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

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Response to Reviewer # 1

Opening Remarks:

We were extremely pleased to have Prof. Clement Narteau as a reviewer for our manuscript. Considering that he is the principal developer of the RESCAL model and has played a major role in expanding cellular automata approaches in the sand dune community, his positive remarks on our work are heartening. Indeed, we would be very happy to have our implementation of sintering be a part of the next release of RESCAL as Prof. Narteau proposes.

We thank Prof. Narteau for his comments and advice and have incorporated most of them into the updated manuscript. What follows is a point-by-point response to the questions and comments made in the review.

A: Main Comments

- ***A.1 : In order to inject the sintering mechanism in the model, I understand that the erosion rate of deposited snow cells writes***

$$\Lambda_e\left(t\right) = \begin{cases} 0 & \textbf{for } \tau_s \leq \tau_1 \textbf{ or } t - t_{dep} \geq t_s \\ \Lambda_0\left(1 - \frac{t-t_{dep}}{t_s}\right)\left(\frac{\tau_s-\tau_1}{\tau_2-\tau_1}\right) & \textbf{for } \tau_1 \leq \tau_s \leq \tau_2 \textbf{ or } t - t_{dep} \leq t_s \\ \Lambda_0\left(1 - \frac{t-t_{dep}}{t_s}\right) & \textbf{otherwise} \end{cases} \quad (1)$$

  where t_s and t_{dep} are the sintering time and the deposition time of the corresponding cell, respectively. Please specify if it is the case of if you use a transition or a substrate.

  Response A.1: We have used the transition-blocking technique that is a part of the RESCAL model already. The CELLTIME variable that is available for each deposited cell is used to track the time of deposition and the age of the cell. Your equation is thus, exactly what we have implemented.

  We expanded the description of the sintering mechanism into a new sub-section and added a version of the above equation to it. We did so by introducing a new variable called *Erodibility factor*, f_{E}. Correspondingly, Fig. 1d's y-axis has also been updated.

- ***A.2 : To limit the aspect ratio of your bedforms, you consider that your elementary cell is a slab 5 times smaller in height than the length of its square base. In this case, you break the symmetry of the lattice-gas cellular automaton model and the momentum is not conserved during collisions. We have encountered the same problem in the past and, to solve it, we have increased the density of the square cells of the lattice- gas model in the horizontal direction (here for example by a factor 5). This option is still in the code but it has not been tested since 2010, before the first version of ReSCAL available online. I admit that it will be difficult to solve this problem within the time frame of a review process and I am also convinced that it will not changed the results significantly. However, you must specify that there is a problem with the aspect ratio of your cell with respect to the air flow modeling.***

Response A.2: We mention in the text that the lattice-gas model is performed on a grid with size equal to the smaller of the two dimensions. Infact, we did exactly as you have done previously and mentioned in your comment. We chose the necessary parameters in the lgca.h file of the source code.

- ***A.3 : In dune dynamics, the relationship between dune height and speed writes as***

$$c = \frac{Q_{crest}}{(H + H_0)}\,, \tag{2}$$

where H_0 is a minimal dune height and

$$Q_{crest} = (1 + \gamma)\, Q_{sat}\,. \tag{3}$$

In this expression, $\gamma = \beta H/L$ is the speed-up factor which accounts for the increase in wind speed above a topographic obstacle. H/L is the dune aspect ratio and β a dimensionless coefficient that accounts for flow properties. Usually, γ is measured between 0.5 and 2 in nature. In the model, $\gamma = 1.6$ (Gao et al. 2015a). Then, instead of Eq.6 of the manuscript you should find the best fit using a relation of the form,

$$c^* = \frac{c}{Q} = \frac{a}{H + H_0}\,. \tag{4}$$

I predict that it will fit the data rather well with a ≈ 2.6 and $H_0 \to 0$. Most importantly, the a and H_0 values will have a physical meaning, the speed-up and a minimum dune size respectively.

Response A.3: This is indeed an interesting question. We infact began with the expression you propose in your comment (and have earlier published on). However, we realized that the two parameter hyperbolic equation was only able to fit the data for small dunes, that is, for small H values. Please find attached, an updated figure with an additional fit as you propose (red line).

What is even more interesting is the fact that the values of $a_{Narteau}$ and $H_{0,Narteau}$ are close to what you predict, 2.694 and 0.02101 respectively. However, we are unable to explain the lack of good fit for larger H values. There are multiple possible reasons for this divergence. However, We feel that this may require more exploration that we leave for the future.

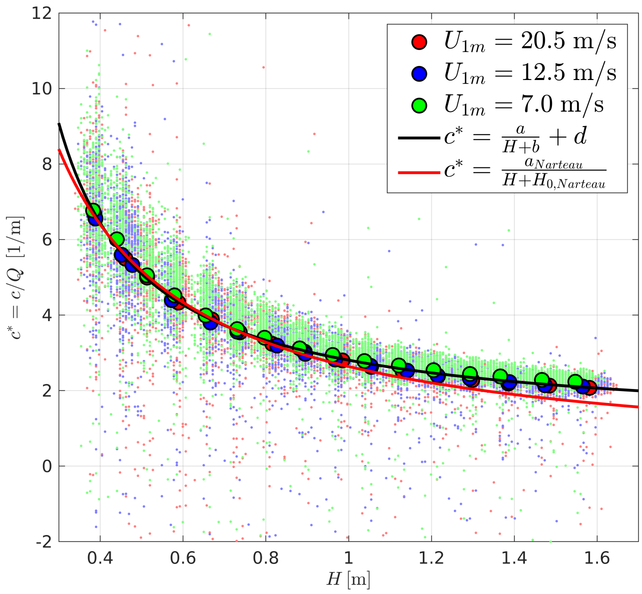

Figure 1: See the additional fit line.

- ***A.4 : The characteristic time scale t_{dune} of a dune should scale with H^2/Q_{sat}. It can be described as the dune turnover time or as the time it takes for a dune to loose the memory of its shape. This characteristic time should be compared to the t_s-value. I guess that for $t_{dune} < t_s$, dunes will remain mobile. For $t_{dune} > t_s$, dunes will sinter. Then it could be informative to test if the maximum streamwise length discussed in the manuscript scales as $\sqrt{t_s Q_{sat}}$.***

  Response A.4: We would like to discuss this topic in a future publication, particularly with real-world field data to test. We were thinking on similar lines but decided to focus on the concept of the maximum streamwise length in this manuscript. The current manuscript was intended to introduce the CA approach to the snow pack community. With the RESCAL model, a lot of topics are left to be explored in the context of snow!

B: Minor comments

- ***B.1 : Lines 3P1, 26P4, 2P9, 25P26 and caption Fig. 1: Specify that you implement a "sintering mechanism" and not a "sintering model".***

  Response B.1: We have replaced "sintering model" with the "sintering mechanism" in the text of the updated manuscript.

- ***B.2 : Line 6P9: Define t_s .***

  Response B.2: As mentioned above for point A.1, in the new sub-section of the sintering mechanism, we additionally define the sintering time scale t_s.

- ***B.3 : Line 2P3: On the basis on the equation of conservation of mass $\partial Q/\partial x = \partial h/\partial t$, erosion and deposition should be associated with increasing or decreasing transport. In a second time, you can specify that transport is positively correlated to the wind shear stress.***

  Response B.3: This concept has been described in the updated manuscript.

- ***B.4 : Section 2: Rozier and Narteau (2014) should be cited as they introduce the ReSCAL model in a more general research perspective, in particular for multidisciplinary studies in landscape dynamics. For information, Narteau et al. (2001) have used a preliminary version of ReSCAL to study dissolution/crystallization mechanisms, which may be of wide interested in icy landscapes where melting/freezing processes are likely to play a crucial role.***

  Response B.4: We have now cited Rozier and Narteau (2014) at the beginning of Section 2.

- ***B.5 : Line 26P5: check spaces after and before parentheses. Similarly, you can remove the math mode for subscripts and upperscripts, for example Q_{sat} instead of Q_{sat}.***

  Response B.5: Thank you for pointing this editing mistake. We have removed the unnecessary spaces before and after parentheses along with updating all the subscripts and upperscripts to be in normal mode.

- ***B.6 : Line 27P9: In linear stability analysis, we measure the exponential growth of the amplitude with respect to time (d ln(A)/dt).***

  Response B.6: Thank you for pointing out this mistake. We have corrected this both in the text as well as the y-axis in Figure 2a.

- ***B.7 : Snow falls are easy to implement using INPUT cells.***

  Response B.7: That is indeed true. We have already made use of it in our ongoing work!

- ***B.8 :Line32p26: using a simplified version of the ReSCAL dune model, Zhang et al. (2014) have compared the rate parameter to physically- based formulations,***

  Response B.8: The necessary line and citation as been added in the updated manuscript.
