Reply on Referee Comment 2: A modeling methodology to study the tributary-junction alluvial fan connectivity during a debris flow event

November 2021

We thank the reviewer for his time in commenting on our paper. In this document, we answer his comments. For clarity, the reviewer's comments are in black, while our answers are in blue.

1 Minor comments

1. Throughout, the authors use the term "telescopic-like" to describe the sediment deposits and landforms they are observing. While this term provides an approximate visual intuition, I think the authors could come up with something more precise to capture this.

The term "telescopic-like" deposit has been used for a long time (Blissenbach, 1954). Colombo (2005) provided a thorough analysis of tributary-junction alluvial fan's geometry in the Argentine Andean Ranges. The alluvial fans described by this author have similar geometry to Crucecita Alta. Colombo (2005) concludes that these telescopic-like deposit morphologies (terraced morphologies) are not associated with regional base levels, tectonic activity, or climatic changes. Instead, the genesis of the telescopic-like morphologies can be explained by the El Niño Southern Oscillation (ENSO). Furthermore, Cabré et al. (2020) characterized the role of telescopic-like deposits in the coupling mechanisms between alluvial fans and the trunk valley. Changes in the surges rheology, for example, produce a shift in the alluvial fan's coupling status from buffers to couplers that allow the transmission of sediment down-system.

We decided to keep the term "telescopic-like" due to their geometric and sedimentological significance (Colombo, 2005; Cabré et al., 2020).

2. Throughout, the authors italicize place names like Crucecita Alta, etc. If this is the journal's style, then so be it, but this is a strange convention that I don't care for.

We thank the reviewer's comment. According to the NHESS house standards, foreign words are italicized, but this does not apply to proper nouns. We will correct this in the manuscript.

3. Several times, the authors refer to "low-frequency, high-magnitude" debris flow events, but no reference values are given. Does low-frequency mean once a decade or once a century? It would be better to be specific here, and talk about the time-scales and magnitudes in dimensional terms that the reader can put in context (example at line 84).

We thank the reviewer's comment. We will add the following analysis in the Study Area section:

It is complicated to assert a specific recurrence interval for these events due to the lack of data. However, there has been a consensus that storms like the 25M event in the Atacama Desert occur once a century (Ortega et al., 2019). Thus, we considered a "low-frequency" event as an event that occurs, on average, once a century. About the magnitude of the event, Aguilar et al. (2020) estimated the mean erosion rate of the Huasco basin during the 25M event equal to 1.3 mm for the entire catchment. On the other hand, Aguilar et al. (2014) estimated erosion rates of $0.03 - 0.08\, mm\, yr^{-1}$ during the last $6 - 10\, Myr$ for the same catchment. Considering that an event such as the 25M event occurs once a century, we can say that the 25M event has a "high-magnitude" because this single event contributed 15% up to 40% of the total eroded volume every one hundred years.

4. The location for this field location is not clear from the manuscript as written. The authors give the location only as "$\sim 29°S, 70°W$" which is very imprecise. I was eventually able to locate the fan in question by cross-referencing the figures in Cabré et al. 2020 (Progress in Physical Geography: Earth and Environment). The fan is located at: $(28.895569°S, 70.449925°W)$. The authors should give this more precise location so that folks can locate this field site and look at aerial imagery in Google Earth, etc.

We have added the specific location suggested by the reviewer to the Figure 1 caption. Also, we changed all our maps from UTM coordinates to lat-log coordinates so anyone can find the place of the alluvial fan without knowing the UTM zone.

5. The authors discuss "sediment connectivity" at several points, but it is not *entirely* clear to me what they mean by this. Do they simply mean that sediment flows from the fan into the river? If so, it is important to talk about the time scale over which this is evaluated. In a mountainous catchment like this, the river will transport all of the sediment in the fan over geologic time (10s of thousands of years), so the fan is simply a temporary sediment storage place. However, if the authors are speaking only about short time-scales, then the connectivity is related to (a) how much sediment can bypass the fan and move directly into the river, plus (b) the amount of sediment the river can scavenge from the fan toe. I might recommend choosing a different term, because it sounds to me more like the authors are evaluating how much the sediment is "partitioned" between the topset of the fan versus how much spills into, and is carried away by the river.

This study captures how a fan-river system evolves during a single storm event. The time scale in which this study focuses corresponds to the length of the 25M event, i.e., $\sim$ 48 - 72 h. About the spatial scale, it corresponds to a specific tributary-junction alluvial fan. Tributary-junction alluvial fans have a spatial scale around $10^1 - 10^3\ m$ (Mather et al., 2017). The development of the "sediment connectivity" characteristics in this time scale ($\sim$ days) has been studied in multiple studies (Aguilar et al., 2020; Cabré et al., 2020). Aguilar et al. (2020) characterize the connectivity of the whole catchment as the efficiency of the system to transport sediment down-system during the 25M event. Cabré et al. (2020) proposed a conceptual model to explain the changes in connectivity due to extreme storm events. Heckmann et al. (2018) reviewed the main indices of "sediment connectivity" which apply to a specific location within the fluvial system. Therefore, the concept of "sediment connectivity" or "(dis)connectivity" implies a balance between top-down and bottom-up processes (see Mather-etal2017 for a comprehensive review). Top-down processes are controlled by climatic and geological variability that directly impact the sediment supply. On the other hand, bottom-up processes are controlled by morphological characteristics such as base-level driven processes. Finally, a balance between these two processes determines the fan-river system's "connectivity" or coupling status.

That said, the reviewer is right when he says that all of the sediment will be transported over geologic time. In fact, Cabré et al. (2017) studied the sedimentary infilling of the Huasco catchment using ^{14}C samples. They demonstrated that alluvial fans and terraces in the valley are younger than 15000 years, and they conclude that the infilling started at 11000 years BP, finishing about 2000 years BP.

2 Figure comments

Figure 1: I like this map a lot. It is well designed, but could the authors put latitude and longitude instead of UTM coordinates? This would help users locate the field site. Without knowing what UTM zone you are in, we cannot accurately locate this catchment. This idea goes for all of the maps.

We have changed all our maps to EPSG 4326, WGS84. The changes in the figures presented here also consider the changes suggested by RC1.

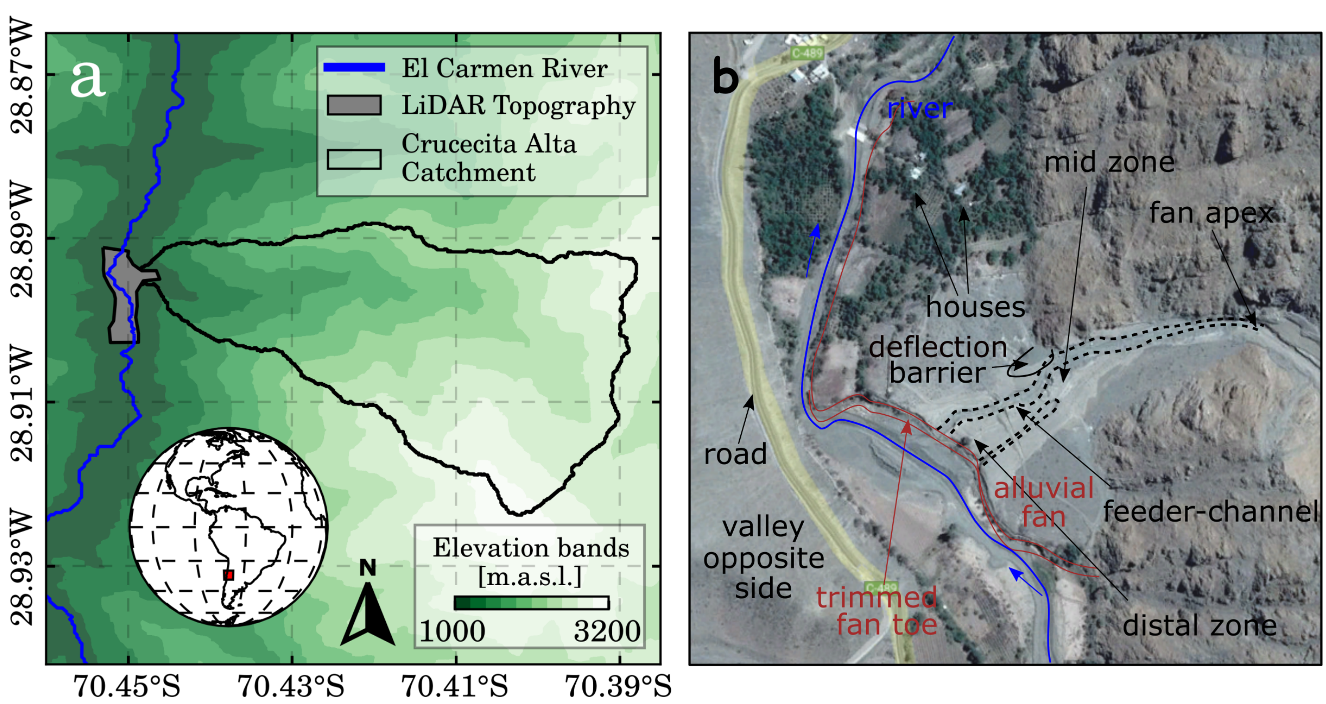

Figure 1: Study Area. (a) *Crucecita Alta* catchment $(28.895569°S, 70.449925°W)$. The grey polygon is the river segment that includes the studied fan topography section used in the numerical model. The unfilled polygon depicts the *Crucecita Alta* catchment (13 km^2). (b) *Crucecita Alta* alluvial fan main geometric features where the feeder-channel generated during the 25M event are presented with dotted lines.

Figure 2: These colors are not friendly to colorblind readers. I am not personally colorblind, but 5-8% of males are, and $\sim 1\%$ of females are. The potential for miscommunication could be easily avoided with a different color choice. I recommend the authors try a multi-panel figure here in addition to changing the color categories.

We have changed the color palette of all our figures to this color-blind-friendly color palette retrieved from `https://www.color-hex.com/color-palette/49436`. We also accepted the suggestion of a multi-panel figure.

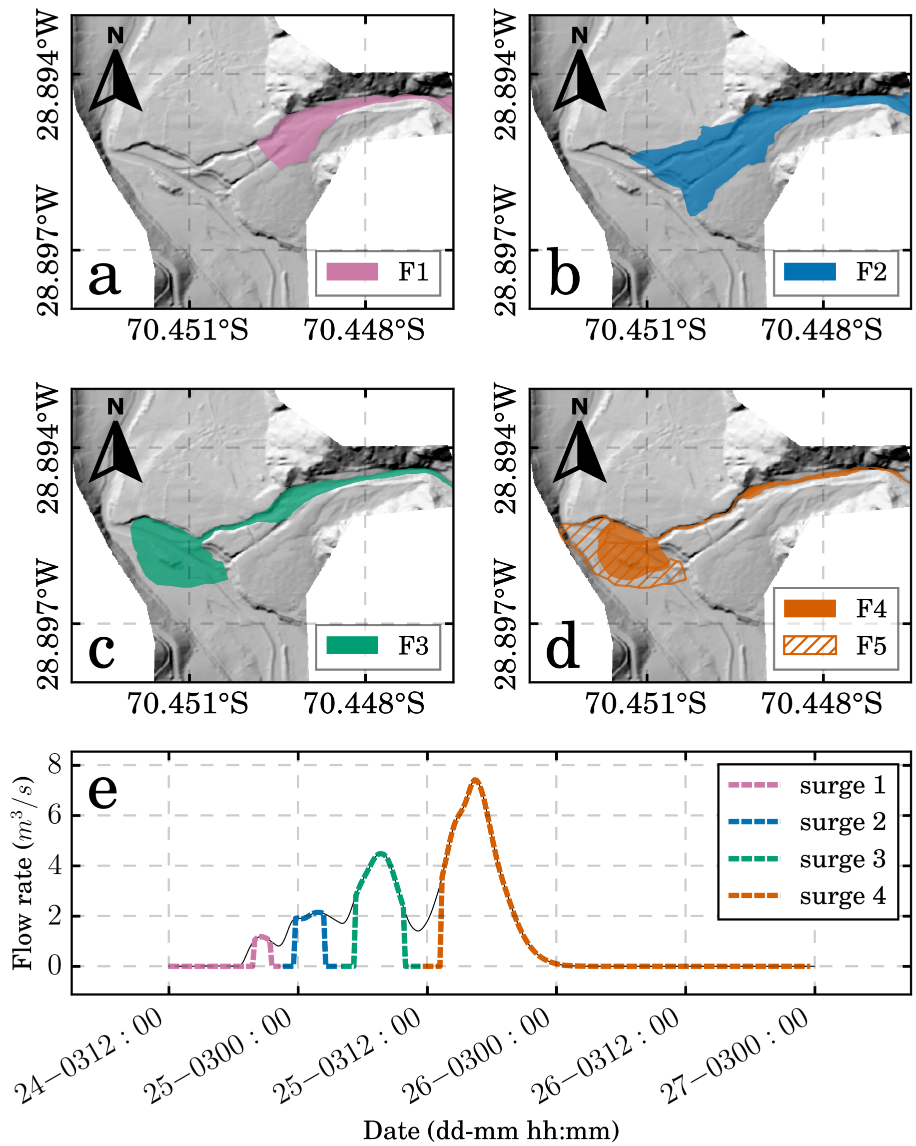

Figure 2: Available data for 25M event in *Crucecita Alta* alluvial fan. (a) The facies F1, F2, F3, F4, and F5 were retrieved from Cabré et al. (2020) and LiDAR topography surveyed by IDIEM (2019). (b) Flow hydrograph obtained from the hydrologic model performed by IDIEM (2019). The colors used to identify the facies in (a) depict their correlation with the surges in (b).

Figure 3: The caption uses "longitude" when I think the authors mean that the channel is 550 long.

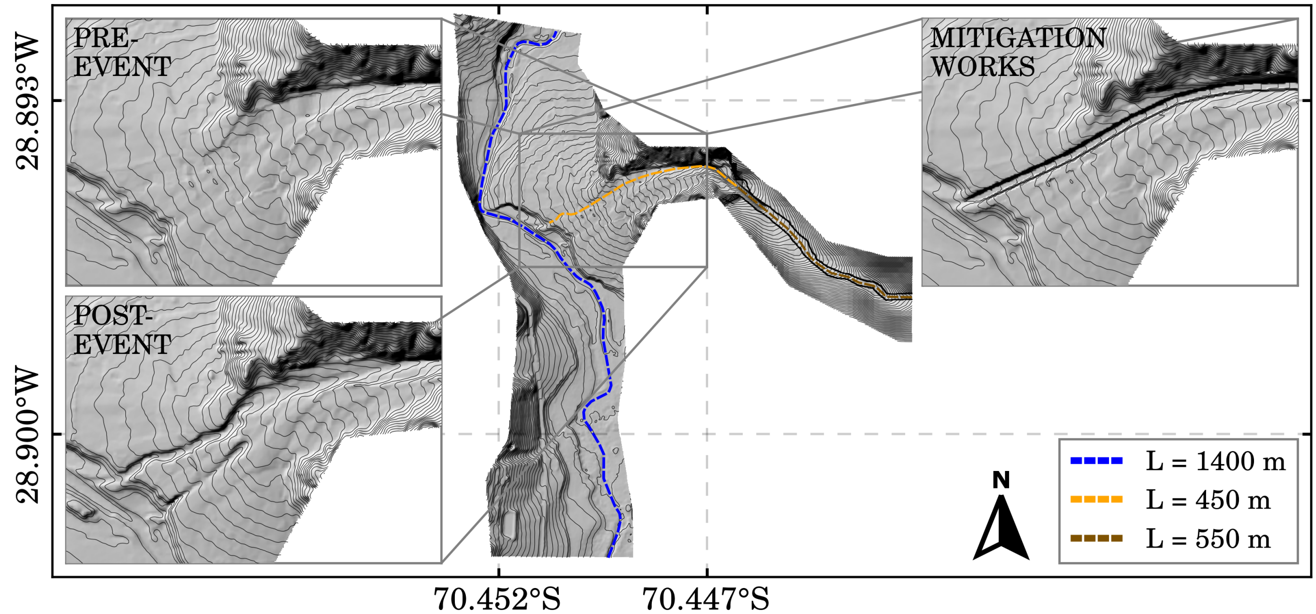

Figure 3: Topographic data modifications. Post-event topography corresponds to the available LiDAR topography, while the pre-event topography is a restitution based on satellite images and the available topography. The synthetic channel (brown dashed line) attached to the LiDAR topography is 550 m long while feeder channel (orange dashed line) is 450 m long. In the post-event topography, the feeder channel results from the inertial debris flow incisions on the alluvial fan. In the mitigation works topography, a straight rectangular channel replaces the feeder channel.

Figure 5: It would be helpful to label the columns and rows of this set of maps since this is a matrix of conditions. Specifically, it would be helpful to have "Surge 1" and "Surge 2" on the left-hand side of the left panels, while "Max Flow Depth", and "Final Flow Depth" were above the top row. This will make it easier for your reader, who has to check back and forth from the caption at the moment.

We have implemented the changes suggested by the reviewer. Also, we changed the color map of our results from "Spectral_r" to "RdBu_r" to avoid having contrasts between red/orange colors and the green color.

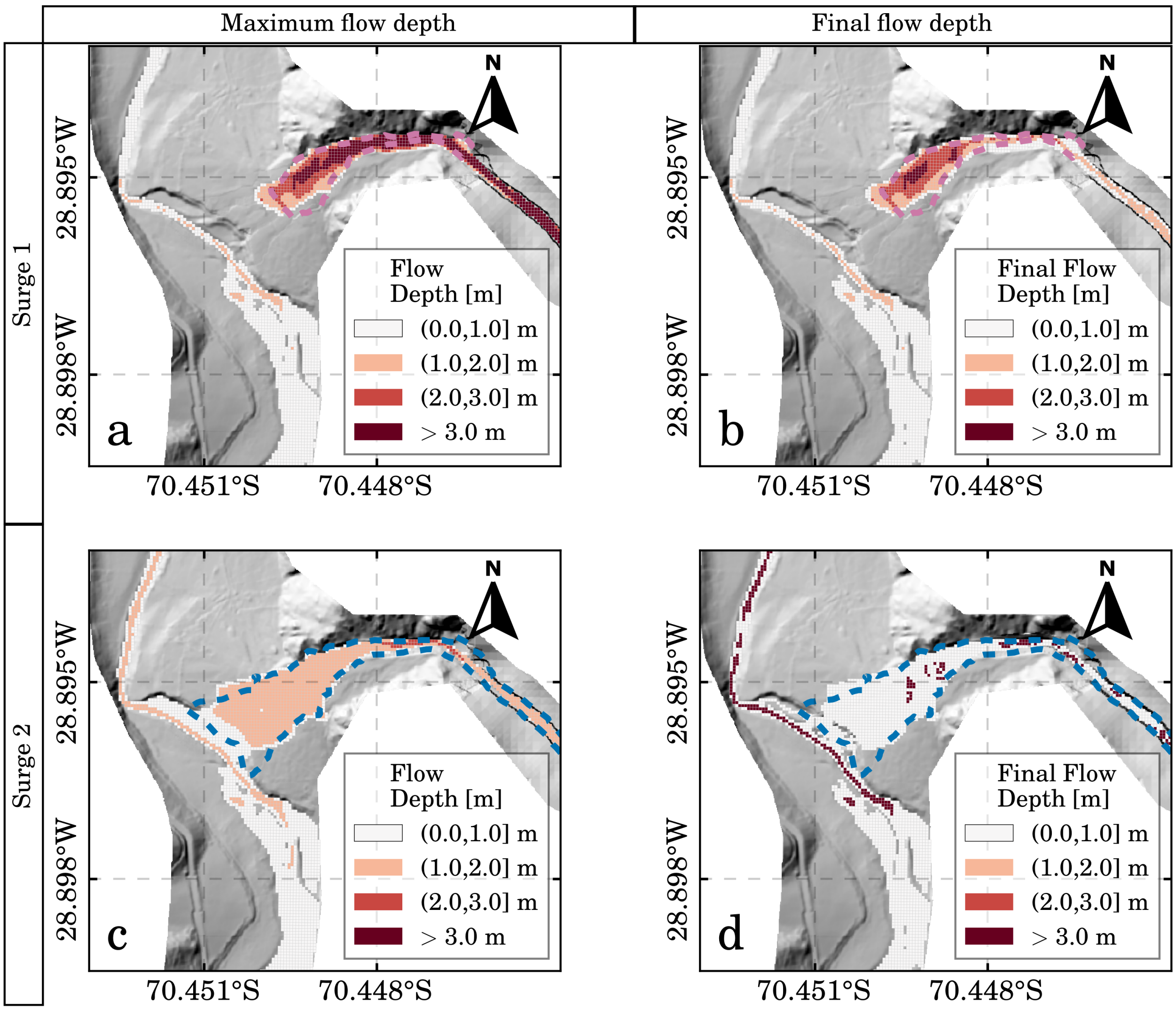

Figure 4: Viscous debris flow surges. Top panels correspond to the results for surge 1, whereas bottom panels correspond to surge 2. Dashed polygons show the extent of mapped facies F1 and F2. Left panels present the maximum flow depth, whereas right panels present the final flow depth at the end of each surge. Topographic changes for subsequent surges are updated based on the final flow depth of the previous surge.

Figure 6: The same panel labeling comment applies here and to all of your other multi-panel map figures. It would make it so much better for the reader.

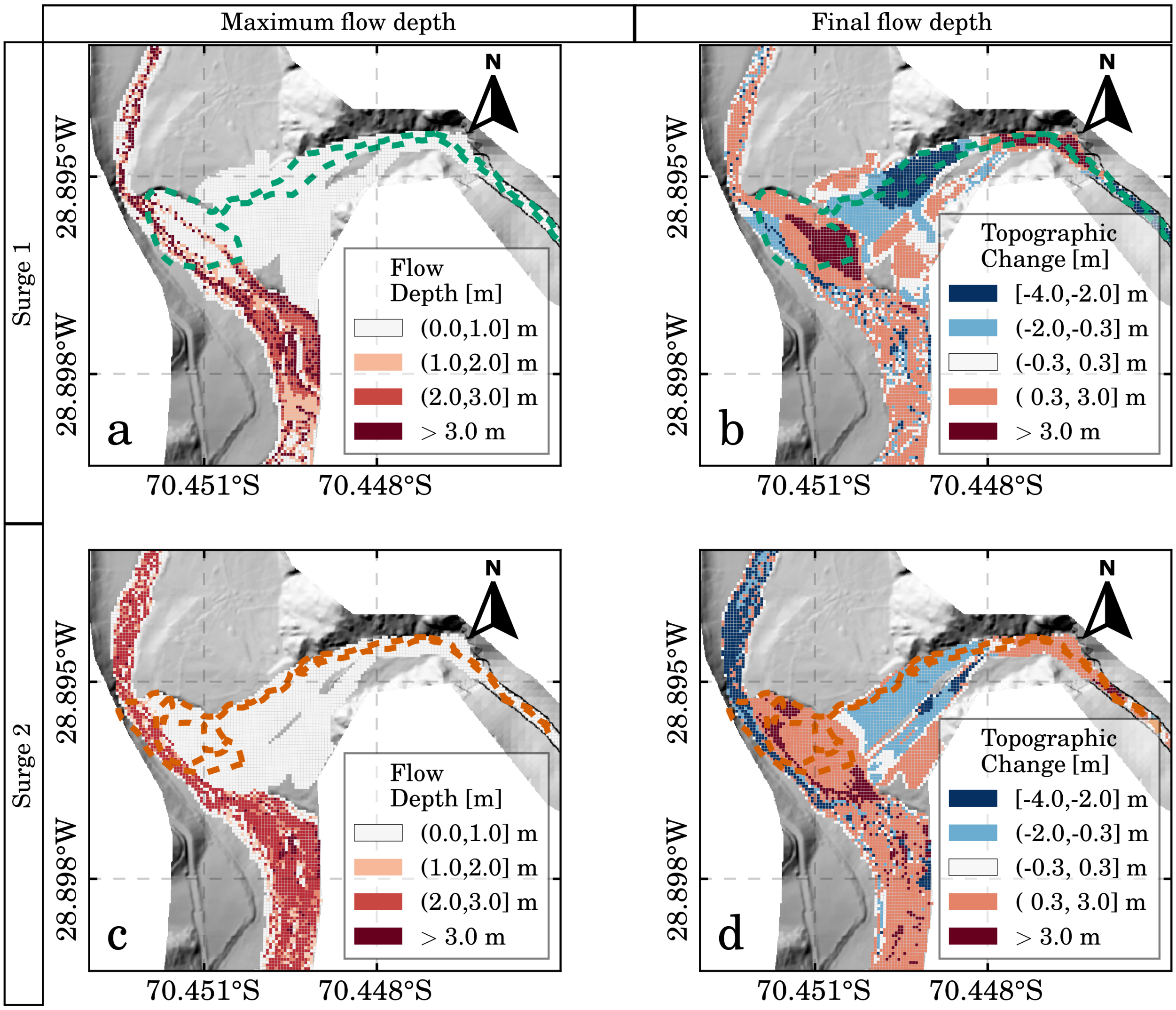

Figure 5: Inertial debris flow surges. Top panels correspond to the results for surge 3, whereas bottom panels correspond to surge 4. Dashed polygons delimit the telescopic-like deposit, i.e., the incision in the alluvial fan and the new lobe at the fan toe. Left panels present the maximum flow depth, while right panels present the topographic change for erosion (negative values) and deposition (positive values).

Figure 7: Again, these color lines are not colorblind-friendly. Some readers will not be able to tell the green and red lines apart.

We also implemented the new colorblind-friendly color palette in this figure, maintaining the relationship between facies and colors consistent.

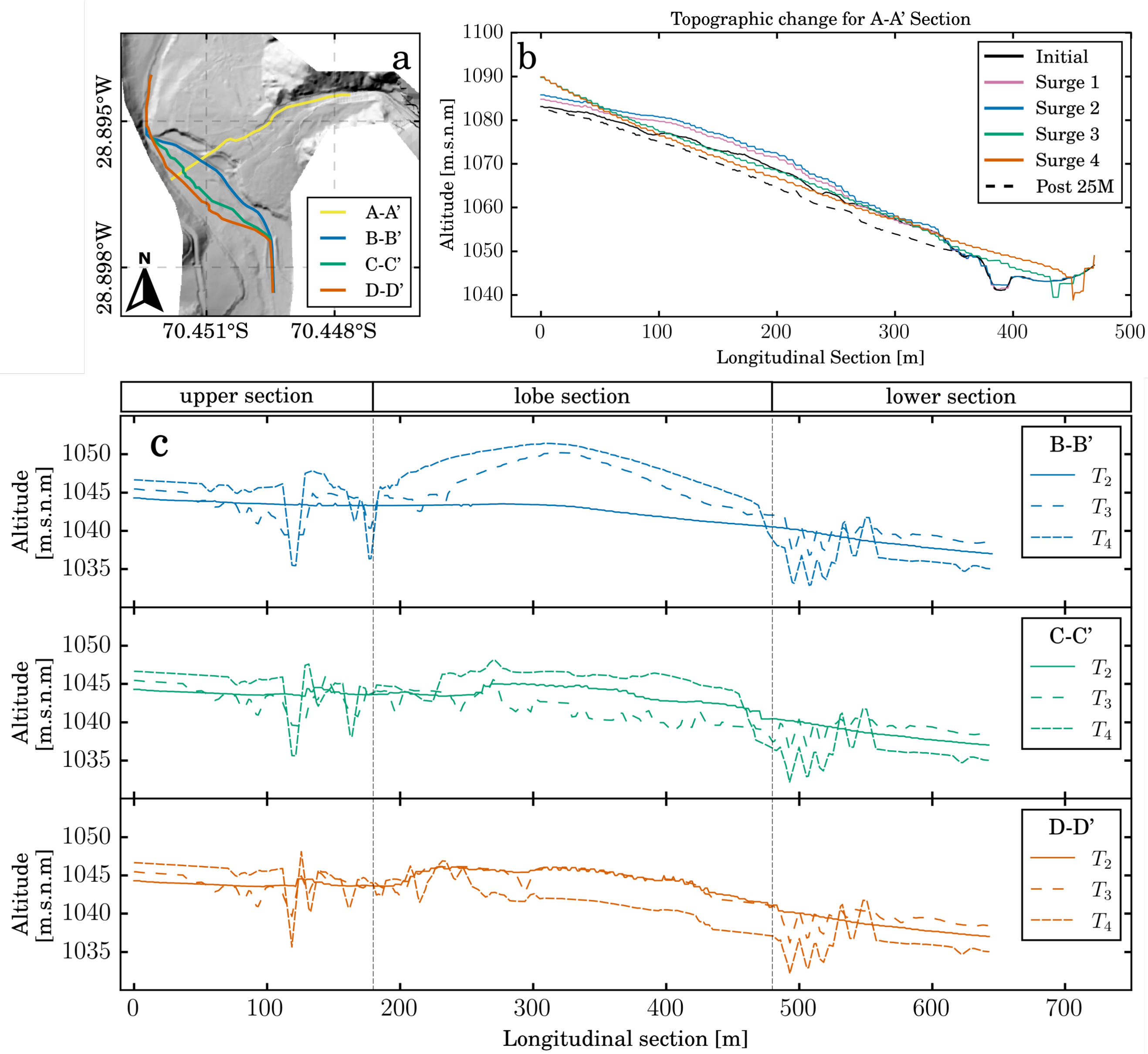

Figure 6: Morphological evolution of the tributary-junction alluvial fan. (a) Location of the longitudinal sections presented in b and c. (b) Longitudinal profile A-A' of the alluvial fan topography after each surge. (c) Longitudinal profiles B-B', C-C', D-D' of the river's topographic evolution.

Figure 8

We implemented all previous changes in Figure 8 of the preprint

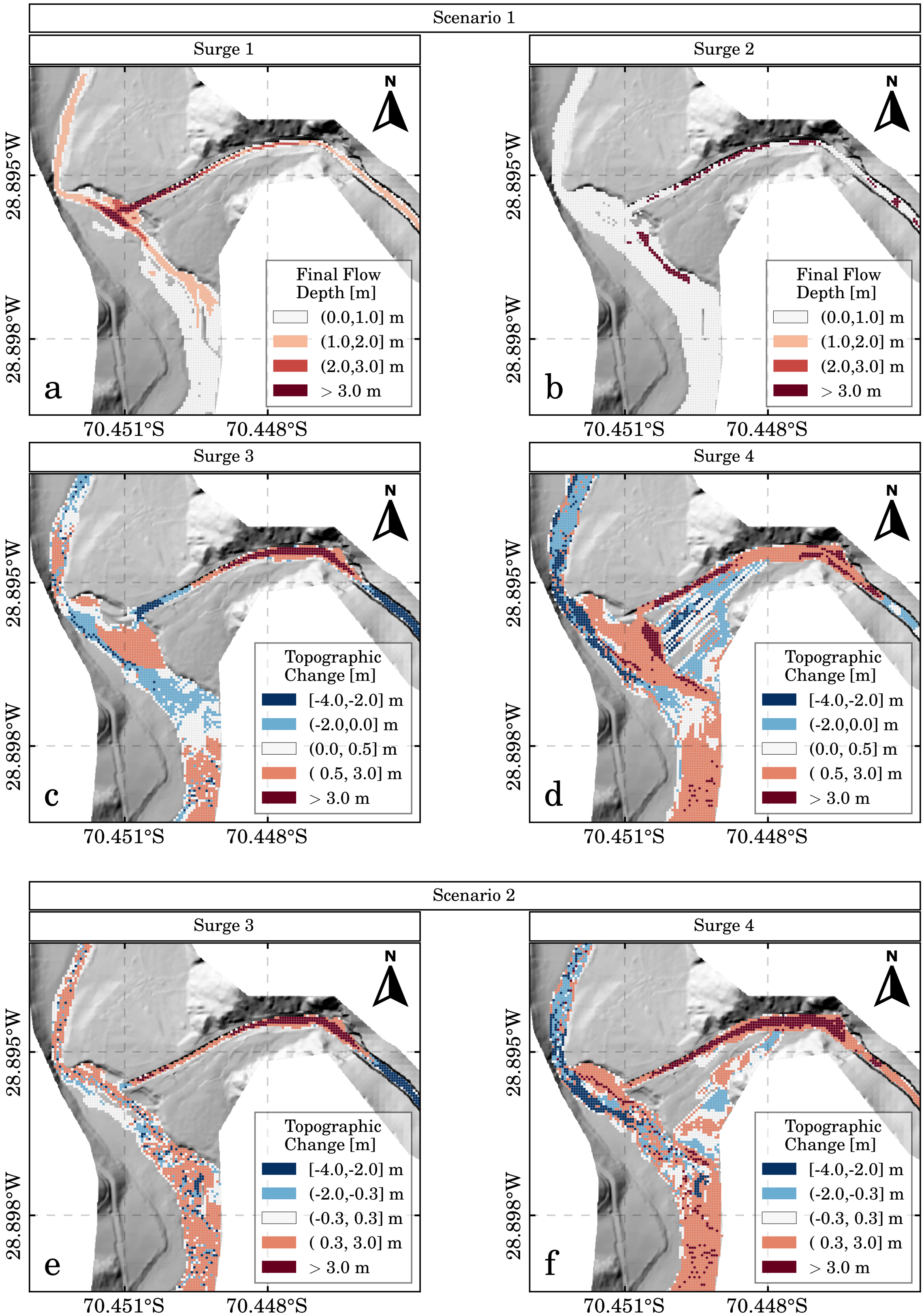

Figure 7: Two future scenarios are modelled to understand the possible effects of a channel (mitigation works): First scenario (a,b,c,d) and second scenario (e,f).

3 Line comments

1. "...in debris flow prone areas..." (no s) line 35

We thank the reviewer's suggestion. We will change the line to: "For example, in debris flows prone areas,.."

2. missing reference? line 50

We apologize for the citation misspelling. It corresponds to Takahashi (2014)

3. "surrogated" is a strange word choice here. Consider "thus, it can be used as a surrogate."

We thank the reviewer's suggestion. We will replace "surrogated" as the reviewer suggests.

4. "Riverbank erosion has previously trimmed the alluvial fan toe to the event" is an awkward construction. Consider revising. line 109

We thank the reviewer's suggestion. We will replace the sentence with "Previous to the event, riverbank erosion trimmed the alluvial fan toe."

5. I do not see a supplement, but it would be good if this imagery were put into a supplementary information file for the reader to easily access. A screenshot would do line 117

We thank the reviewer's suggestion. We will add a supplement file with screenshots of google satellite imagery of Crucecita Alta fan for 2013, 2016, and 2017.

6. "it can surrogate the flow" -¿ "it can be a surrogate for the flow" line 173

We thank the reviewer's suggestions. We will change this line to "it can be a surrogate for the flow rheology".

7. Is this a typo? It seems you refer to W_i^* being a function of the function before it is defined? line 197

Parker et al. (1982) proposed the dimensionless sediment transport rate W^* as a function of ϕ_{50} (equation (7) of the preprint). Parker & Klingeman (1982) modified this equation to subdivide the transport rate into fractions. Thus, the dimensionless fractional transport rate W_i^* is associated with a specific sediment size diameter i. To this purpose, W_i^* is also calculated with equation (7) but using ϕ_i instead of ϕ_{50}. Equation (9) of the preprint defined ϕ_i.

8. put this link to the data somewhere else, like a supplement or data availability statement. Does it have a DOI? line 217

We will add the topographic data to a supplement.

9. The authors say that low-frequency events are becoming more frequent. So are they still low-frequency? better to put an actual recurrence interval here. line 461

Estimating the recurrence interval of these events is one of the critical problems that hazard assessment projects in Chile are facing. Debris flow hazard matrices such as the one proposed by Hürlimann et al. (2008) require an estimation of the intensity and the probability of occurrence of debris flows. However, it is very uncertain to estimate the probability of occurrence. The triggering of debris flows in this arid system is related to climatic, hydrologic, and geological characteristics, but no standard procedure exists to estimate the recurrence interval.

In this arid system, Aguilar et al. (2020) showed that catchments are transport-limited, i.e., the more water flows, the more sediment is transported. On the other hand, Ortega et al. (2019) showed that the recurrence of extreme rainfall events has increased in the last century, but the mean annual volume of rain has decreased. This condition is unfortunate because the lack of mild-to-normal rains (i.e., rains with two years of return periods) enhance sediment storage. Consequently, when an extreme storm event occurs (i.e. rains with one hundred return period), there is a more significant amount of sediment available. Since extreme rainfall events are the main responsible for debris flow triggering in the Atacama Desert, one may guess that debris flow events are becoming more frequent.

References

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