pointed us to this article: Why isn't the clip tool available for a basic scene in Planet Explorer?

Figure 5: «Scenes acquired from an opposite view direction at high view angles are strongest affected by orthorectification errors.» Opposite view direction to what? why should orthorectification errors be stronger with some specific viewing angles? This sentence is not clear.

Opposite of each other, i.e. a left- and right-looking satellite at 5° off-nadir. However, for clarity reasons, we have removed this sentence from the figure description to focus on the acquisition parameters only.

Furthermore, Figure 5 may not be necessary to understand the study. In fact, it is mentioned only once in the text. Could you place this figure in the supplements?

We placed Figure 5 in the Supplementary Material.

Lines 250-287: This section can really be reduced. Figure 4 illustrates this well. I also wonder if this section should not be mixed with section 3.1, when the effect of orthorectification errors is illustrated in figure 2. In this section, you do not propose a method for reducing this error, but you do illustrate it. In my opinion, it should not be included in the "data and methods section".

We greatly streamlined the description of the orthorectification error and included it in section 3.1 as suggested.

Reorganisation: Lines 288 to 313: I get the impression that this section is a bit vague and that the flow is not easy to follow because it's a mixture of methods and results. If I understand you correctly, you identify the acquisition parameter that allows you to form pairs and reduce uncertainties while correlating them. I have the impression that you could state this much more clearly and separate the methods from the application to the data. The choice of figures also makes things less easy to follow: Figure 6 is closely related to Figure 4 in terms of illustrating the problem (perhaps one of the two figures could be placed in the supplementary material?) Figure 7 is an application of the methods that shows the important effect of the actual azimuth of observation. Figure 8 shows your results once the groups have been created.

This section has been greatly restructured. We have moved our analysis of the relationship between orthorectification error and true view angle difference on the basis of short temporal baseline pairs across the Siguas landslide to the Supplementary Material along with former Figure 7. The description of the orthorectification errors was relocated from the method section to section 3.1.1 describing the spatial patterns of orthorectification errors in PlanetScope data. We would like to show both Figures 4 and 6 (now 4 and 5), as we think the conceptual sketch is instructive, but it is also necessary to see the effect in actual data.

In the same section, it is not clear, once your pairs are created, how you will use them to create a time series of movements. In fact, there is no possible relationship between the different groups of images. How do you put them back together? I have the impression that a general diagram at the beginning of section 4 would be useful to explain your processing chain based on images L3B or L1B.

While no correlation pairs are formed between images from different groups, the results are still spatially related. Given the ~2-pixel geolocation accuracy, measurements from different disparity maps may exhibit an offset of approximately 6 m. However, for landslides spanning several hundred meters in diameter, neighboring pixels are likely to exhibit similar movement patterns. The key is ensuring the offset estimation for a given pixel is reliable which is achieved by reducing orthorectification errors and other factors affecting co-registration precision.

We have significantly restructured our method section for enhanced clarity and therefore do not see the need for a general diagram, especially considering the feedback about too many conceptual figures. If in doubt, our workflow is clearly documented in our accompanying GitHub repository.

Line 375: I have the impression that the method you describe has already been described and used by Berthier et al (2007). You can certainly simplify your text by refering to it.

We read the Berthier et al. 2007 paper and their approach is to minimize the standard deviation of the difference between the two DEMs outside glaciated regions, while we minimize the sum of displacement between pixel correspondences when projected from one image to the other using the PlanetScope DEM at a given position. We have, however, further simplified the text in order to shorten this section.

Line 394: MPIC-OPT is not strictly a correlator but a processing chain that does more than correlate. The correlator behind MPIC-OPT is Mic-Mac (Rupnik et al., 2017).

Thank you for clarifying that. We have included the reference to Mic-Mac in the revised manuscript.

Line 399: Why do you use 35x35 pixel windows? Did you do several trials before choosing?

Yes, we have experimented with several window sizes and matching algorithms. Results within a ± 10 pixel range are comparable at the study sites. Smaller windows generally produce noisier disparity maps, but can better capture large magnitude displacements and spatial variability. As both the Siguas and the Del Medio landslide are slow-moving targets, we preferred to use a larger correlation kernel to reduce noise and obtain smoother displacement estimates.

Line 399: I would also delete "slightly larger correlation".

We removed that.

Figure 11: There is no reference to sub-graphs C and D.

Thank you for noting that. We now reference the entire figure in line 335.

Line 417: You mention striping effect due to the misalignment of the subplots, but I assume that your polynomial (line 420) does not correct this effect. How effective is your polynomia at correcting other artefacts when you have such effects?

That is true – stripes are not corrected for by the polynomial fit. We have restructured our method section to make clear which approach is used to correct for what pattern of co-registration error. Scenes that show severe striping in the derived disparity maps were sorted out (see section 4.5). If slight striping is still present, the polynomial fit still is very efficient in eliminating other effects, as visible in former Figure 11 (now Figure 9) in the dy component.

Line 435: The speed of the landslide may vary over time, but you are assuming here that the speed is constant over the period in question. This needs to be made clear. In fact, you mention this transient in the caption to Figure 12. This assumption could be verified by comparing satellite measurements with field data. These validation data are available on the Siguas landslide (Lacroix et al., 2019). See also my following comment on the results validation.

Yes, we address this in the discussion (section 6.1), but have clarified that the offset is averaged over the time that lies between the acquisition of first and secondary image:

Lines 441-442: It is important to note that the offset estimates obtained from correlating two images captured at different points in time represent an average offset over that time span. The velocity is therefore assumed to be constant over the considered period. The actual displacement may occur more abruptly …

By the way, your Figure 13 seems to show that the standard deviation of velocity is significantly reduced when using manually orthorectified 1B products compared to correlating 3B products from the same group. To me, this means that the higher standard deviation observed on the landslide in Figure 12 does not come from transient motion but rather from orthorectification errors in the 3B products, even if you select the pairs. Can you comment on this point?

Yes, the strong reduction of standard deviation shown in Former Figure 13 (now 11) is related to the reduction of orthorectification errors as the L1B images are mapprojected using an updated reference surface. This is our motivation for the proposed correction approach. The transient offset is only responsible for the slightly elevated standard deviation at the lower part of the Siguas landslide in groups 1-3, see lines 379 to 382:

“Slightly higher standard deviations for groups 1-3 at the landslide toe are likely related to transient changes in velocity. In contrast, when PlanetScope scenes are selected randomly (group 4), variations in view angle and satellite azimuth, combined with outdated DEM surfaces used for orthorectification, result in misprojections over the landslide surface.”

Line 436: remove an "only".

Done.

Figure 15: I don't quite understand how you obtain these time series. I understand that you correlate either the L1B data from the same group or the L3B data from group 4, but do you correlate them all within each group or do you only correlate those that are separated by the shortest time to see the transients?

We correlate only within a group and here we correlate all pairs that have a minimum time difference of 180 days to ensure that enough displacement has accumulated to reach the detection limit. Consequently, the data points indicate the average displacement across variable time scales. To get individual time steps, an inversion approach such as SBAS could have been applied. We are currently working on a separate manuscript that evaluates the inversion approaches for optical data. This is a different topic and beyond the scope of this work.

Line 541 : The correct reference is Lacroix et al., 2019 not 2015

Corrected.

Line 550-553 : Are you removing the low quality pixels from the « good pixel map » ? In this case it should highly remove the changes in soil occupation, and therefore the errors. Are you not sure that the higher standard deviation with time in the Siguas case study is not caused by the motion of the landslide that occupies a quite important area of the image ?

Yes, we always remove the low quality matches using the “good pixel mask”. This does remove a large portion of the high-offset pixels within the agricultural areas towards the NW of the study area, but not all of them. To be absolutely sure that the higher standard deviations are not related to the landslide, we reran the analysis and masked the landslide, so that statistics were only calculated across stable terrain.

Rather than a hypothetic section on the «Transferability to other regions and targets», I would have rather see a discussion on which of the L1B or L3B processing should we use (See my major comment n°3). From the Figures you show, manually orthorectified L1B sounds more efficient, except for the sub-frames alignment. However it lacks this analysis for all the scenes processed. Furthermore, is the sub-frame alignment really better now ?

We would like to keep the section on transferability to other regions and targets in the main manuscript as we believe it is important to readers. Nevertheless, we have added an additional section, titled “Comparison of L1B and L3B approaches” (see above), where we discuss advantages and drawbacks of both approaches.

Figure 15 and lines 610-612 : Can you explain how you obtain the shown uncertainties and add uncertainties on your velocity estimations ?

In the initial manuscript, the uncertainties presented in Figure 15 (now 14) were based on the standard deviation of all pixel values within the landslide area. However, given the frequent use of displacement across stable terrain as a quality metric, we have reevaluated these uncertainties. The data points still reflect the mean velocity inside the landslide area, while the uncertainties represent the mean velocity across stable terrain (areas outside the landslide mask). We have also updated Figure 14 in the regard that we no longer separate the Siguas landslide into head and toe regions. To emphasize the spatial variability of velocity across the landslide, we instead incorporated a map view in Figure 14 A, showcasing the average velocity derived from all correlation pairs within the landslide mask.

The updated Figure 15 (now 14) is shown below: