tc-2019-45 Review

"Understanding Snow Bedform Formation by Adding Sintering to a Cellular Automata Model"

by Varun Sharma et al.

This manuscript presents a numerical analysis of snow bedforms using a cellular automaton approach, which has been extensively used to study sand dune morphodynamics. The main originality of this work is to introduce a new mechanism to account for the cohesive properties of ice particles. This is achieved by a characteristic residence time above which the deposited snow particles can no longer be mobilized. Using this new model, the authors study in full details the emerging bedforms (shape, velocity) under different conditions of snow availability and wind strength. They convincingly show how consolidated barchans (low snow availability) and longitudinal structures (high snow availability) may develop. In addition to the modeling of these topographic features, they propose a threshold length-scale for the activity of the bedforms from which they develop.

The model is described in mathematical details and the first sections provide a comprehensive and accessible introduction to the feedback mechanisms that control the emergence of bedforms. The results are clearly presented and the structure of the manuscript allows a clear understanding of the different stages of the research.

I am convinced that this manuscript will be an inspiring and informative read for the cryosphere community and I highly recommend it for publication. I have just some comments below that, I hope, could help to give greater perspectives to this nice piece of work.

Preliminary words

Note that I am biased about the model because I have been developing this approach for almost 14 years. Nevertheless, I can appreciate the amount of work dedicated to this study and the quality of the research. The authors kept the model as simple as it is and only added a new level of complexity to explore some specific properties of snow bedforms. Thus, they have been able to built on prior knowledge to identify new patterns relevant to the evolution of icy landscapes. The precise evaluation of the characteristic length and time scale of the model makes it applicable to a wide range of conditions and provides a new tool for the analysis of practical issues. Therefore, this work will form the basis for further investigations of landforms in cold environments. In collaboration with Ghislain Picard, we wanted to study snow bedform with a similar approach. This manuscript demonstrate that it was a good idea.

I hope that the authors will help us to implement their model in the ReSCAL depository available online on a GNU General Public License. To do so, we can take advantage of the CELL_TIME option in the most recent version of the code, which simply record the last motion of sedimentary/snow cells (see Fig. 6a of *Gao et al., 2015*). The CELL_COLOR option may be also useful to decompose sedimentary/snow state into substates (see *Gao et al., 2016*).

Main comments:

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

$$\Lambda_e(t) = \begin{cases} 0 & \text{for } \tau_s \leq \tau_1 \text{ or } t - t_{\text{dep}} \geq t_{\text{s}}, \\ \Lambda_0 \left(1 - \dfrac{t - t_{\text{dep}}}{t_{\text{s}}}\right)\left(\dfrac{\tau_s - \tau_1}{\tau_2 - \tau_1}\right) & \text{for } \tau_1 \leq \tau_s \leq \tau_2 \text{ and } t - t_{\text{dep}} < t_{\text{s}}, \\ \Lambda_0 \left(1 - \dfrac{t - t_{\text{dep}}}{t_{\text{s}}}\right) & \text{else.} \end{cases} \tag{1}$$

  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 or if you use a transition or a substate.

- 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.

- In dune dynamics, the relationship between dune height and speed writes
$$c = \frac{Q_{\text{crest}}}{(H + H_0)},$$
  where H_0 is a minimal dune height and
$$Q_{\text{crest}} = (1 + \gamma) Q_{\text{sat}}.$$
  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
$$c^* = \frac{c}{Q} = \frac{a}{H + H_0}.$$
  I predict that it will fit the data rather well with $a \approx 2.6$ 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.

- 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 loss the memory of its shape. This characteristic time should be compared to the $t_{\rm s}$-value. I guess that for $t_{\rm dune} < t_{\rm s}$, dunes will remain mobile. For $t_{\rm dune} > t_{\rm s}$, dunes will sinter. Then, it could be informative to test if the maximum streamwise length discussed in the manuscript scales as $\sqrt{t_s Q_{\rm sat}}$.

<u>Minor comments:</u>

Line nPm is for Line n of Page m.

- Lines 3P1, 26P4, 2P9, 25P26 and caption Fig. 1: Specify that you implement a "*sintering mechanism*" and not a "*sintering model*".
- Line 6P9: Define $t_{\rm s}$.
- 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.
- 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.
- Line 26P5: check spaces after and before parentheses. Similarly, you can remove the math mode for subscripts and upperscripts, for example $Q_{\rm sat}$ instead of Q_{sat}.
- Line 27P9: In linear stability analysis, we measure the exponential growth of the amplitude with respect to time $({\rm d}\ln(A)/{\rm d}t)$.
- Snow falls are easy to implement using INPUT cells.
- Line32p26: using a simplified version of the ReSCAL dune model, *Zhang et al. (2014)* have compared the rate parameter to physically-based formulations,

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