Response to reviewers:
Understanding snow bedform formation by adding sintering to a cellular automata model

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A note to all reviewers

Response to Reviewer # 2

Opening Remarks:

We thank Reviewer# 2 for his/her mostly positive comments and for finding the manuscript suitable for publication in The Cryosphere.

Below, we address the points of criticism raised by Reviewer# 2.

A: Concerns in the main text

- ***A1 : " a year "***

  Response A.1: Corrected in the updated manuscript.

- ***A.2 : P2 L7-9: I don't find this sentence very clear.***

  Response A.2: We updated these lines in the revised manuscript as follows.
  The importance of snow bedforms primarily stems from the fact that their presence results in an undulating surface which affects basic exchange parameters that dictate transfer of mass, energy and momentum between the surface and the atmosphere, namely the roughness lengths for specific humidity, sensible heat and velocity.

- ***A.3 : P.3 L.5: "is the fact that"***

  Response A.3: Corrected in the updated manuscript.

- ***A.4 : P.3 L.7: "time-scales of snow transport are much shorter "***

  Response A.4: Corrected in the updated manuscript.

- ***A.5 : P.5 L.15: I understand the reason to use a finer grid in the vertical resolution than in the horizontal resolution. Could the other explain the choice of a ratio of 5 or talk about the potential impact of this ratio on model results?***

  Response A.5: The ratio of 5 is chosen as a balance between excessive computational expense, that increases with the resolution ratio and the accurate representation of the surface. Tests with a higher resolution ratio showed that the results were not significantly different. This is now explained in the revised manuscript.

- ***A.6 : P.5 L.19: "known". Please correct the added spaces before and after parentheses.***

  Response A.6 : Corrected in the updated manuscript. The spaces before and after the parentheses have been removed. Thank you for pointing our this discrepancy.

- ***A.7 : P.5 L.26: you are introducing the transition-rate parameters here and then taking again about them again in P.7 L.33 (and Table 1, P.8). Please introduce the notation Λ for the transition-rate parameter in the last paragraph of page 5.***

  Response A.7: We now introduce the notation of Λ earlier. Additionally, we point to Table 1 in the same paragraph unlike much later as in the original manuscript.

- ***A.8 : P.5 L.10 and P.7 L.3: I would change the names of the subsections to make them more descriptive. For instance, Section 2.1 could be named "Description of the CA model for snow transport" and the Section 2.2 could be "Description of the LGCA model for snow surface evolution".***

  Response A.8: We agree with your comment and have changed the section titles appropriately.

- ***A.9 : Section 2.1: For a reader not familiar to CA modelling, it is difficult to understand how the transitions happen for the doublets. Fig. 1a is not helping to explain these transitions and the meaning of the variables Λ, b, and δ is not explained until later in the text.***

  Response A.9: On this point, considering that the CA model has been described in many publications in the past, our intention was to only give a general idea of the CA modelling technique while pointing to the relevant literature. To explain the model in detail would require the manuscript to extended by many more pages, while simply repeating or paraphrasing earlier works. We instead chose to focus on the results of such a model and illustrate its capabilites both qualitatively (with attached videos for example) as well as quantitatively.

- ***A.10 : P.7. L.14: Please specify that the direction and number of particles are represented by the arrows in Fig 1b.***

  Response A.10: The description of Figure 1b has been updated in the revised manuscript. In particular the significance of the green arrows is better explained. Furthermore, a citation is added for the N-body collision rules.

- ***A.11 : P.7 L.14: "collision rules". What are these rules? At least a citation describing these rules would be needed.***

  Response A.11: See response to A.10 above.

- ***A.12 : P.9 L.11: "Fig. 1d". Fig. 1d needs a better description. What do the boxes mean? In addition, the variable t_s should be introduced in P.9, first paragraph, when introducing the 24h sintering time.***

  Response A.12: In response to your comment, which is also shared by the other reviewer, we have expanded the description of the sintering mechanism by introducing a new subsection. The model description is more detailed now, along with a better description of Fig. 1d as well as defining t_s which indeed an oversight.

- ***A.13 : In all graphs expressing time, the unit showed by the authors is [t/t_s]. I believe it should be "[-]" (or "[s/s]") and the label in the x-axis should state "Normalized time (t/t_s) [-]". Similar comment about the units as above for the variables in Fig. 2.***

  Response A.13: We have modified the x-axis labels in almost all plots to be more clear about the normalized time or age variables. We thank you for pointing out the inconsistencies in this regard in the original manuscript.

- ***A.14 : P.10 L.8: What is the meaning of the threshold velocity? The velocity at which erosion starts?***

  Response A.14: u_c is the threshold friction velocity for aeolian transport. These lines have now been added to the revised manuscript.

- ***A.15 : Section 3.1: Please make it clear in the first paragraph if sintering is turned on or not.***

  Response A.15: We have not described this clearly in the revised manuscript.

- ***A.16 : End of P. 13 + Fig. 4a + P. 14: I believe Fig. 4 shows the speed of the dune vs. time for different dune heights (see caption of Fig. 4a). In the text and in the legend of the figure, it is not clear that this graph presents results for different dune heights. Indeed, the legend of the figure shows the length of the dune "L" and not "H". In the text, the authors talk about "dune length" (P.13 L.13) and "dune size" (P. 14 L.7).***

  Response A.16: Thank you for pointing out these discrepancies. We stick to 'dune length' in the legend as well as the text.

- ***A.17 : P.16 L.11: "the dune is deposited as a non-erodible layer"***

  Response A.17: Corrected in the updated manuscript.

- ***A.18 : P.17 L.7: "this behaviour becomes clear"***

  Response A.18: Corrected in the updated manuscript.

- ***A.19 : P.17 L.25: "These simulations allow us to identify"***

  Response A.19: Corrected in the updated manuscript.

- ***A.20 : Fig. 7: It is hard to see the legend of the color bars of the left graphs.***

  Response A.20: We have updated with figure with larger color bars that are indeed more readable.

- ***A.21 : For all the simulations, I could not find any information on the initial conditions for the wind speed. Is it initially 0 m/s and then the left boundary condition is where the wind speed is set or is the wind speed initially set to the chosen value over the whole area?***

  Response A.21: The initial velocity is indeed equal to 0 m/s. The LGCA model is run initially without any aeolian transport for the wind speed to accelerate and reach equilibrium with the initial surface morphology. Only once the wind speeds are statistically homogenous is the surface morphology allowed to evolve.

- ***A.22 : There is no information about the snow properties (e.g. snow density and grain size) used for the simulations. How do they impact the snow bedform formation?***

  Response A.22: The snow properties used in all the simulations were described on Line 31 of Page 9 in the original manuscript.

  While it is likely that these parameters would have some influence over the surface features, these numbers are by themselves highly constrained. Note the density of the solid phase refers to density of ice grain rather than bulk density of the snowpack, which, admittedly is quite variable.

- ***A.23 : I do not understand how dunes form in the simulations presented in Section 4. If the snow surface is initially flat and the wind speed is constant, how do the first snow dunes form? It seems to me that some sort of heterogeneity would be needed for the first dunes to form and then propagate.***

  Response A.23: In a modelling or even theoretical framework, it has been shown that a perfectly flat granular bed can be transformed into an undulating surface with ripples and waves. The initial heterogeneity need not come from the surface but from the overlying turbulent fluid that is indeed heterogeneous. This heterogeneity can be evidenced by the fact the instantaneous surface shear stress varies significantly in both time and space over a perfectly flat, smooth surface even if mean stress converges to a fixed value. Aeloian transport and particularly erosion is controlled not by averaged but instantaneous shear stresses at the surface. As soon as aeloian transport commences, bedform structures can develop. After a certain time, the structures grow to be large enough to significantly perturb the air flow and the feedback between the morphodynamics of the surface and the overlying flow become the dominant mechanism.

In reality, indeed the granular bed shall consist of heterogeneities - even a surface which is 'flat' at large scales will have heterogeneities at least of the diameter/pore scale by definition. But these heterogeneties are still much smaller than the length scale of even the smalled ripples that form.