We thank the reviewer for the very helpful and relevant comments. Our responses are below in black.

Reviewer 1

Specific comments

The title could be made more informative by including mention of shadows. When I first read it I expected seasonal biases to also discuss things such as the effect of seasonal snow, but this isn't included.

We thank the reviewer for this suggestion. We reworded the title: "Seasonal biases induced by illumination changes and shadow casting in remote sensing derived glacier flow velocities" . We also added precision in the abstract : « In the meantime, systematic seasonal errors (i.e. biases) induced **by illumination changes and shadow casting** have been reported in time series derived from optical imagery on various land forms, such as landslides or dunes. »

L19: I'm unclear as to what this sentence is referring to: '*the measured velocities still reflect shadow tracking in areas affected by shadow casting*'. In particular, is this reflecting to errors computed over static areas, or over moving glaciers? Please clarify.

We thank the reviewer for his feedback, and clarify the sentence: « However, the measured velocities still reflect shadow tracking, **rather than actual terrain motion**, in areas affected by shadow casting. »

L23: change 'evidences' to 'evidence'

We have corrected this point in the text.

L27: should make it clear here that it's the resolution of newly available optical and SAR satellite imagery that's important (i.e., high enough to detect glacier motion over short timescales), in addition to the number of images and their repeat cycle

We thank the reviewer and have added some information: « Since the 2010s, the increasing number of optical and SAR satellites with a short repeat cycle (~5 days) and **high spatial sampling (~10 m)** has facilitated measurements of glacier surface flow velocities on sub-annual time scales »

L43: It may also be useful to mention that there are inherent biases in the availability of glacier velocity data based on the sensor used: e.g., SAR imagery is best for winter imagery and accumulation areas; optical imagery is best for summer imagery and ablation areas.

We thank the reviewer for this suggestion. This point is discussed in L316.

L57: would be useful to include a map of your study area which shows the locations you refer to in the text (e.g., Argentiere Glacier, Bossons Glacier), and highlights some of the features (e.g., steep slopes, shadowing, location of GNSS antenna). An inset photo of Argentiere Glacier might also be useful to include to show the steepness of the surrounding topography. Fig. A2 could provide a good starting point for this, but with more information included.

We thank the reviewer for this suggestion. We have added a map of our study area showing the location of the GNSS antenna and the name of the glaciers we are referring in the text, on top of a hillshade. Shadows can be seen in Fig B5. We removed Fig A2 to avoid duplicated information.

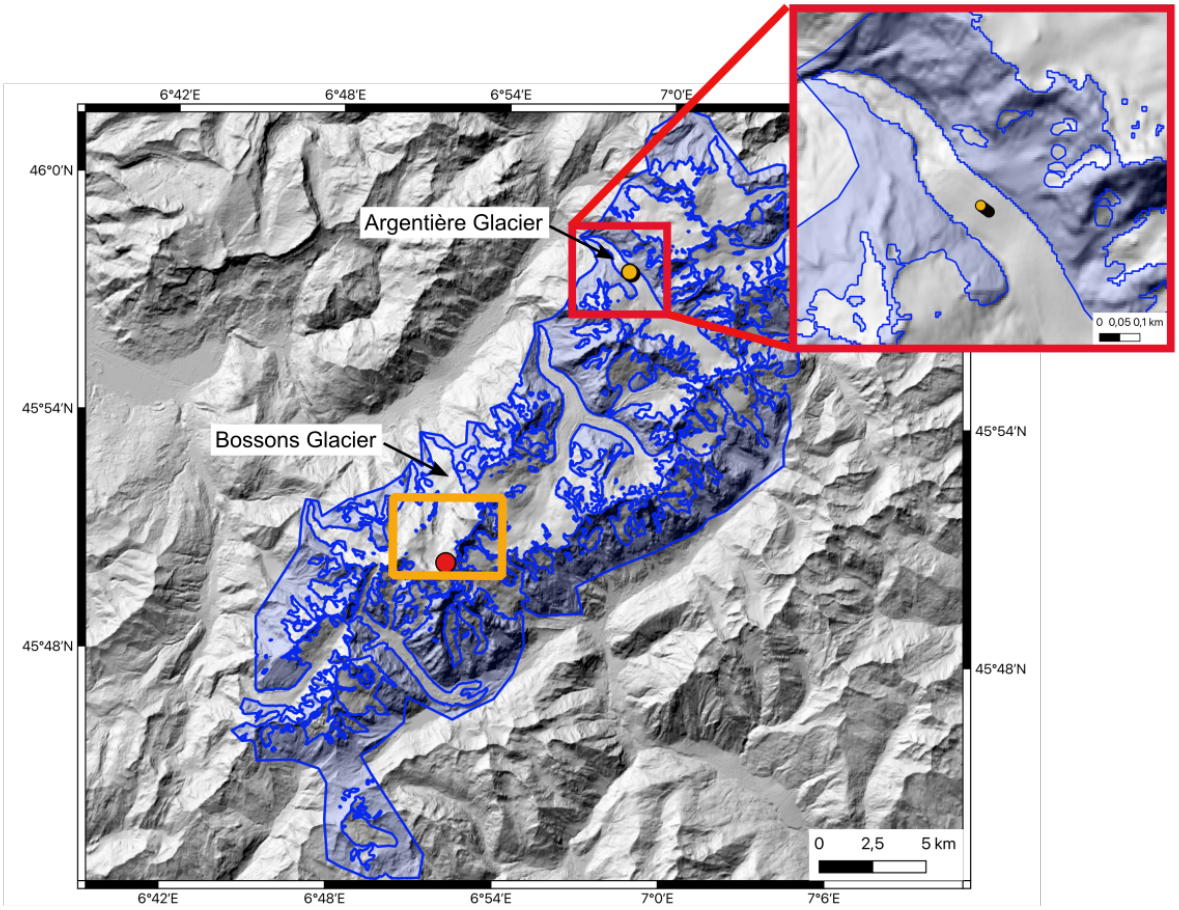

Figure 1 Study area of the Mont-Blanc Massif. The static areas used to estimate the seasonal bias are represented in transparent blue. The Arg1 GNSS station on Argentière Glacier tongue is represented with yellow dots (the station moved ~130 m over the 3 years period). The area covered by Fig. C4 is represented by a yellow rectangle. The point considered in Fig. 7 is represented in red. It is located at (6.86759°E, 45.83930°N) over the accumulation area of the Bossons Glacier. The projection of the map is EPSG:32632 and the displayed coordinates are in EPSG:4326.

L119: I think this should read: 'focus only on the seasonal variations **in section** 4.1'?

Thanks for noticing this point. We corrected it.

L147: change to 'by **an** exponential decay"

Thanks for noticing this point. We corrected it.

L158: add am to the time here (10:30 am) to avoid any ambiguity, and to be consistent with the format used on L168. Also check for similar issues elsewhere (e.g., L109)

Corrected

L158: you state here that 10:30 local time corresponds to the time of acquisition of Sentinel-2 images. However, L109 states that Sentinel-2 acquisitions occur at 10:30 UTC, which is 2 hrs behind local time in France in the summer and 1 hr behind local time in the winter. These statements therefore need to be corrected, and/or the shadow calculations need to be redone to match up with the actual Sentinel-2 acquisition time.

We thank the reviewer for this careful check. Sentinel-2 and Landsat-8/9 images are acquired at 10:30 and 10:00 **Mean** Local **Solar T**ime (MLST) (Copernicus, 2015). MLST are the hour angle of the mean position of the Sun, plus 12 hours. MLST can be converted to UTC using a longitude correction. For the Mont-Blanc Massif 10:30 am MLST corresponds to 10:02 am UTC, and 10:00 am MLST to 9:32 UTC.

The HORAYZON package used to simulate shadow cast takes as input hours in UTC. Therefore, we computed the shadow mask for 10:00 am UTC to check if there was any significant difference with our previous results.

While doing that, we realized that an update in the HORAYZON package corrected some artefacts around the crest in the study area. This end up in slightly different results. On Figure 2 below, are the updated results at 10:30 am UTC on the left, and the updated results at 10:00 am UTC on the right.

We can see that the trend remains really similar: there is still linear correlation between the number of days under shadow extent and edges and the velocity magnitude amplitude.

To be as rigorous as possible, we updated Figure 4 with the graphics at 10:00 UTC. We also updated Figure B5 (now C1) with the new shadow maps. We modified the method section, now line 159: "To map areas affected by shadow casting, we simulate shadows projected by the Copernicus 30 m DEM every day at 10:30 am MLST, corresponding to the hour of acquisition of Sentinel-2 images (ESA, 2024), for one arbitrary year (here 2024). For that, we use the package horayzon which takes as

input hours in UTC (Steger et al., 2022). Therefore, we converted MLST to UTC using a longitude correction: 10:30 am MLST corresponds to 10:02 am UTC."

We also modified line 109 to: "Note that Sentinel-2 and Landsat-8/9 images are acquired at 10:30 am and 10:00 am **Mean Local Solar Time (MLST)**."

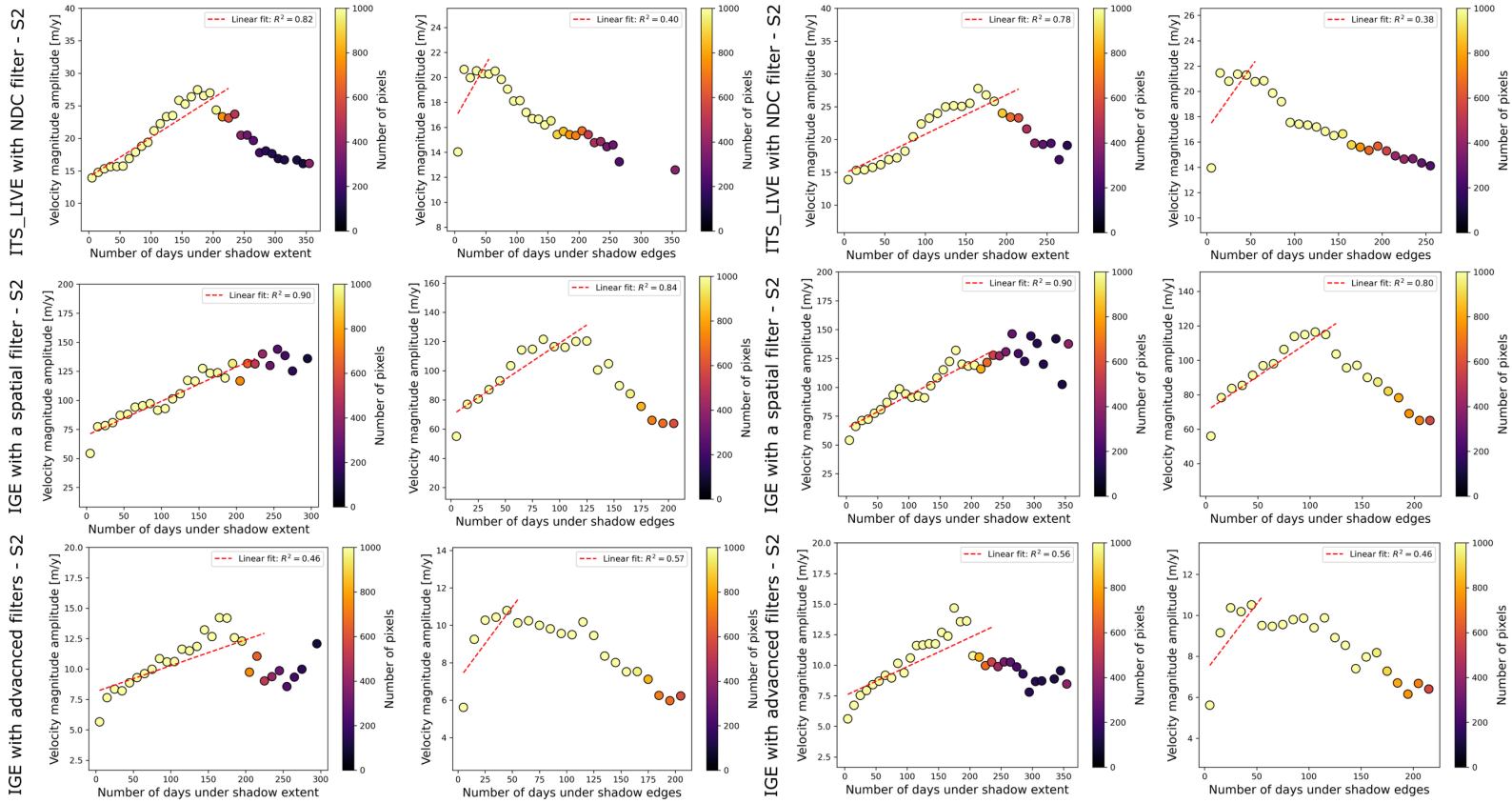

Figure 2 Comparison between shadow simulation at 10:30 UTC (left) and 10:00 (right)

Reference: Copernicus (2015). Sentinel-2 User Handbook. European Space Agency. https://sentinels.copernicus.eu/documents/247904/685211/Sentinel-2_User_Handbook

L223: provides units for 29 and 55 (presumably m yr^{-1}?)

Corrected

L251: change 'shadow extend' to 'shadow extent'

Corrected

Fig. 5 caption: I don't know what this is referring to: "Shadow casting is illustrated on two Sentinel-2 images in Fig. 5". Perhaps the reference here is meant to be to Fig. B7?

We thank the reviewer for noticing that, that's correct.

L294/5: this needs a bit more explanation as to exactly what role the DEM co-registration played in the Provost (2025) study of Aletsch Glacier

We added one more sentence: « geometric refinement of the DEM used to co-register the optical images may also play a role, as described by (Provost et al, 2025) They noticed strong seasonal displacement over the Aletsch Glacier before summer 2021, and much smaller displacements afterwards for the same pixel**. This may be due to a geometric refinement with the Copernicus DEM after summer 2021**. »

L298: I find this entire section 4.4 awkwardly worded and difficult to follow (additional comments are below). The sentences and thoughts seem to be disconnected from each other, and I can't tell what exactly you've done compared to what you're proposing to do, and how this relates to the findings of your study. Please reword/clarify this section!

We thank the reviewer for this feedback, and have clarified as much as possible this section.

L299: this sentence reads like an incomplete thought. Do you actually implement what you propose here? Needs better explanation.

Reworded as: « We propose a strategy to mitigate the effects of shadows and illumination changes in two steps: (1) the mapping of areas affected by shadow casting and (2) the estimation of seasonal biases over glacier areas. The methodology is implemented in a Python package called "SeBVel" for Seasonal Biases in Velocity measurements. »

L302: I don't understand why Combe Maudite is specifically mentioned here, when it isn't mentioned anywhere else in the manuscript.

We thank the reviewer for this remark. We put example of Combe Maudite to show that shadow casting effect is not restricted to the accumulation part of Bossons Glacier. We clarified the location of Combe Maudite in the manuscript: "For example, some areas affected by shadow casting, such as the upper part of the Bossons Glacier or the Combe Maudite in the accumulation zone of the Mer de Glace (red point and green rectangle respecively in Fig. C1) were not excluded from the study of Troilo et al. (2024), despite manual mapping of areas affected by shadow casting "

L307: this is a weird way to start a paragraph. Does the first sentence connect to the previous paragraph? The second sentence says that you propose something, but I can't tell whether you actually implement this.

We thanks the reviewer for this feedback. We reworded L301 (now L331) as: "First, SeBVel enables the user to automatically map shadows because this is not

straightforward to do manually.". Then, we reworded L307 (now L338) as : « Second, we propose to estimate the amplitude of the expected seasonal bias. For that, we rely on the derived seasonal amplitude over static areas, as explained in section 3.2. »

L319: it seems that you've forgotten to provide any reference to Fig. 8 in this section, which is important to understand what's being referred to. This section 5 also needs expanding to much better explain your methods and input data sources for computing the stated seasonal biases. Some of this information is included in the caption for Fig. 8 (e.g., that you used ITS_LIVE image-pair velocities), but this also needs to be in the main text.

We thank the reviewer, and added a reference to Figure 8 in the text. We also added more information in the text: "We apply the same methodology described in Section 3.3.1 on ITS_LIVE image-pair velocities to infer the seasonal velocity amplitude and peak over both static and moving areas. » « Over the range of static areas represented in blue in Figure 10, velocity peaks in spring and/or autumn for both site »

Fig. 8: I have a few significant concerns about this figure (not helped by the fact that the methodology to produce it is not properly described – see previous comment):

- I don't understand why only the y component of the velocity is plotted, when this likely isn't the only direction in which the ice is flowing. This is also inconsistent with the earlier velocity plots, in which the absolute magnitude is plotted

We thank the reviewer for this comment. Seasonal amplitudes are retrieved for each of the velocity component because velocity magnitudes follow a Rice distribution which could lead to an overestimation of the seasonal bias, see on Figure 3 below a comparison on the static areas near Kaskawulsh and Issungata Sermia glaciers. We plot velocity magnitude only for the Figure 2 because we did not notice significant differences. We added some explanation in the manuscript l. 221.

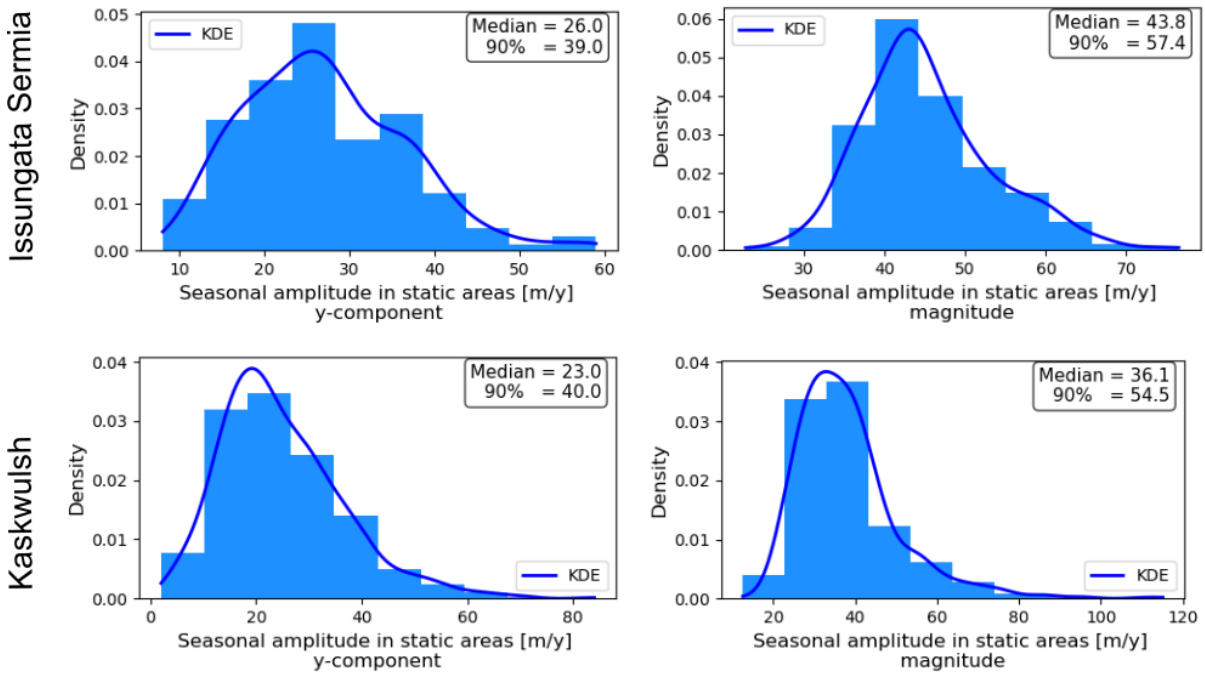

Figure 3 Seasonal amplitude over static areas

- the axes on the satellite image of Kaskawulsh Glacier are flipped, so that north is showing on the x-axis and west on the y-axis. Please change to the correct orientation.

Corrected. We put both Kaskawulsh and Russel in UTM projection.

- the area in the blue box used to identify the static area for Kaskawulsh Glacier is significantly steeper than the orange point on the glacier surface. The glacier has a low surface slope near its terminus, so a similarly low slope area should be chosen for the static area comparison

We thank the reviewer for highlighting this point which was not clear in the manuscript. We have masked out the areas in blue rectangle which are outside the range of slopes [0 :30°] and the range of aspects [0,90°]. This corresponds to the bins used in section 4.4 to interpolate the seasonal bias.

Here is the histogram of slopes and aspects used for Kaskawulsh:

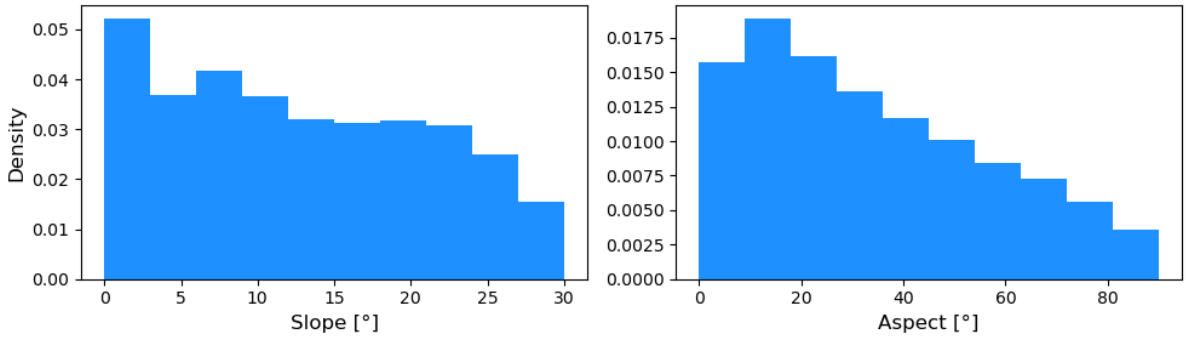

Figure 4 Distribution of slope and aspect of static areas

We have clarified this point in the manuscript by displaying the areas of similar slope and aspect used for estimated the histogram over static areas.

- there is long-term in situ GNSS data available for the terminus of Kaskawulsh Glacier (e.g., see Fig. 6a in Charrier et al. (2025): https://tc.copernicus.org/articles/19/4555/2025/), so the arguments about the potential influence of shadowing would be much stronger if this was included in the comparison

As a preliminary analysis, we compared each of the ITS_LIVE image-pair velocity magnitude to the GNSS data on the Lower GNSS station of Kaskawulsh Glacier [Figure 5 below]. Here for simplicity, we neglected the temporal baseline and assumed that each velocity observation corresponds to one date: the central date. We stacked the difference between the image-pair velocity and the GNSS, i.e., the errors, by day of the year. Then, we compute a rolling median with a window of 30 days. The errors seem to follow a seasonal behaviour. Two modes are visible: one around day 120 to 150 of the year, and the other one around day 250 to 300 of the year. This is consistent with the seasonal bias identified in the paper. However, our analysis is simplistic and a more rigorous approach should also take into account the temporal baselines and should be extended to a larger number of GNSS stations to be more robust. Considering the number of pages and figures of the paper, and the fact that this analysis misses maturity, we decided to include this figure in the supplement only.

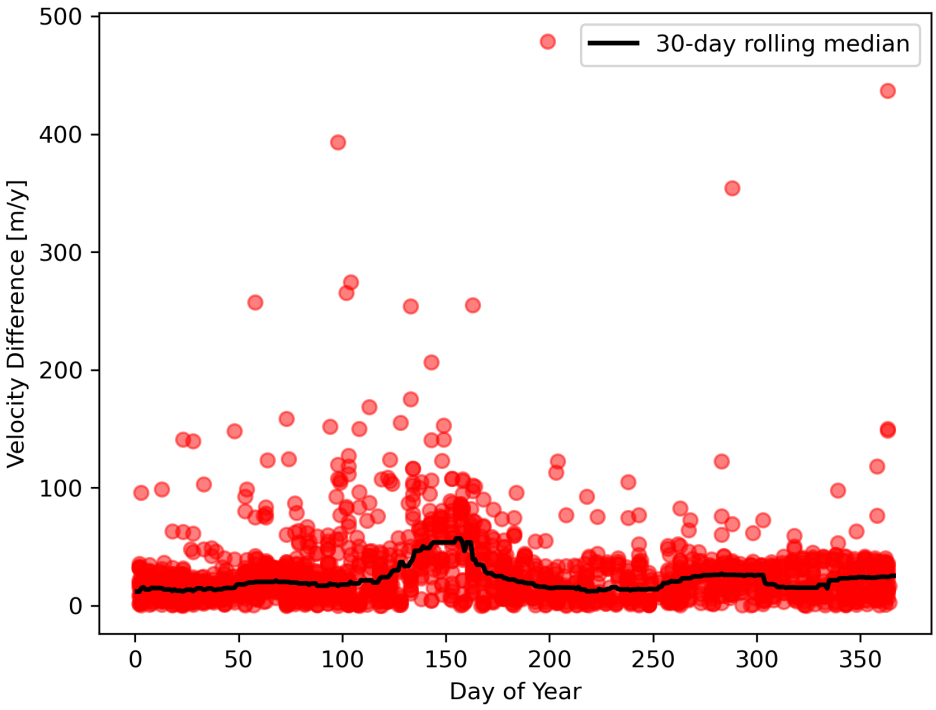

Figure 5 Difference between the velocity magnitude of GNSS and ITS_LIVE image-pair velocities

- change west labels from O to W.

Corrected

Fig. B4 caption: state that the blue dot is on Bossons Glacier

Corrected

Fig. B7 caption: state that the point is on Bossons Glacier

Corrected