Review Report for

Morphodynamics of snow barchans at Concordia Station, Antarctica

Marine Poizat*, Jeanne Alkalla, Ghislain Picard, Laurent Arnaud, Daniel J. Nowacki, Simon Filhol, Eric Lefebvre, Clément Narteau

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Round 1 Review

Comments by reviewer 1 (Anonymous Reviewer 1)

Completed: 2026-02-16 10:47 am
Recommendation: Major revisions

The paper reports a field study of snow barchans at Concordia Station. The authors document the morphology and migration of snow barchans over a six-year period. They highlight that snow barchans obey the same scaling laws as those observed for sand barchans in air and water. They also argue that sintering processes limit the size of active barchan dunes and preserve their shapes when wind speeds fall below the transport threshold. In addition, the authors indicate that, during wind events, barchan dunes are highly reactive to changes in wind direction due to their small size.
I am impressed that the authors succeeded in collecting valuable data on snow barchans in such an inhospitable climate, and I believe that this field study is worthy of publication. However, I feel that the authors should avoid overstating their conclusions, as some aspects of the analysis are based on assumptions that cannot be directly confirmed by field measurements, in particular those concerning snow drifting and the transport threshold. Below, I list several issues that should be clarified prior to publication.

1) Introduction:
Eq. 4, concerning the mass flow rate at the crest and presented in the Introduction, is understandable. However, the authors introduce a speed-up parameter δ, which is related to the aspect ratio of the dune, without explicitly stating the relationship between δ and γ. This relationship is explained later in the manuscript, and I therefore suggest avoiding such a level of detail in the Introduction before all relevant information is provided.

2) Methods: Snow flux
– The sand transport law from Schmidt (Eq. 6) exhibits a cubic dependence on the friction velocity, whereas the equivalent transport law for aeolian sand transport is quadratic. Can the authors comment on this difference?

– The authors also provide values for the parameters of this transport law, such as the transport threshold and the terminal velocity. However, the particle size is not specified, and it is unclear whether these values are kept constant in the subsequent analyses. Do these values correspond to cohesionless snow or to sintered snow? Are they applicable to conditions at Concordia Station?

–The authors do not discuss the existence of two distinct transport thresholds, namely the static and dynamic thresholds. For cohesive particles, these two thresholds can differ significantly: the static threshold is expected to increase with sintering, whereas the dynamic threshold is much less sensitive to cohesion (see, for example, Selmani et al., PRF 2025). This raises the question of which transport threshold should be used in the transport law. I believe this issue should be discussed in more detail.

– Another important issue concerns the saturation of the snow flux. Eq. 6 is expected to provide the saturated flux, whereas it is well known that for cohesive particles such as snow, the distance required to reach saturation can be much greater than the drag length used to estimate the minimum dune size. This issue should therefore be discussed in more detail.

– Finally, given that Eq. 6 relies on several assumptions (transport threshold, degree of saturation) that cannot be directly verified in the field, what level of confidence can be placed in the subsequent analysis based on the transport law given by Eq. 6?

3) Snow barchan morphodynamics and Discussion:
– I feel that the analysis reported in these sections (e.g., Section 4.3.2 on the snow transport threshold and Sectio 5 on the characteristic length scales for snow barchans) should be revised, or at least that the statements and conclusions should be more cautiously stated, given the issues listed above.

Comments by reviewer 2 (Anonymous Reviewer 2)

Completed: 2026-01-28 08:15 pm
Recommendation: Minor revisions

Geomorphica

In this paper, the authors use a unique and extensive set of photogrammetric measurements of snow barchans at Concordia, Antarctica to examine the shape, size, and migration of barchans. The paper is clear, informative, well-referenced, and with minor revision is ready publication. What follow are my suggestions to improve the paper, based on 45 years of mostly anecdotal, but frequent, field observations of barchans and dunes in Alaska, Antarctica, and on sea ice while they are forming and mobilized.

1. The authors use a framework of snow barchans as "fast" analogs for sand barchans. As a snow scientists this offends me. Snow barchans are almost certainly more widespread than sand barchans, and therefore worthy of attention in their own right. In all seriousness, I think the paper would be better off being framed around snow mostly, with a separate section called "What do snow barchans tell us about sand barchans?" in the discussion. Using the equations for sand is OK, but it left me thinking I would learn about sand dunes, which I did not. Since the paper is already quite long, I think focusing on snow, then briefly contrasting snow results to sand would streamline the flow without losing any relevant information.
2. There are many useful flux, wind speed, and geometric formulae in the paper, and some from the sand literature, all of which I found interesting. But eventually, as a reader, there are too many to keep track of, and see their relationships in one's mind. We know wind drives snow flux, which feeds barchan growth, with produces geometry. It is all useful, but a summary table of the equations, and some effort to package these in a way that keeps their inter-relationships clear, would be very useful.
3. This is a pet peeve, but (line 112) our paper (Filhol and Sturm, 2015; Section 4) clearly introduces the sintering time clock as a control on size. It would be nice for this to be acknowledged. Similarly (and I can indulge in a bit of lecture to a younger generation after 46 years of working in snow blizzards), the authors slight older works on barchans that deserve mention: e. g. Moss (1938), and Doumani (1967). The latter work in fact states ". . . the advance of barchanoids on hard, glazed snow surfaces is faster than on soft..." which possibly relates to the authors' contention concerning barchans on sea ice. The authors might even want to find a copy of Cornish (1902- On snow-waves and snow-drifts in Canada, with notes on the" snow-mushrooms" of the Selkirk Mountains. The Geographical Journal, 20(2), 137-173.) By 1902, the form and the fact that the barchans migrated was well know. Basically, if authors of an article today hope to have their work to have a long residence time in the pool of knowledge, then they need to be careful to credit older work themselves.
4. Noise and Interaction: There is little discussion in the text of the impact of other snow structures (dunes, sastrugi, old vs. new surfaces) on morphology, yet (as in the authors' Figures 6, 7, 10, and 10) clearly such interactions were taking place everywhere. These figures

are wonderful images, but some discussion of the impact of noise (e.g., other structures impacting barchan geometry) and interaction (collision of features) seems necessary.

5. Barchans on sea ice: The reference for this is no longer available on-line, so I don't know what was done, but I question whether one example is enough on which to base the rule. I have spent about half my snow career on sea ice. Here are my thoughts: If the authors' read through Doumani (1967) and return to Bagnold's work, they will recall that the material flux for barchans is both saltation and creep (rolling), and which may dominate in building barchans I am not sure is known. I have frequently witnessed creep to be greatly enhanced on glazed snow surfaces and on bare sea and lake ice ….but only when here are no frost feathers of surface rime and hoar have grown on the ice (which is common). When the latter conditions prevail, then the ice is actually rougher than a normal snow surface and potentially reduces creep and maybe even saltation. So one example from sea ice is not enough to conclude anything general.
6. Threshold wind speed: I have read a dozen or more papers trying to nail down this speed. I have even written several papers in which I tried to do the same (cf. Sturm, M., & Stuefer, S. (2013). Wind-blown flux rates derived from drifts at arctic snow fences. Journal of Glaciology, 59(213), 21). As the authors correctly conclude, the threshold wind speed is a range, a very complex function of the age, particle size and shape, humidity and wind speed. Even our understanding of the transport modes is probably a too-simple abstraction (see Aksamit, N. O., & Pomeroy, J. W. (2016). Near-surface snow particle dynamics from particle tracking velocimetry and turbulence measurements during alpine blowing snow storms. The Cryosphere, 10(6), 3043-3062.). While there is nothing wrong with Figure 9, I am not sure it is needed, and as before, the paper could be shorter.
7. Stabilization: Figure 10 top is really interesting. The authors are correct in their discussion of sintering times, that it is complex. After studying Figure 10, I went back to photographic data we have from Arctic Alaska, where a barchan field moves through the camera field of view in 7 hours (e.g. 30 m or about 4 m/h). But 50 hours later, when the wind shifted 180°, these same barchans marched back through the field of view, though this time at about 2.5 m/h). This seems broadly consistent with the paper's findings. What I would call the authors attention to (see their Figure 6) are the increasingly cross-hatched and scalloped tails that migrating brachans drag with them as they migrate. In the images we collected this dragged tail becomes progressively more visible the farther the feature moves, which I think means that the tail sculpting is getting deeper/higher. Hence a barchan seems to be shedding mass as it goes. It could well be worthwhile for the authors to think about this and discuss this universal feature in snow. It would also be useful to contrast snow tails to sand. I would be happy to send our images to them.
8. Barchan preservation: My mentor, Carl Benson, worked extensively in Greenland, and noted that he could not find in snow pits evidence of buried dunes or barchans. His view was that these did not last long enough or burial and preservation. Surely there have been extensive snow pits dug and stratigraphy measured at Concordia. Are dune forms and barchans preserved or not? This seems an important point.

Summary: A very interesting paper, well worth publishing. I hope the authors take some of my points to heart and do a bit more work on the paper to make it even better.

Recommendation by Associate Editor 2 (Roberto Fernandez)

Completed: 2026-03-03 08:03 PM
Recommendation: Major revisions

I've read the manuscript with great interest and the comments from the two reviewers and I recommend major revisions. Equation 6 is essential to the paper and I find, as reviewer 1, that more details need to be provided. The authors attribute the equation to Schmidt but it seems to have been available before that publication. Schmidt references Iversen and colleagues (papers from 1975, 1976, and 1980). The 1970s papers are for aeolian transport in Mars. If the equation was indeed developed to estimate transport rates in Mars, the authors should justify its use and the specific parameters chosen. The Schmidt paper mentions 'ice spheres of 220 microns' and the authors do not provide a specific number or grain size distribution. When they draw comparisons with sand barchans, they use 100 microns.
A few more issues with Eq 6 need to be discussed. The ratio between the fall velocity (which the authors should justify because the 0.75 m/s seems to be the 'standard' since 1970s and 1980s) and the threshold shear velocity is similar to the Rouse number which is used for sediment transport calculations when the particles move in suspension and not as bedload. The excess velocity term (in parenthesis) is similar to excess shear forms of bedload transport equations. I am intrigued by this transport equation that mixes both approaches.

In subaqueous environments, the shear stresses used to do sediment transport estimates needs to be separated into a part that is 'lost' to form drag (due to the bed having bedforms, i.e. not being flat) and a part that is responsible for particle transport. These approaches are called shear partitions and I encourage the authors to explore them and see if separating the wind shear between 'drag' and 'friction' will help reduce the large spread present in Figure 6d. Running a sensitivity analysis on the parameters chosen for Eq 6 is also needed.

Finally, sediment transport equations developed for other environments (e.g. fluvial) are used to estimate the transport capacity of the system. However, barchans form in environments where sediment supply is insufficient. A sediment transport equation would predict a sediment flux given the particle characteristics and the driving force of the fluid but in a setting where the material available is below the transport capacity, they would overestimate. Since sand barchans appear under depleted sediment supply, I wonder how Equation 6 and related equations in the manuscript deal with the issue. Is Eq 6 a transport capacity equation?

The shear partition, and the 'snow supply' issue might explain differences between equation estimates and actual observations. I encourage the authors to look into this in more detail.

I had some minor comments on typos etc but I do not think they are necessary at this stage. The only minor thing I'll mention is that Figures 2c and 2d should be results and not methods.

The authors have a great dataset and this paper has a lot of potential given the little amount of research on snow bedforms/barchans. I encourage the authors to spend a bit more time evaluating the implications of the choices associated with Eq 6 and do revisions/edit to make the manuscript even stronger.

Decision by Editor-in-Chief (Alice Lefebvre)

2026-03-06
Decision: Moderate revisions

Dear Marine Poizat, Jeanne Alkalla, Ghislain Picard, Laurent Arnaud, Daniel J. Nowacki, Simon Filhol, Eric Lefebvre, Clément Narteau,

Thank you for submitting your manuscript entitled "Morphodynamics of snow barchans at Concordia Station, Antarctica" to Geomorphica. I have now received two reviews and an Associate Editor recommendation (included at the bottom and/or attached to this email). I have looked at the paper, the reviews and the Associate Editor recommendation myself. All three are positive about the manuscript but also say that it should be improved before publication.

On this basis, we would like you to undertake a **moderate revision** of your manuscript. As this is a moderate revision decision, after you revise your manuscript, it will be assessed by our associate editors and may be sent to the reviewer who suggested major revisions.

Authors' responses to review comments

2026-04-15

Anonymous Associate Editor

I've read the manuscript with great interest and the comments from the two reviewers and I recommend major revisions. Equation 6 is essential to the paper and I find, as reviewer 1, that more details need to be provided. The authors attribute the equation to Schmidt but it seems to have been available before that publication. Schmidt references Iversen and colleagues (papers from 1975, 1976, and 1980). The 1970s papers are for aeolian transport in Mars. If the equation was indeed developed to estimate transport rates in Mars, the authors should justify its use and the specific parameters chosen.

We thank the Associate Editor for raising this important point. Indeed, the original formulation by J. Iversen, Greeley, White, and Pollack (1975); J. D. Iversen, Greeley, White, and Pollack (1976) was developed in the context of aeolian transport on Mars. However, this formulation was subsequently adapted and tested for blowing-snow applications by J. D. Iversen (1980); Schmidt (1982), who adjusted parameters such as particle density and threshold friction velocity to reflect snow conditions. In particular, Schmidt (1982) adapted the parametrisation for Antarctica snow transport.

The underlying physical framework of the equation remains valid for snow. The specific parameters employed in our study, including particle size, density, and threshold wind speed, are consistent with values commonly used in Antarctic snow transport studies (Amory et al., 2021). Accordingly, while acknowledging the historical origins of the equation, we respectfully submit that its use in the present study is justified and provides a physically consistent estimate of snow flux at Concordia Station. We modified the text as followed:

L254-257 We therefore used the snow transport law developed by Schmidt (1982) *(derived from J. Iversen et al. (1975); J. D. Iversen (1980); J. D. Iversen et al. (1976)), which was evaluated against in situ snow flux measurements at Mizuho Station, Antarctica (Figure 1a).*

L274-276 *However, despite the limitations in estimating the flux, in part due to the transient nature of snow, estimates made here are of the same order of magnitude of snow flux values measured in Antarctica Amory et al. (2021).*

The Schmidt paper mentions 'ice spheres of 220 microns' and the authors do not provide a specific number or grain size distribution. When they draw comparisons with sand barchans, they use 100 microns.

We thank the associate editor for pointing this out. We have clarified the particle size assumptions in the added summary table (Table 1), specifying that Schmidt (1982) used ice spheres of 220 μm, atmospheric pressure of 1000 mbar, and a temperature of −10 ◦C, whereas for comparisons we consider a representative particle size of 100 μm, atmospheric pressure of 600hPa, and temperature of −30 ◦C. Observational studies indicate that terminal fall velocities for snow particles span a broad range due to variability in size, shape, and density, typically between about 0.5 and 1.4 m s−1. Within this range, changing the assumed particle size from 220 μm to 100 μm has a limited impact on the resulting flux estimates (Satoh & Takahashi, 2006; Zawadzki, Jung, & Lee, 2010) compared to other sources of uncertainty, such as the threshold wind speed. This ensures transparency regarding the parameters used in our analyses.

Name	Parameter	Value
Wind speed	u	Measured
Grain diameter	d	$100\,\mu\mathrm{m}$
Grain density	ρ_p	$917\ \mathrm{kg\,m^{-3}}$
Air density	ρ_{air}	$0.95\ \mathrm{kg\,m^{-3}}$
Drag length	L_{drag}	$(\rho_p/\rho_f)d = 0.096$ m
Particle fall velocity	u_f	$0.75\ \mathrm{m\,s^{-1}}$
Static threshold wind speed	u_*^{th}	$0.26\ \mathrm{m\,s^{-1}}$
Aerodynamical roughness	z_0	1 mm
Von Karman constant	κ	0.4
Friction velocity	u_*	$\frac{u\kappa}{\log(z/z_0)}$
Flux on flat bed	Q_{flat}	$\frac{\rho_{air}}{g}\frac{u_f}{u_*^{th}}u_*^2(u_*-u_*^{th})$
Flux at the crest	Q_{crest}	$Q_{flat}(1+\gamma)$
Flux-up ratio	γ	$(Q_{crest}-Q_{flat})/Q_{flat}$
Dimensionless coefficient	β	6
Speed-up ratio	δ	$\beta H/L_D \approx 0.3$
Saturation length	L_{sat}	$2.2L_{drag} \approx 0.2$ m
Surface of barchan	S	$\frac{L_D H}{2}$
Turn over time	τ_{theory}	$\frac{S}{Q_{crest}}$
Left horn length	L_2	Measured
Right horn length	L_1	Measured
Length of the horns	L_{horns}	$\frac{L_1+L_2}{2}$
Width	W	Measured
Height	H	Measured
Length of the body	L_{body}	Measured
Asymmetry	a	$\frac{L_1}{L_2}$
Length of dune stoss slope	L_D	Measured
Migration rate	c	$\frac{Q_{crest}}{H}$ and measured

Table 1: Key parameters and governing equations used.

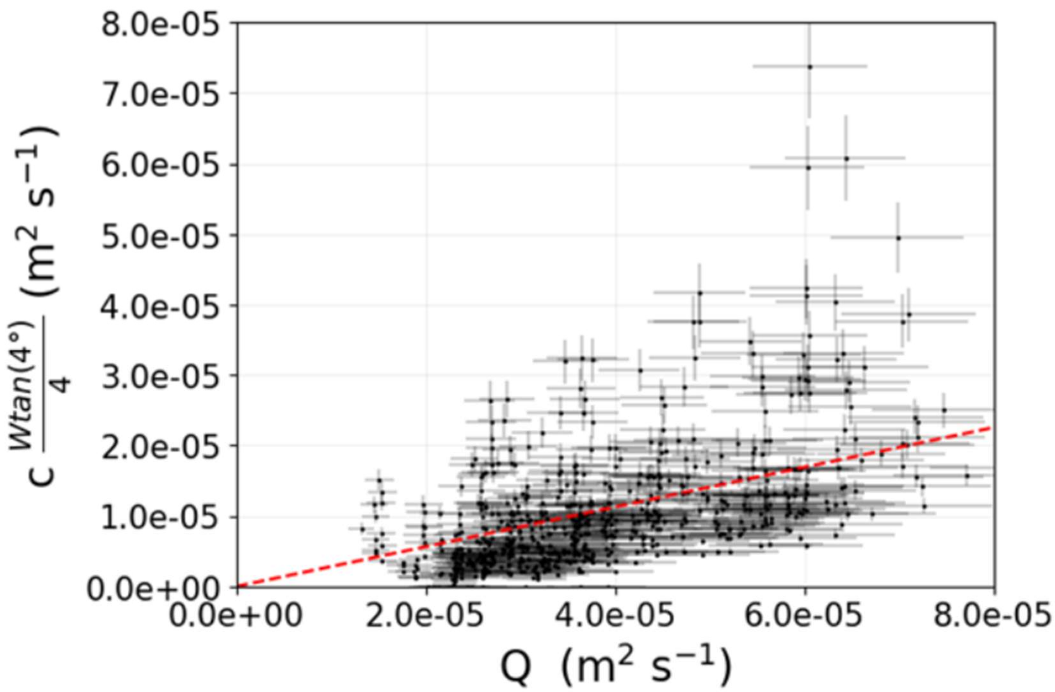
A few more issues with Eq 6 need to be discussed. The ratio between the fall velocity (which the authors should justify because the 0.75 m/s seems to be the 'standard' since 1970s and 1980s) and the threshold shear velocity is similar to the Rouse number which is used for sediment transport calculations when the particles move in suspension and not as bedload. The excess velocity term (in parenthesis) is similar to excess shear forms of bedload transport equations. I am intrigued by this transport equation that mixes both approaches. In subaqueous environments, the shear stresses used to do sediment transport estimates needs to be separated into a part that is ’lost’ to form drag (due to the bed having bedforms, i.e. not being flat) and a part that is responsible for particle transport. These approaches are called shear partitions and I encourage the authors to explore them and see if separating the wind shear between ’drag’ and ’friction’ will help reduce the large spread present in Figure 6d. Running a sensitivity analysis on the parameters chosen for Eq 6 is also needed.

We have clarified the use of a terminal fall velocity of 0.75 m s−1, which follows Schmidt (1982) and is consistent with commonly reported values for blowing-snow particles.

In addition, we performed a sensitivity analysis on the key parameters of Eq. 6, including the threshold wind speed, terminal fall velocity, and the choice of transport law. These results are now presented in the supplementary material.

Following the editor’s suggestion, we also explored the effect of shear partitioning by separating the total shear stress into a component associated with form drag and a component available for particle transport. We recomputed the flux for each contribution and compared it to the original formulation. This analysis shows no significant reduction in the spread observed in Figure 6d (see figures below, top drag and bottom friction).

This suggests that the dispersion reflects the intrinsic variability of snow transport. In particular, the snow flux varies both spatially and temporally due to evolving grain properties (size, cohesion, availability), while geometric parameters such as dune height are also subject to uncertainty and local perturbations. For instance, interactions with surrounding bedforms such as sastrugi can locally modify dune morphology, temporarily inhibit migration, or alter height estimates.



Finally, sediment transport equations developed for other environments (e.g. fluvial) are used to estimate the transport capacity of the system. However, barchans form in environments where sediment supply is insufficient. A sediment transport equation would predict a sediment flux given the particle characteristics and the driving force of the fluid but in a setting where the material available is below the transport capacity, they would overestimate. Since sand barchans appear under depleted sediment supply, I wonder how Equation 6 and related equations in the manuscript deal with the issue. Is Eq 6 a transport capacity equation?

Equation 6 indeed corresponds to a saturated flux, i.e. the flux expected under steady conditions for a given wind forcing assuming sufficient sediment availability.

We acknowledge that snow barchans typically evolve under sediment-limited conditions, such that the actual flux may be lower than the transport capacity. However, the formulation adopted here, following Schmidt (1982), assumes a cubic dependence on friction velocity, which is commonly associated with transport over rigid or supply-limited beds where the saltation length increases with wind strength (e.g. Bagnold (1941); Melo, Sigmund, and Lehning (2024). In that sense, the chosen scaling is consistent with conditions where sediment availability constrains transport.

At the same time, Eq. 6 provides a saturated flux estimate, and therefore may overestimate the actual flux when sediment supply is limited. We compared our flux estimates with available observations of blowing-snow transport in Antarctica (e.g. Amory et al. (2021)) and found that they are of the same order of magnitude. We therefore interpret more cautiously the derived fluxes as order-of-magnitude estimates, representative of transport conditions approaching saturation locally (e.g. over adjustment lengths or at dune crests. The manuscript is changed in this direction.

L258-260 *The flux is assumed to be in equilibrium with the local wind conditions and therefore to be at saturation, and actual fluxes may locally remain below these values where equilibrium conditions are not fully established.*

L269-274 *This formulation exhibits a cubic dependence on the friction velocity, which results from the assumptions that the saltation length scales as the square of friction velocity and the near surface particle velocity increases linearly with friction velocity Kok, Parteli, Michaels, and Karam (2012); Melo, Sharma, Comola, Sigmund, and Lehning (2022); Melo et al. (2024). Sensitivity to other transport law was also evaluated (Figure 13). The absolute differences of the flux between cubic, quadratic, and quartic dependencies remain generally below 50% (80th quantile) for the most frequently observed wind speeds.*

L582-583 *Given the uncertainty in flux estimation, because of threshold wind speed and parametrization choice, these values should be interpreted as order of magnitude estimates.*

The shear partition, and the ’snow supply’ issue might explain differences between equation estimates and actual observations. I encourage the authors to look into this in more detail

We agree that both snow supply limitation may contribute to discrepancies between transport law estimates and observations. In particular, snow transport is inherently complex and influenced by time-dependent changes in snow properties, such as sintering, fragmentation, and sublimation, all of which evolve spatially and at time-scale of one event. Sintering, in particular, can modify inter-particle cohesion over short timescales, thereby affecting both sediment availability and the effective transport threshold during an event.

Moreover, spatial variability in snow supply and interactions with surrounding bedforms (e.g. sastrugi) can locally enhance or inhibit transport. These combined effects likely explain a significant part of the dispersion and are now discussed in the revised manuscript. A more detailed treatment of shear partitioning and snow availability would require dedicated measurements and is beyond the scope of the present study

L415-425 However, without direct flux measurements, we cannot constrain the *static* threshold wind speed in the field where the environmental conditions change, and snow undergoes metamorphism. *However, in our observations, wind speeds measured when snow transport is visible on the barchans range between 5 m s−1 to 12 m s−1, indicating that the transport threshold must lie within these values (or be lower), but this threshold is probably different variable across events. These values are consistent with previous studies in Antarctica, which report thresholds between 5 m s−1 to 12 m s−1 depending on snow cover conditions (e.g., presence of fresh snow), 5.6 m s−1 for small particles and 7.2 m s−1 for coarser particles or 5 m s−1 at Mizuho station (Amory, 2020; Leonard, Tremblay, Thom, & MacAyeal, 2012; Nishimura & Nemoto, 2005). The value used here therefore lies on the lower end of the range reported in Antarctic studies, which is consistent with the relatively smaller particle sizes expected at Concordia. Therefore, we used a unique representative mean value over space and time, which might contribute this variability.*

L626-631 *Snow transport is complex and influenced by time-dependent changes in snow properties, such as sintering, fragmentation, and sublimation, which can evolve over the course of a single transport event. Sintering, in particular, can rapidly modify inter-particle cohesion, thereby affecting both sediment availability and the effective transport threshold. In addition, spatial variability in snow supply and interactions with surrounding bedforms (e.g. sastrugi) can locally enhance or inhibit transport. These combined effects likely account for a significant part of the observed dispersion.*

I had some minor comments on typos etc but I do not think they are necessary at this stage. The only minor thing I'll mention is that Figures 2c and 2d should be results and not methods.

We thank the editor for this suggestion. To improve the structure of the manuscript, we have separated Figures 2c and 2d from Figures 2a and 2b. The former are now presented in the Results section (Figure 3), while the latter remain in the Methods section (Figure 2). A new figure has been created accordingly to reflect this distinction more clearly.

The authors have a great dataset and this paper has a lot of potential given the little amount of research on snow bedforms/barchans. I encourage the authors to spend a bit more time evaluating the implications of the choices associated with Eq 6 and do revisions/edit to make the manuscript even stronger.

Again, we thank the reviewers and editors for their constructive contribution to our paper.

Reviewer 1

The paper reports a field study of snow barchans at Concordia Station. The authors document the morphology and migration of snow barchans over a six-year period. They highlight that snow barchans obey the same scaling laws as those observed for sand barchans in air and water. They also argue that sintering processes limit the size of active barchan dunes and preserve their shapes when wind speeds fall below the transport threshold. In addition, the authors indicate that, during wind events, barchan dunes are highly reactive to changes in wind direction due to their small size. I am impressed that the authors succeeded in collecting valuable data on snow barchans in such an inhospitable climate, and I believe that this field study is worthy of publication. However, I feel that the authors should avoid overstating their conclusions, as some aspects of the analysis are based on assumptions that cannot be directly confirmed by field measurements, in particular those concerning snow drifting and the transport threshold. Below, I list several issues that should be clarified prior to publication. 1) Introduction: Eq. 4, concerning the mass flow rate at the crest and presented in the Introduction, is understandable. However, the authors introduce a speed-up parameter δ, which is related to the aspect ratio of the dune, without explicitly stating the relationship between δ and γ. This relationship is explained later in the manuscript, and I therefore suggest avoiding such a level of detail in the Introduction before all relevant information is provided.

We thank the reviewer for this helpful suggestion. To improve the clarity and logical progression of the manuscript, we have simplified the Introduction by removing Equations 2–4, including the expression for the crest flux and the associated parameters. These equations are now introduced in a dedicated section of the Methods (Section 3.2.1, "Migration rate and fluxes", L219–236). As suggested, this restructuring avoids introducing parameters before they are fully explained and improves the overall readability of the manuscript.

2) Methods: Snow flux

– The sand transport law from Schmidt (Eq. 6) exhibits a cubic dependence on the friction velocity, whereas the equivalent transport law for aeolian sand transport is quadratic. Can the authors comment on this difference?

The dependence of sediment transport flux on friction velocity varies depending on the assumptions used to derive the transport law and the physical conditions of transport. A quadratic dependence is typically obtained for erodible beds, where the saltation length is assumed to be approximately independent of friction velocity. In contrast, a cubic dependence arises in formulations where the saltation length increases with friction velocity, for example when transport occurs over rigid or supply-limited beds (Bagnold, 1941; Melo et al., 2024). These different scaling can also be interpreted in terms of transport regimes: aerodynamic entrainment tends to lead to quadratic relationships, whereas regimes dominated by splash processes may produce cubic scaling (Melo et al., 2024).

In this study we adopt the formulation proposed by Schmidt (1982), which leads to a cubic dependence on friction velocity and has been widely used in blowing-snow studies. However, we acknowledge that alternative formulations are possible. To evaluate the potential impact of this choice, we compared the resulting snow flux with that obtained using a quadratic transport law (Pomeroy and Gray (1990) formulation), which is commonly used in snow transport models over Antarctica (Amory et al., 2021). The comparison is added to the supplementary material in the new version. We have clarified these assumptions and added the comparison of flux laws in the supplementary information. Based on the conditions at Concordia Station, where precipitation is low and saltation is likely supply-limited, we expect the cubic scaling to be more appropriate, although direct measurements are not available to evaluate this choice.

Integrated mass flux (kg m^{-1} s^{-1})	Constant parameters	References	Friction velocity dependency
$Q_{PG} = C\frac{\rho_{air}}{g} u_*^{th}(u_*^2 - (u_*^{th})^2)$	$C = 0.68$	Pomeroy and Gray et al., 1990	Quadratic
$Q_{Sc} = \frac{\rho_{air}}{g}\frac{u_f}{u_*^{th}} u_*^2(u_* - u_*^{th})$	$u_f = 0.75\,m\,s^{-1}$	Schmidt, 1982	Cubic
$Q_B = C\frac{\rho_{air}}{g} u_*^3\sqrt{\frac{d}{d_R}}$	C=1.5 or C = 2.8	Bagnold, 1941	Cubic
$Q_{Sa} = 2\alpha\frac{\rho_{air}}{g}(u_*^2 - (u_*^{th})^2) \left(u_*\frac{2}{\kappa}\sqrt{(\frac{z_1}{z_m} + (1 - \frac{z_1}{z_m})\frac{(u_*^{th})^2}{u_*^2})} - \frac{2u_*^{th}}{\kappa} + u_{st}\right)$	$C_d = 3, \alpha = 0.35, z_1 = 0.005\,m, z_m = 0.04\,m$	Sauermann et al., 2001	Cubic
$Q_P = \sqrt{\frac{2\Theta_{th} d\rho_{air}}{\kappa\mu(\rho_P - \rho_{air})g}}(u_*^2 - (u_*^{th})^2) (1 + \frac{\rho_{air} C_M}{gd\mu(\rho_P - \rho_{air})}(u_*^2 - (u_*^{th})^2))\rho_P$	$C_M = 1.7$	Pähtz et al., 2020	Quartic

Table 2: List of some commonly used saltation mass flux relations.

We changed the text as follows :

L269-274 *This formulation exhibits a cubic dependence on the friction velocity, which results from the assumptions that the saltation length scales as the square of friction velocity and the near surface particle velocity increases linearly with friction velocity Kok et al. (2012); Melo et al. (2022, 2024). Sensitivity to other transport law was also evaluated (Figure 13). The absolute differences of the flux between cubic, quadratic, and quartic dependencies remain generally below 50% (80th quantile) for the most frequently observed wind speeds*

The authors also provide values for the parameters of this transport law, such as the transport threshold and the terminal velocity. However, the particle size is not specified, and it is unclear whether these values are kept constant in the subsequent analyses. Do these values correspond to cohesionless snow or to sintered snow? Are they applicable to conditions at Concordia Station?

In the transport law used here, the particle size directly affects the terminal fall velocity only. The terminal velocity depends on the particle size distribution and density of snow particles. The value used in this study is taken from Schmidt (1982), corresponding to an ice sphere with a diameter of 220 μm, atmospheric pressure of 1000 mbar, and a temperature of −10 ◦C, which are commonly used reference conditions for snow particles. In the present analysis, we use this value even if our conditions are different, and it is kept constant. Observations indicate that terminal fall velocities for snow particles typically range between 0.5 and 1.4 m s−1, depending on particle size, shape, density (Satoh & Takahashi, 2006; Zawadzki et al., 2010). We added a sensitivity analysis of the terminal velocity over the flux in the supplementary information.

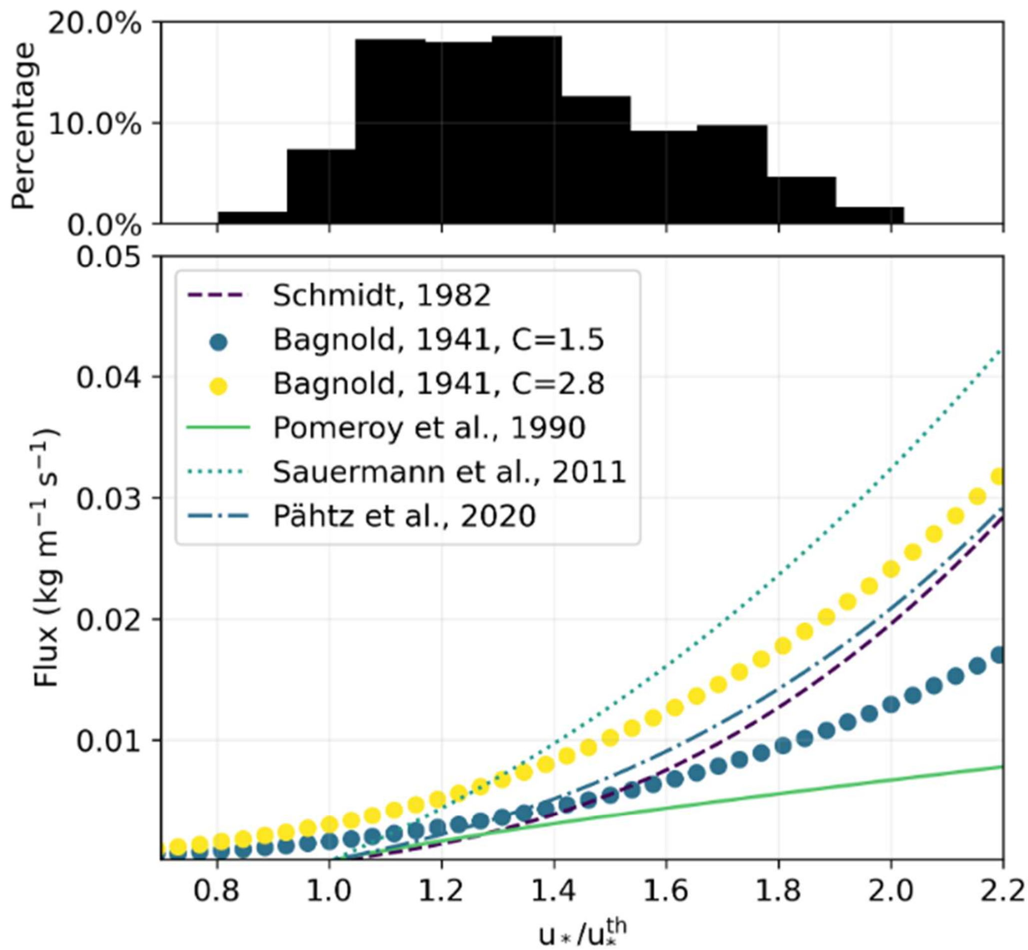


Figure 1: (Bottom) Comparison of the different flux relations as a function of normalized friction velocity. (Top) Distribution of the wind speed measured during barchan events, illustrating the range of conditions over which the transport models are evaluated.

For sake of clarity, we have added a summary table in the manuscript listing all equations and parameter values used in the study. No direct measurements of terminal fall velocity are available at Concordia Station; therefore, we adopt values commonly used in blowing-snow studies. A sensitivity analysis, added in the supplementary material, shows that the impact of terminal velocity on flux calculations is more pronounced at higher wind speeds.

L264-269 *Sensitivity to the threshold wind speed (Figure SI4), which was reported between 5 m s−1 to 12 m s−1 in Antarctica depending on snow cover conditions, and terminal fall velocity, which typically range between 0.5 m s−1 to 1.4 m s−1 depending on particle size, shape, density (Satoh & Takahashi, 2006;*

Zawadzki et al., 2010), were evaluated (Figure SI3), indicating that the uncertainty associated with the threshold wind speed is larger than that associated with the terminal fall velocity.

Direct measurements of the threshold wind speed for snow transport are not available at Concordia Station. Moreover, this threshold is known to vary substantially in space and time depending on surface snow properties and the presence of particle sources such as freshly precipitated snow. It is a complex function of particle size, shape, age and local environmental conditions such a humidity and wind. In our observations, wind speeds measured when snow transport is visible on the barchans range between 5 and 12 m s−1, indicating that the transport threshold must lie within these values (or be lower), but this threshold is probably different variable across events. These values are consistent with previous studies in Antarctica, which report thresholds between 5 and 12 m s−1 depending on snow cover conditions (e.g., presence of fresh snow) (Amory, 2020). Other studies report thresholds of about 5.6 m s−1 for small particles (Leonard et al., 2012), and around 5 m s−1 at Mizuho Station (Nishimura & Nemoto, 2005). The value used here therefore lies on the lower end of the range reported in Antarctic studies, which is consistent with the relatively smaller particle sizes expected at Concordia. This threshold should be not interpreted as an exact value, but rather as a representative mean over space and time. We highlighted those difficulties by adding details in the text:

L59-64 *The combination of wind reworking, topography, and layered history produces surfaces where snow patches of different age and history are exposed side by side (Picard, Arnaud, Caneill, Lefebvre, & Lamare, 2019). As a result, the snow exposed to the wind exhibit great variability in size, shape and sintering state, both in time and space. So, unlike sand, snow is highly dynamic material, whose properties can evolve even within a single transport event, including during dune migration.*

L412-425 This *static* threshold is known to vary widely both in space and time, depending on the snow characteristics (e.g., grain size, He & Ohara, 2017) and environmental parameters (e.g., air temperature, Li, 1997), *and is especially sensitive to cohesion (Selmani, Besnard, Ould El Moctar, Dupont, & Valance, 2024).* However, without direct flux measurements, we cannot constrain the *static* threshold wind speed in the field where the environmental conditions change, and snow undergoes metamorphism. *However, in our observations, wind speeds measured when snow transport is visible on the barchans range between 5 m s−1 to 12 m s−1, indicating that the transport threshold must lie within these values (or be lower), but this threshold is probably different variable across events. These values are consistent with previous studies in Antarctica, which report thresholds between 5 m s−1 to 12 m s−1 depending on snow cover conditions (e.g., presence of fresh snow), 5.6 m s−1 for small particles and 7.2 m s−1 for coarser particles or 5 m s−1 at Mizuho station (Amory, 2020; Leonard et al., 2012; Nishimura & Nemoto, 2005). The value used here therefore lies on the lower end of the range reported in Antarctic studies, which is consistent with the relatively smaller particle sizes expected at Concordia. Therefore, we used a unique representative mean value over space and time, which might contribute to this variability*

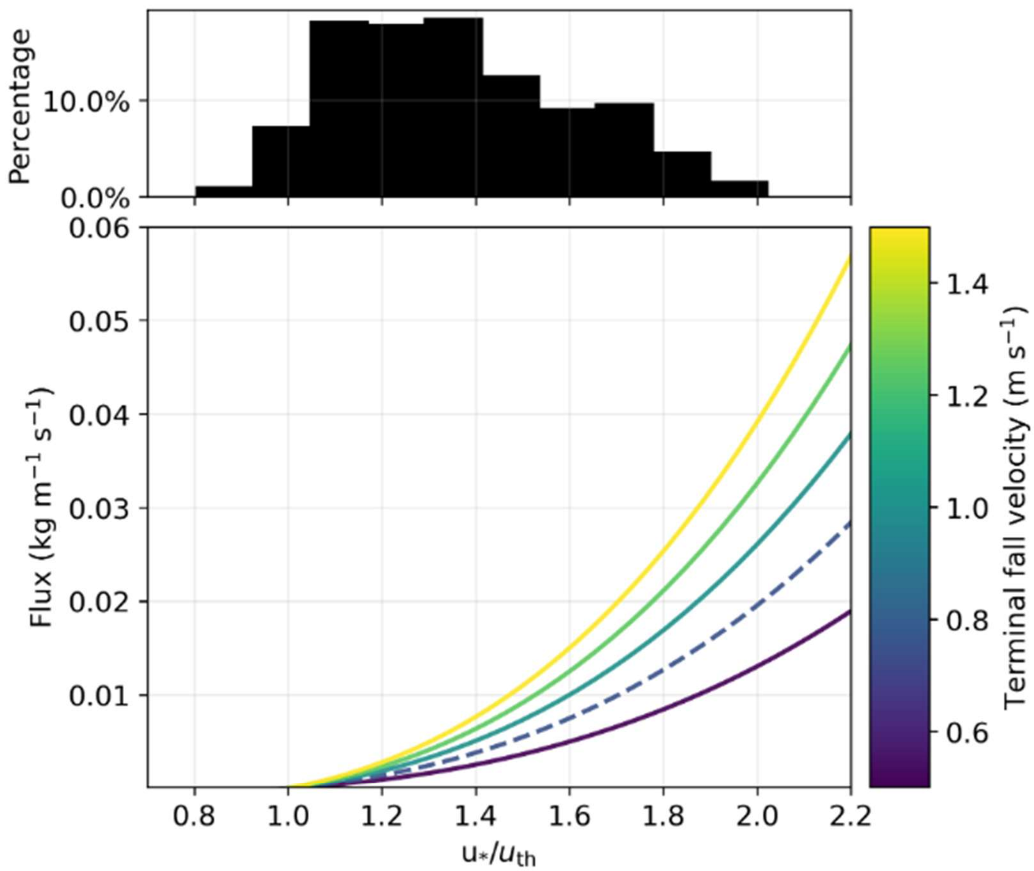


Figure 2: (Bottom) Comparison of the flux from Schmidt (1982) for different fall velocity values as a function of normalized friction velocity. Dashed line is for a terminal fall velocity of 0.75 m s^{-1}, which is the value used in this study. (Top) Distribution of the wind speed measured during barchan events, illustrating the range of conditions over which the transport models are evaluated.

To provide additional insight, we evaluated the sensitivity of the transport flux to the threshold wind speed, using the range of minimum wind speeds measured during barchan migration events. This analysis, added as a figure in the supplementary material, shows that the choice of threshold wind speed has a significant impact on the predicted fluxes. This highlights that the uncertainty associated with the threshold wind speed is larger than that associated with the terminal fall velocity.

- The authors do not discuss the existence of two distinct transport thresholds, namely the static and dynamic thresholds. For cohesive particles, these two thresholds can differ significantly: the static threshold is expected to increase with sintering, whereas the dynamic threshold is much less sensitive to cohesion (see, for example, Selmani et al., PRF 2025). This raises the question of which transport threshold should be used in the transport law. I believe this issue should be discussed in more detail.

Two distinct thresholds for transport can be indeed defined: a static threshold for initiating motion; and a dynamics for sustaining transport. For non-cohesive particle, the dynamics threshold is usually lower, around 80% of the static threshold (Bagnold, 1941; J. Iversen et al., 1975).

In this study, the transport law uses the static threshold, consistent with Schmidt (1982). As pointed out, the static threshold is more sensitive to cohesion. Some models try to capture this dependency (Gall´ee, Guyomarc'h, & Brun, 2001; Guyomarc'h & M´erindol, 1998; Lehning, Doorschot, & Bartelt, 2000). For snow, some studies suggest the dynamic threshold can be lower than the static threshold (Niiya & Nishimura, 2017), while others predict that it can be higher(Melo et al., 2022; Nemoto & Nishimura, 2004) depending notably on snow cover conditions. Moreover, for the same initial snowpack conditions, the dynamic threshold varies depending on the duration of the event (Li, 1997).

Given these complexities, including spatial and temporal variability of the thresholds and the influence of particle sources such as precipitation, the uncertainty in both static and dynamic thresholds is large. We use the static threshold as a representative mean value. We clarify in the manuscript which threshold is used

L263-264 the *static* threshold wind speed for snow transport (i.e., *the wind speed needed to initiate transport*

L413-415 This *static* threshold is known to vary widely both in space and time, depending on the snow characteristics (e.g., grain size, He & Ohara, 2017) and environmental parameters (e.g., air temperature, Li, 1997), textitand is especially sensitive to cohesion (Selmani et al., 2024).

L557-558 when the wind speed falls below the *dynamic* threshold speed for transport,*which is the wind speed needed to maintain transport,*

– Another important issue concerns the saturation of the snow flux. Eq. 6 is expected to provide the saturated flux, whereas it is well known that for cohesive particles such as snow, the distance required to reach saturation can be much greater than the drag length used to estimate the minimum dune size. This issue should therefore be discussed in more detail.

Eq.6 indeed follows the formulation of Schmidt (1982) and represents an equilibrium (saturated) transport flux formulation derived from steady-state saltation theory. As in classical aeolian transport models originally proposed byBagnold (1941), the formulation assumes that the saltation layer has reached equilibrium between entrainment and deposition. We agree that for cohesive particles such as snow, the distance required to reach this equilibrium can be significant, and therefore the predicted flux should be interpreted as a potential saturated transport rate.

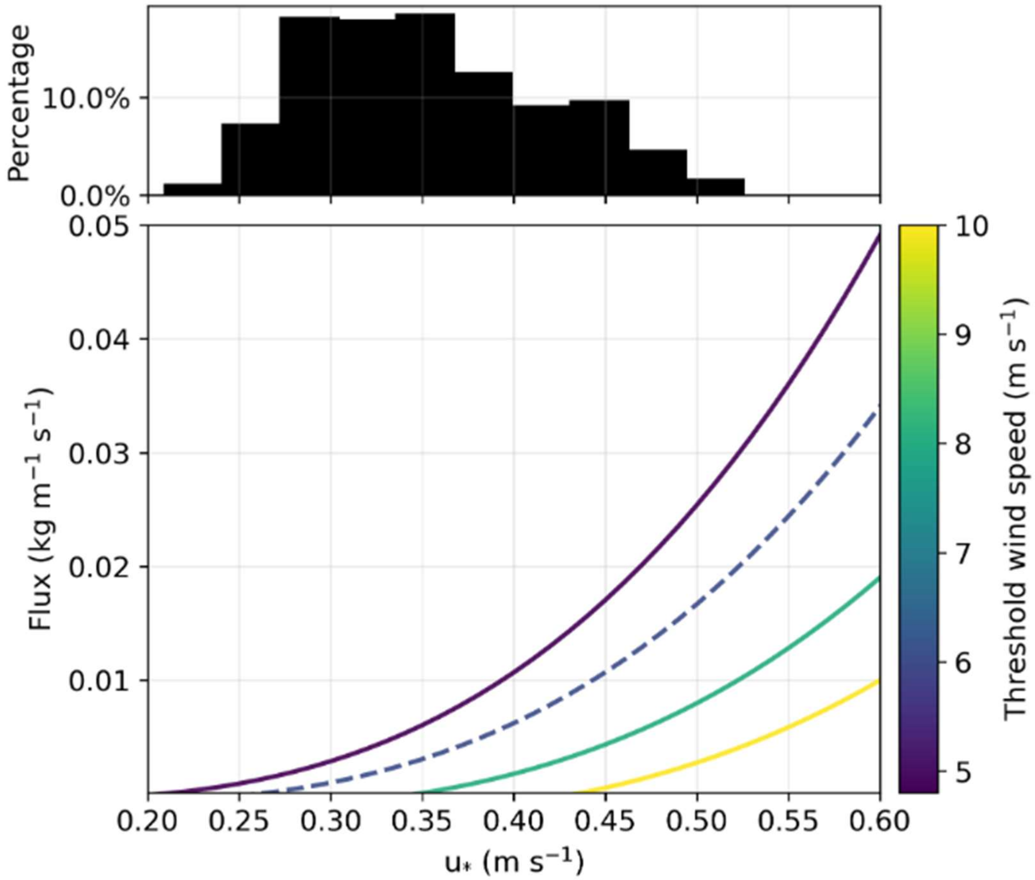


Figure 3: (Bottom) Comparison of the flux from Schmidt (1982) for different threshold values. Dashed line is for a threshold speed of 6 m s^{-1} at 10 m height, which is the value used in the article. (Top) Distribution of the wind speed measured during barchan events, illustrating the range of conditions over which the transport models are evaluated.

This therefore implies that the actual transport rate may locally remain below the saturated flux predicted by Eq.(6).

In the context of this study, Equation (6) is used as a first-order estimate of potential transport under the assumption that the flow has sufficient fetch to approach equilibrium conditions.

L258-260 *The flux is assumed to be in equilibrium with the local wind conditions and therefore to be at saturation, and actual fluxes may locally remain below these values where equilibrium conditions are not fully established.*

– Finally, given that Eq. 6 relies on several assumptions (transport threshold, degree of saturation) that cannot be directly verified in the field, what level of confidence can be placed in the subsequent analysis based on the transport law given by Eq. 6?

As points out by the reviewer, this transport law has sensitivity on both the parametrisation of the transport law, (mainly threshold speed), and the transport law with dependency on friction velocity. With the absence of direct measurements, the estimated flux is somehow uncertain, but it is of similar order of magnitude of observation in other part of Antarctica (Amory, 2020). In addition, snow flux is not solely controlled by wind shear, but also depends on the properties of snow grains and those properties evolve during transport. For example, blown snow grains undergo sublimation, particularly efficient because grains surfaces are exposed to unsaturated air, which modifies their size and shape (Bordiec et al., 2020; Comola, Kok, Gaume, Paterna, & Lehning, 2017; Sharma, Comola, & Lehning, 2018). Snow grain properties are therefore continuously evolving over the course of transport.

Even with snow-specific formulations, flux calculations remain inherently uncertain. Key grain properties, such as density, size distribution, and cohesion, evolve due to sintering, sublimation, and wind-induced fragmentation, making transport rates time and space-dependent. Consequently, the flux values derived here should be interpreted as approximates for instantaneous transport conditions, constrained by the best available observations and by formulations tailored for snow, but still limited by the transient nature of the material. Snow flux therefore reflects both aerodynamic forcing and the evolving properties of the material, making it intrinsically more variable and more difficult to parameterize than sand flux.

In short, snow flux depends not only on wind speed but also on snow surface and subsurface conditions and is therefore intrinsically variable (Sturm & Stuefer, 2013).

In the manuscript, the analysis that depends on the transport law include : (i) the relationship between the snow flux and dune migration. (ii) characteristic time of reorientation of snow barchans. (iii) characteristic time of sintering in Section 5.2. To assess the robustness of our results, we compared different transport formulations, including those of Dur´an, Claudin, and Andreotti (2011) and Sauermann, Kroy, and Herrmann (2001). These lead to relationships such as cH = 0.7 Qflat and cH = 0.95 Qflat, which are not physically consistent, indicating that such formulations are not directly applicable to snow in our study conditions. We further evaluated the sensitivity of our results to the threshold wind speed using the Schmidt formulation. We evaluated its sensitivity to the threshold wind speed by varying it between 4 m s−1 to 8 m s−1, which produced γ values ranging between -0.3 and 3.5.

The impact of the wind threshold speed on the characteristic time of reorientation of snow barchans was evaluated in Figure 9. Regarding the sintering timescale (iii), which is already estimated over a broad range, variations in the transport law do not significantly alter our conclusions.

Overall, while the calculation of snow flux relies on several assumptions and remains uncertain, we think that the underlying physical framework is robust and provides meaningful insight into snow transport processes and dune dynamics, and the added sensitivity analysis also help understanding the limit and future research needed. We modify the text as follows

L51-61 *Unlike sand, snow is a warm material as it exists near its fusion temperature under the temperature conditions at the Earth's surface. Consequently, snow undergoes metamorphism, therefore impacting its mechanical and thermodynamic properties. One effect, relevant to snow bedforms, is sintering. Sintering is the progressive formation of ice bonds between grains, gradually increasing cohesion, making snow harder the longer particles remain in contact and the smaller they are (Colbeck, 1997; Schweizer, Bruce Jamieson, & Schneebeli, 2003). Sintering occurs as the system seeks to minimize the free surface energy of the ice grains. The sintering process operates over different time scales, from seconds to* *hours, and is strongly influenced by environmental parameters, such as wind, humidity and surface temperature (Bernache-Assollant, 1993; Blackford, 2007; Herwijnen & Miller, 2013; Szabo & Schneebeli, 2007). The combination of wind reworking, topography, and layered history produces surfaces where snow patches of different age and history are exposed side by side (Picard et al., 2019).*

L274-276 *However, despite the limitations in estimating the flux, in part due to the transient nature of snow, estimates made here are of the same order of magnitude of snow flux values measured in Antarctica (Amory, 2020)*

L362-366 *To evaluate the robustness of γ, we evaluated its sensitivity to the threshold wind speed by varying it between 4 m s−1 to 8 m s−1, which produced γ values ranging between -0.3 and 3.5. Similarly, we also varied the particle terminal fall velocity between 0.5 m s−1 to 1.4 m s−1, resulting in γ values between 0.26 and 2.54. As expected γ is sensitive to the flux parametrisation, especially to threshold wind speed which is expected to vary between events.*

L582-586 *Given the uncertainty in flux estimation, including threshold wind speed and parametrization, these values should be interpreted as order of magnitude estimates. Despite these uncertainties, the estimates are broadly consistent with the sintering time scales inferred from observations of barchan mobility, thereby suggesting that snow bedforms may serve as useful proxies for the quantification of snow processes in environments where such features form.*

3) Snow barchan morphodynamics and Discussion:

– I feel that the analysis reported in these sections (e.g., Section 4.3.2 on the snow transport threshold and Sectio 5 on the characteristic length scales for snow barchans) should be revised, or at least that the statements and conclusions should be more cautiously stated, given the issues listed above.

We thank the reviewer for this comment. We have revised the relevant sections to state our conclusions more cautiously, explicitly acknowledging the uncertainties associated with snow flux estimation, threshold wind speeds, and transport law assumptions. The text now emphasizes that the derived characteristic length scales and transport thresholds represent our best estimates considering the available observations and modeling framework, rather than exact or universal values.

L454-456 *Therefore, while the formulation of snow flux remains associated with uncertainties, more accurate flux estimates could help refine the constraints on threshold wind speeds inferred from barchan migration.*

L579-586 For a typical estimated value of the transport rate at the crest of dunes, Qcrest = 10−5 m2 s−1 (Figure 7), and for snow barchans with maximum lengths of 5 and 10 m (Figure 5a) the *resulting* characteristic times for sintering are *approximately* 18 hours and 3 days, respectively. *Given the uncertainty in flux estimation, because of threshold wind speed and parametrization choice, these values should be interpreted as order of magnitude estimates. Despite these uncertainties, the estimates are broadly consistent* with the sintering time scales inferred from observations of barchan mobility, thereby *suggesting that snow bedforms may serve as useful* proxies for the quantification of snow processes in environments where such features form

3 Reviewer 2
Review of Morphodynamics of snow barchans at Concordia Station, Antarctica
Geomorphica

In this paper, the authors use a unique and extensive set of photogrammetric measurements of snow barchans at Concordia, Antarctica to examine the shape, size, and migration of barchans. The paper is clear, informative, well-referenced, and with minor revision is ready publication. What follow are my suggestions to improve the paper, based on 45 years of mostly anecdotal, but frequent, field observations of barchans and dunes in Alaska, Antarctica,and on sea ice while they are forming and mobilized.

1. The authors use a framework of snow barchans as "fast" analogs for sand barchans. As a snow scientists this offends me. Snow barchans are almost certainly more widespread than sand barchans, and therefore worthy of attention in their own right. In all seriousness, I think the paper would be better off being framed around snow mostly, with a separate section called "What do snow barchans tell us about sand barchans?" in the discussion. Using the equations for sand is OK, but it left me thinking I would learn about sand dunes, which I did not. Since the paper is already quite long, I think focusing on snow, then briefly contrasting snow results to sand would streamline the flow without losing any relevant information.

We agree that snow barchans are worthy of study in their own right. Snow bedforms are indeed widespread in nature, less in the literature, and present specific physical characteristics, particularly related to the cohesive nature of snow, which distinguishes them from sand dunes.

Our intention in using snow barchans as "fast" analogs of sand barchans was to place our observations within the well-developed theoretical framework that exists for sand dunes. A substantial work has established methods and physical interpretations for sand barchans, and using this framework allows us to connect our observations to the broader understanding of dune dynamics. However, we agree that the framing of the manuscript should more clearly emphasize the snow system itself. In response to the reviewer's suggestion, we have modified the introduction to highlight snow barchans as the primary focus of the study. We also renamed the discussion section from "Distinctive characteristics of snow barchans and similarities with sand barchans" to "Snow and sand barchans, what can they learn from each other?" in order to clarify this perspective.

We believe this revised structure better emphasizes the importance of snow barchans while still allowing insightful comparisons with the extensive literature on sand dunes.

L44-66 *Applying these concepts to snow requires accounting for its unique properties. Snow is a granular material that can precipitates from the sky and accumulate in layers to form snowpacks, which in exposed regions (tundra, sea ice, ice caps, and alpine regions) are reworked by wind. This re-mobilization by wind has multiple consequences for snow: 1) mass may be eroded and deposited in preferential locations in relation to terrain topography (Liston & Sturm, 1998), 2) particles when entrained break in smaller pieces (Comola et al., 2017), 3) sublimation of ice into the atmosphere is enhanced (Bordiec et al., 2020; Gadde & family=Berg, 2024; Palm, Kayetha, Yang, & Pauly, 2017), and 4) self-organized structures, snow bedforms,* *form at the snow surface (Filhol & Sturm, 2015; Mather, 1962). Unlike sand, snow is a warm material as it exists near its fusion temperature under the emperature conditions at the Earth's surface. Consequently, snow undergoes metamorphism, therefore impacting its mechanical and thermodynamic properties. One effect, relevant to snow bedforms, is sintering. Sintering is the progressive formation of ice bonds between grains, gradually increasing cohesion, making snow harder the longer particles remain in contact and the smaller they are (Colbeck, 1997; Schweizer et al., 2003). Sintering occurs as the system seeks to minimize the free surface energy of the ice grains. The sintering process operates over different time scales, from seconds to hours, and is strongly influenced by environmental parameters, such as wind, humidity and surface temperature (Bernache-Assollant, 1993; Blackford, 2007; Herwijnen & Miller, 2013; Szabo & Schneebeli, 2007). The combination of wind reworking, topography, and layered history produces surfaces where snow patches of different age and history are exposed side by side (Picard et al., 2019). As a result, the snow exposed to the wind exhibit great variability in size, shape and sintering state, both in time and space. So, unlike sand, snow is highly dynamic material, whose properties can evolve even within a single transport event, including during dune migration.* In this context, to demonstrate that snow barchans can serve as a useful model for the characterization of bedform and aeolian transport, especially in the presence of cohesion forces, a brief introductory section is devoted to the relevant properties of sand barchans.

2. There are many useful flux, wind speed, and geometric formulae in the paper, and some from the sand literature, all of which I found interesting. But eventually, as a reader, there are too many to keep track of, and see their relationships in one's mind. We know wind drives snow flux, which feeds barchan growth, with produces geometry. It is all useful, but a summary table of the equations, and some effort to package these in a way that keeps their inter-relationships clear, would be very useful

To improve clarity and make the relationships between variables more accessible, we have added a summary table (Table 1) compiling the main equations, parameters, and their defining equation. This table should help guide the reader through the different formulations used in the manuscript, and clarify which parameters are measured and which are kept constant.

3. This is a pet peeve, but (line 112) our paper (Filhol and Sturm, 2015; Section 4) clearly introduces the sintering time clock as a control on size. It would be nice for this to be acknowledged. Similarly (and I can indulge in a bit of lecture to a younger generation after 46 years of working in snow blizzards), the authors slight older works on barchans that deserve mention: e. g. Moss (1938), and Doumani (1967). The latter work in fact states "... the advance of barchanoids on hard, glazed snow surfaces is faster than on soft... " which possibly relates to the authors' contention concerning barchans on sea ice. The authors might even want to find a copy of Cornish (1902- On snow-waves and snow-drifts in Canada, with notes on the" snow-mushrooms" of the Selkirk Mountains. The Geographical Journal, 20(2), 137-173.) By 1902, the form and the fact that the barchans migrated was well know. Basically, if authors of an article today hope to have their work to have a long residence time in the pool of knowledge, then they need to be careful to credit older work themselves.

We respectfully thank the reviewer for providing a longer perspective and highlighting these important references. We have revised the manuscript to better acknowledge earlier work on snow barchans and drifting snow. In particular, we now explicitly cite Filhol and Sturm (2015) regarding the role of sintering timescales in controlling dune size.

We have also incorporated the suggested historical references, including Moss (1938), Doumani (1967), and Cornish (1902), where relevant. These studies provide valuable early observations of snow bedform morphology and migration, and we now better situate our results within this broader historical context. In particular, the observations of faster migration over hard, glazed surfaces reported by Doumani (1967) are now discussed in relation to our interpretation of barchan dynamics over sea ice.

L572-574 *Filhol and Sturm (2015) suggested that sintering is acting against the growth of dunes, as snow grains need to be remobilized before being sintered. Therefore, they suggested that sintering is limiting dune growth and age.*

L528-529 *It was for example observed than barchanoid move faster on glazed snow Doumani (1967).*

L74 and L549 for other citations

4. Noise and Interaction: There is little discussion in the text of the impact of other snow structures (dunes, sastrugi, old vs. new surfaces) on morphology, yet (as in the authors' Figures 6, 7, 10, and 10) clearly such interactions were taking place everywhere. These figures are wonderful images, but some discussion of the impact of noise (e.g., other structures impacting barchan geometry) and interaction (collision of features) seems necessary.

We have added a discussion in the manuscript addressing the role of interactions between snow bedforms and surrounding surface structures. In particular, we now highlight how neighbouring features such as sastrugi and other dunes can influence barchan morphology and migration, and contribute to the observed variability.

L552-556 *As in sand systems, snow barchans also collide (Hersen & Douady, 2005), and their migration is influenced by other nearby bedforms of similar size, such as sastrugi, which can partially explain the variability we observed as they can stop barchans migration (Kochanski, Anderson, & Tucker, n.d.). These interactions, however, remain poorly characterized in snow, and further studies are needed to quantify the effects of collisions and neighboring bedforms on snow barchan dynamics.*

5. Barchans on sea ice: The reference for this is no longer available on-line, so I don't know what was done, but I question whether one example is enough on which to base the rule. I have spent about half my snow career on sea ice. Here are my thoughts: If the authors' read through Doumani (1967) and return to Bagnold's work, they will recall that the material flux for barchans is both saltation and creep (rolling), and which may dominate in building barchans I am not sure is known. I have frequently witnessed creep to be greatly enhanced on glazed snow surfaces and on bare sea and lake ice . . . .but only when here are no frost feathers of surface rime and hoar have grown on the ice (which is common). When the latter conditions prevail, then the ice is actually rougher than

a normal snow surface and potentially reduces creep and maybe even saltation. So one example from sea ice is not enough to conclude anything general.

We thank the reviewer for sharing this valuable information. We agree that a single observation on sea ice is not sufficient to draw general conclusions. We have therefore revised the manuscript to adopt a more cautious interpretation and to better reflect the variability of surface conditions on sea ice. In particular, we now acknowledge the role of surface state (e.g., glazed ice versus the presence of frost, hoar, or roughness elements) in modulating snow transport processes, in line with the observations of Doumani (1967).

L527-533 On ice, snow can be more easily eroded and redistributed *in the absence of frost or hoar. It was for example observed than barchanoid move faster on glazed snow (Doumani, 1967).* Although the available snow supply may be limited, its cohesion to the substrate is weaker, making mobilization more efficient. This *reduced threshold for transport likely explains the elongated shapes of barchans observed on sea ice (Bintanja, Lilienthal, & T¨ug, 2001; Liston et al., 2000). However, this behaviour is probably not universal across all sea-ice conditions, as surface conditions of sea ice can vary substantially. The presence of frost, hoar, or other roughness elements may instead inhibit transport and modify dune dynamics*.

6. Threshold wind speed: I have read a dozen or more papers trying to nail down this speed. I have even written several papers in which I tried to do the same (cf. Sturm, M., & Stuefer, S. (2013). Wind-blown flux ratesderived from drifts at arctic snow fences. Journal of Glaciology, 59(213), 21). As the authors correctly conclude, the threshold wind speed is a range, a very complex function of the age, particle size and shape, humidity and wind speed. Even our understanding of the transport modes is probably a too-simple abstraction (see Aksamit, N. O., & Pomeroy, J. W. (2016). Near-surface snow particle dynamics from particle tracking velocimetry and turbulence measurements during alpine blowing snow storms. The Cryosphere, 10(6), 3043-3062.). While there is nothing wrong with Figure 9, I am not sure it is needed, and as before, the paper could be shorter.

We thank the reviewer for highlighting the inherent complexity and variability of the threshold wind speed. We fully agree that this threshold cannot be described by a single value and depends on multiple evolving snow and atmospheric properties, as also discussed in the manuscript.

Figure 9 is intended to provide an independent constraint on the range of plausible threshold wind speeds by linking them to the observed reorientation times of snow barchans. In this sense, it illustrates how barchan dynamics can be used as an integrative indicator of snow transport conditions. For this reason, we believe that the figure adds value to the manuscript by connecting observations to transport parameters that are otherwise difficult to measure directly.

To address the reviewer’s concern, we have clarified the purpose of this figure in the text and slightly streamlined the associated discussion to improve readability.

L413-425 This *static* threshold is known to vary widely both in space and time, depending on the snow characteristics (e.g., grain size, He & Ohara, 2017) and environmental parameters (e.g., air temperature, Li, 1997), *and is especially sensitive to cohesion (Selmani et al., 2024).* However, without direct flux measurements, we cannot constrain the static threshold wind speed in the field where the environmental conditions change, and snow undergoes metamorphism. *However, in our observations, wind speeds measured when snow transport is visible on the barchans range between 5 m s−1 to 12 m s−1, indicating that the transport threshold must lie within these values (or be lower), but this threshold is probably different variable across events. These values are consistent with previous studies in Antarctica, which report thresholds between 5 m s−1 to 12 m s−1 depending on snow cover conditions (e.g., presence of fresh snow), 5.6 m s−1 for small particles and 7.2 m s−1 for coarser particles or 5 m s−1 at Mizuho station (Amory, 2020; Leonard et al., 2012; Nishimura & Nemoto, 2005). The value used here therefore lies on the lower end of the range reported in Antarctic studies, which is consistent with the relatively smaller particle sizes expected at Concordia. Therefore, we used a unique representative mean value over space and time, which might contribute to this variability.*

L456-458 *Barchan dynamics can provide an independent constraint on the range of plausible threshold wind speeds and be used as an integrative indicator of snow transport conditions.*

7. Stabilization: Figure 10 top is really interesting. The authors are correct in their discussion of sintering times, that it is complex. After studying Figure 10, I went back to photographic data we have from Arctic Alaska, where a barchan field moves through the camera field of view in 7 hours (e.g. 30 m or about 4 m/h). But 50 hours later, when the wind shifted 180°, these same barchans marched back through the field of view, though this time at about 2.5 m/h). This seems broadly consistent with the paper's findings. What I would call the authors attention to (see their Figure 6) are the increasingly cross-hatched and scalloped tails that migrating brachans drag with them as they migrate. In the images we collected this dragged tail becomes progressively more visible the farther the feature moves, which I think means that the tail sculpting is getting deeper/higher. Hence a barchan seems to be shedding mass as it goes. It could well be worthwhile for the authors to think about this and discuss this universal feature in snow. It would also be useful to contrast snow tails to sand. I would be happy to send our images to them.

We thank the reviewer for this very insightful comment and for sharing these detailed field observations, which are highly valuable. The described evolution of barchan tails and the apparent mass redistribution during migration are particularly interesting and consistent with some of our observations. We have added a discussion in the manuscript addressing the presence of cross-hatched and scalloped tails, highlighting their potential role in snow redistribution and their possible link to mass loss during migration. Wealso emphasize that, although these features are frequently observed, their formation mechanism and impact on barchan dynamics remain unclear and deserve further investigation. We would be very interested in examining the reviewer's dataset and thank them for offering to share these images

L509-513 *Cross-hatched and scalloped tails are observed in both study locations (Figure 1, 2, 3, 6, and Figure 11 in Filhol and Sturm (2015)). These features may reflect redistribution of snow and its erosion and possible sintering processes during barchan migration, although their precise role remains unclear. Although these features are frequently present at Concordia, they do not systematically occur on all snow barchans, and they have no known equivalent in sand barchans. Therefore they warrant further investigation*

8. Barchan preservation: My mentor, Carl Benson, worked extensively in Greenland, and noted that he could not find in snow pits evidence of buried dunes or barchans. His view was that these did not last long enough or burial and preservation. Surely there have been extensive snow pits dug and stratigraphy measured at Concordia. Are dune forms and barchans preserved or not? This seems an important point

We agree that the preservation of snow barchans in the stratigraphic record is not straightforward, as these features can be transient and subject to rapid reworking or erosion, but also as they are widely spread, they would need long snow pit to be able to find one. Ooms et al. (2025) report results from 43 snowpits in a 50 m-long trench at Concordia Station in which layered structures interpreted as former dune features are identified. This indicates that, although probably not systematic depending on the environment, preservation of such features is possible at least in low-accumulation and low-wind environments. This suggests that the preservation potential of snow barchans likely depends strongly on local conditions, including accumulation rate, wind regime, and post-depositional metamorphism.

Summary: A very interesting paper, well worth publishing. I hope the authors take some of my points to heart and do a bit more work on the paper to make it even better.
Recommendation: Minor revisions

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Round 2 Review

Recommendation by Associate Editor 2 (Roberto Fernandez)

Completed: 2026-06-25 05:22 pm
Recommendation: Accept

The authors have taken an extensive revision that addresses every single aspect raised by reviewers and the editor. I believe that the revisions and updates are satisfactory and the manuscript may now be accepted for publication, pending any format requirements needed for production.

Decision by Editor-in-Chief (Alice Lefebvre)

2026-06-26
Decision: Accept

Dear Marine Poizat, Jeanne Alkalla, Ghislain Picard, Laurent Arnaud, Daniel J. Nowacki, Simon Filhol, Eric Lefebvre, Clément Narteau,

Congratulations! I am pleased to inform you that your manuscript entitled "Morphodynamics of snow barchans at Concordia Station, Antarctica" has been accepted for publication in Geomorphica.