Supporting Information for "Evolving dunes under flow reversals: from an initial heap toward an inverted dune"

W. R. Assis[1], E. M. Franklin[1], N. M. Vriend[2,3,4,5]

[1]School of Mechanical Engineering, UNICAMP - University of Campinas, Rua Mendeleyev, 200, Campinas, SP, Brazil

[2]Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK

[3]BP Institute, University of Cambridge, Cambridge, UK

[4]Department of Earth Sciences, University of Cambridge, Cambridge, UK

[5]Department of Mechanical Engineering, University of Colorado Boulder, Boulder, USA

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Additional Supporting Information (Files uploaded separately)

Introduction

This supporting information presents a brief description of some computations (identification of moving grains and number of grains entrained further downstream), a microscopy image of the used grains, snapshots of numerical barchans, additional graphics and tables, and movies showing the motion of grains within the central slice of 3D bedforms. We note that tables, individual images and movies used in the manuscript are available on Mendeley Data, http://dx.doi.org/10.17632/fw3bcrxknf.1.

Identification of moving grains in the central slice

We carried out CFD-DEM simulations, which compute the instantaneous position of each grain. Once the simulations finished, we selected the grains within a 2-mm-thick central slice and applied a threshold above which we considered that they were moving as bedload. For that, we used the typical bedload velocity $0.1u_*$ (Wenzel and Franklin, Granular Matter, 2019). As a result, we identified the grains entrained as bedload and those static in the central slice, at each time instant. Finally, in order to compute the total number of grains that moved during the simulations, we tracked all the moving grains of the central slice along the simulation.

For the tracking of grains we did not consider the first second of simulations to avoid the relatively large initial transient. This transient was caused by imposing a fully-developed flow at $t = 0$ s, which does not occur in experiments (where the flow is accelerated gradually). The detailed description of the initial conditions in the numerical simulations, and their implications, can be found in Lima et al., Physics of Fluids, 2022.

Number of grains leaving the barchan dune

The number of grains leaving the barchan dune was computed by counting the grains that left a region around the dune and were entrained further downstream.

Captions

Movie S1. top_formation_4x.mp4 Animation from the numerical simulation showing a conical pile being deformed into a barchan dune. The animation shows top-view images of the solid spheres and is sped up 4 times.

Movie S2. top_reverse_4x.mp4 Animation from the numerical simulation showing a barchan dune being inverted under a reverse flow. The animation shows top-view images of the solid spheres and is sped up 4 times.

Movie S3. slice_formation_4x.mp4 Animation from the numerical simulation showing a conical pile being deformed into a barchan dune. The animation shows a lateral view of the the 2-mm-thick central slice and is sped up 4 times.

Movie S4. slice_reverse_4x.mp4 Animation from the numerical simulation showing a barchan dune being inverted under a reverse flow. The animation shows a lateral view of the the 2-mm-thick central slice and is sped up 4 times.

Figures

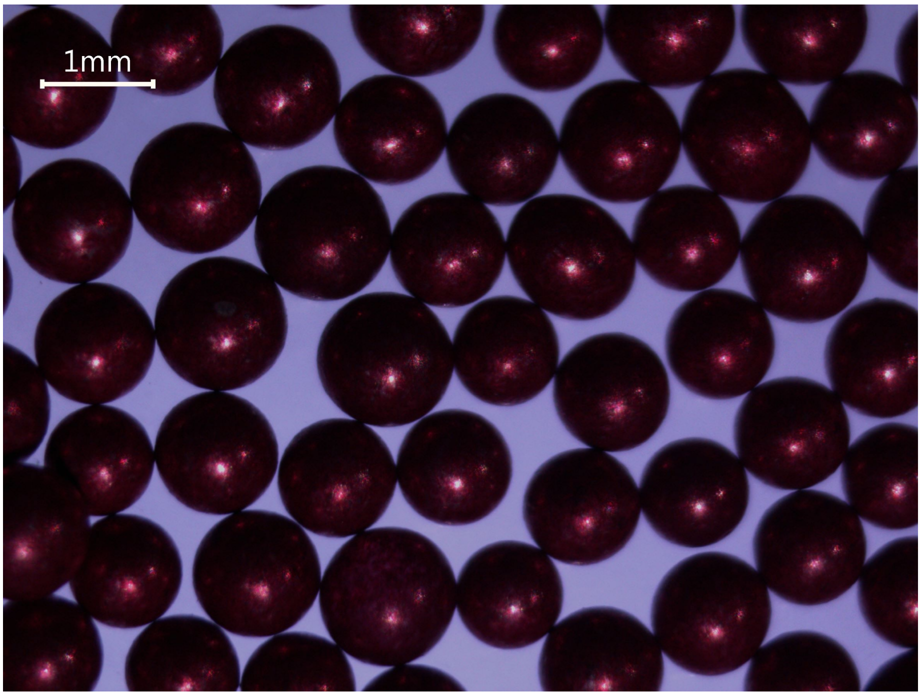

Figure S1. Microscopy image of the glass spheres used in the experiments (1.00 mm $\leq d \leq$ 1.3 mm).

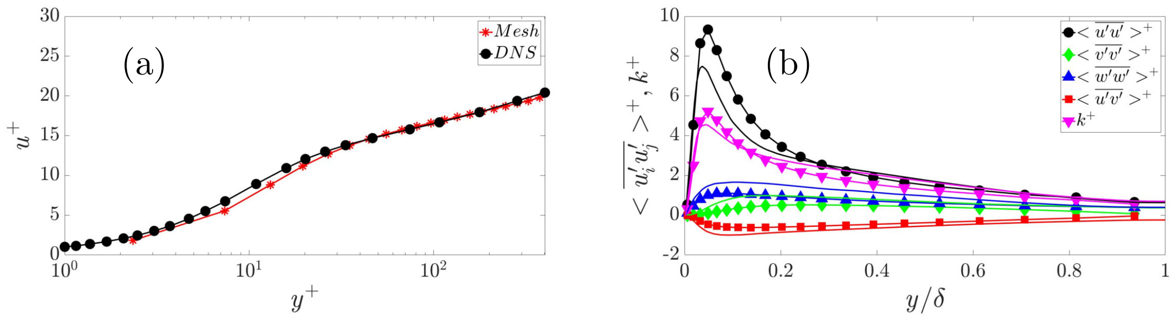

Figure S2. Mesh validation of the CFD part. (a) Mean velocity u^+ as a function of the vertical coordinate y^+; (b) turbulent kinetic energy k^+ and components of the shear stress $<\overline{u_i'u_j'}>$ as a function of y/δ. All quantities are dimensionless, the superscript + meaning normalization by the inner scales and δ corresponding to the channel half-height. DNS (direct numerical simulation) results in figure (a) are from Moser et al., Phys. Fluids 11, 943–945 (1999).

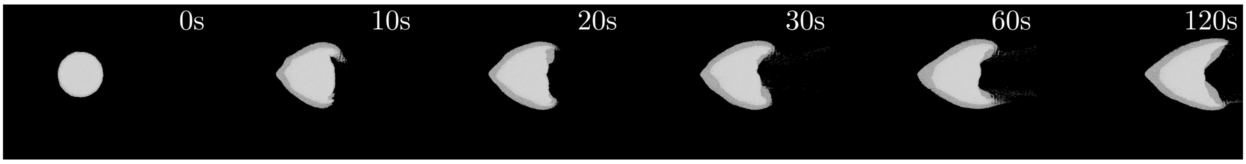

Figure S3. Snapshots from numerical simulations, showing top view images of a developing barchan from a conical pile. The flow comes from left to right in the images.

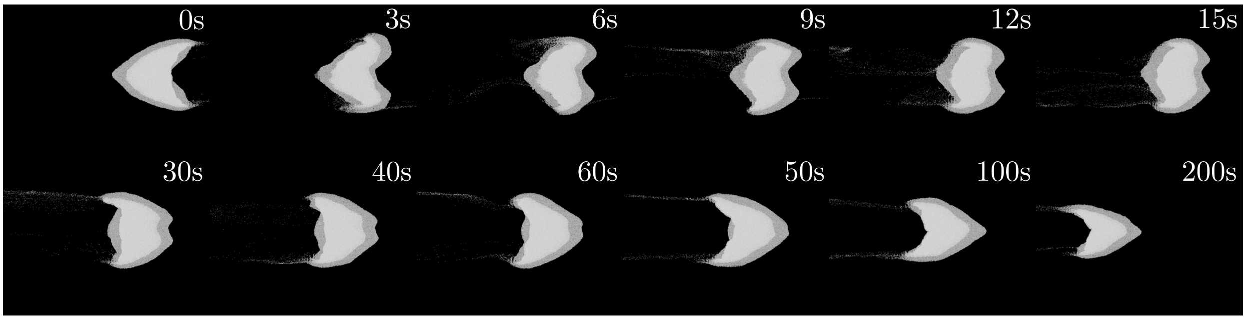

Figure S4. Snapshots from numerical simulations, showing top view images of a numerical barchan undergoing a flow reversal. The flow is from right to left.

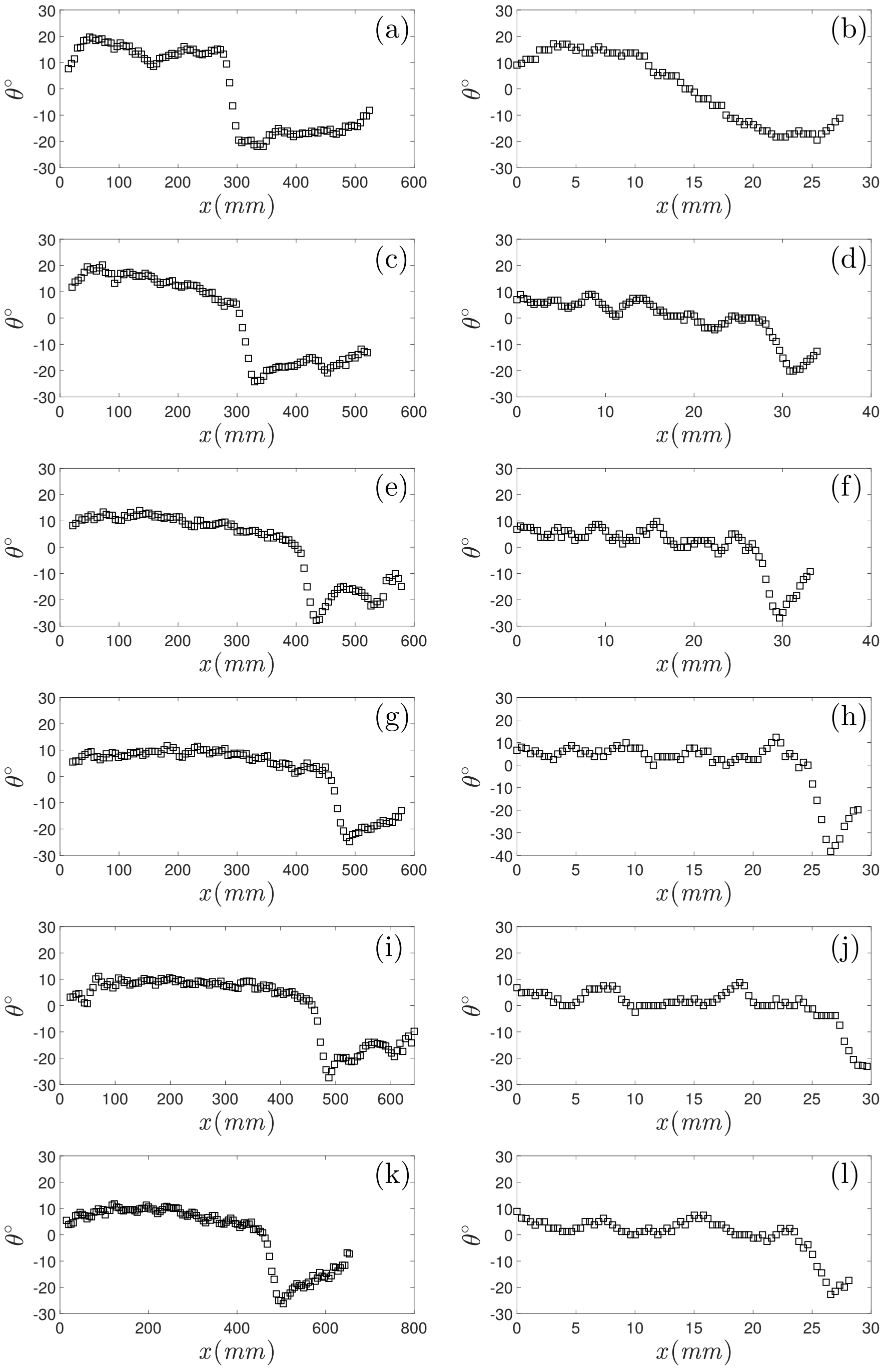

Figure S5. Local slope θ as a function of the longitudinal coordinate x for different time instants for the initial pile being deformed into a dune. Figures (a),(c), (e),(g), (i) and (k) correspond respectively to 4 s, 15 s, 39 s, 64 s, 76 s and 800 s of experiments (Figure 2 of the paper), and Figures (b), (d), (f), (h), (j) and (l) to 0 s, 1 s, 5 s, 7 s, 85 s and 120 s of numerical simulations (Figure 4 of the paper). Figures k and l present a stoss mean value of 8.0° and 3.5° with standard deviations of 2.0° and 2.1°, respectively.

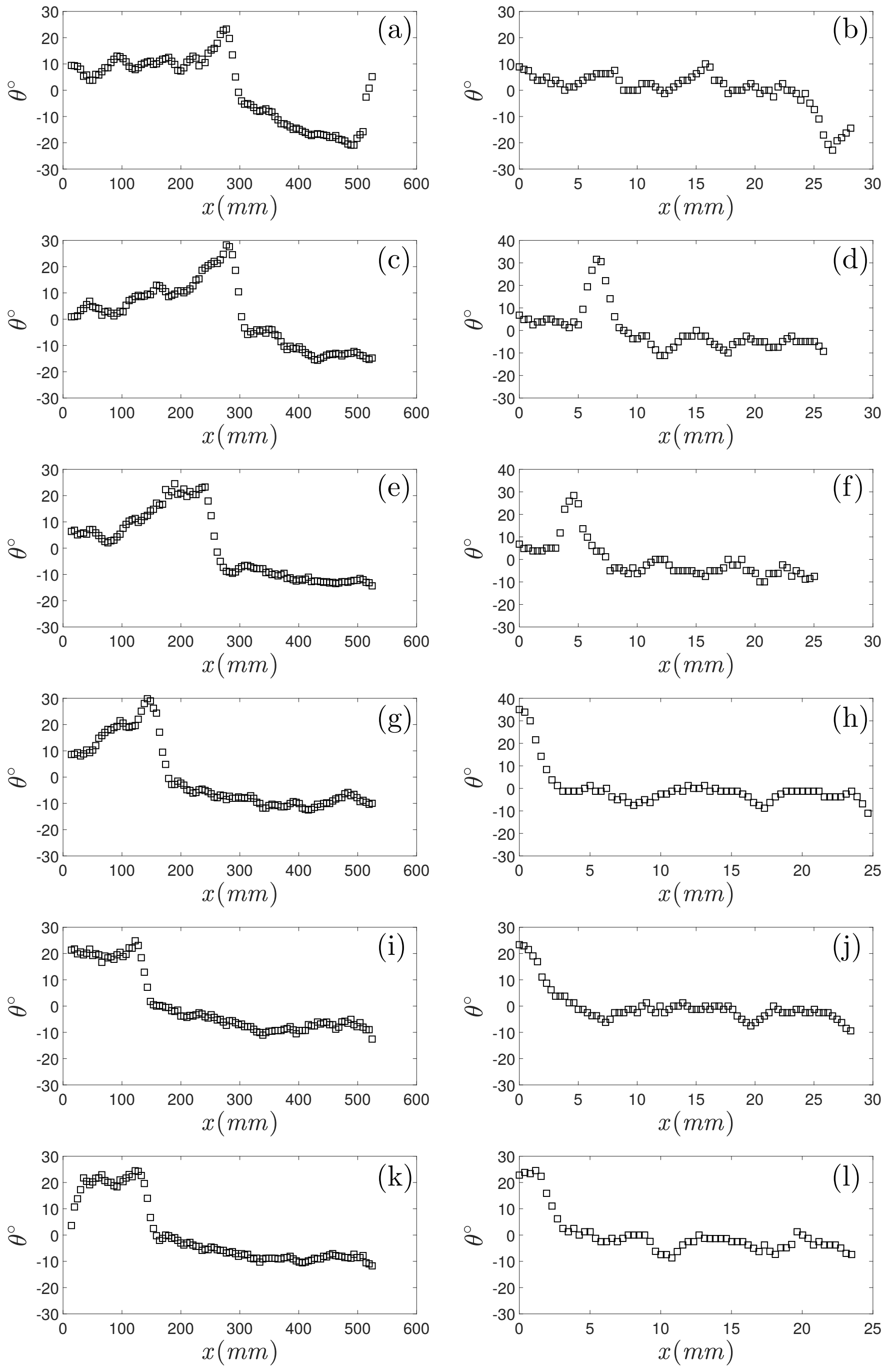

Figure S6. Local slope θ as a function of the longitudinal coordinate x for different time instants for the a dune under a reversed flow. Figures (a),(c), (e),(g), (i) and (k) correspond respectively to 28 s, 43 s, 51 s, 100 s, 315 s and 729 s of experiments (Figure 6 of the paper), and Figures (b), (d), (f), (h), (j) and (l) to 0 s, 1 s, 3 s, 45 s, 75 s and 160s of numerical simulations (Figure 8 of the paper). Figures k and l present a stoss mean value of -7.4° and -3.0° with standard deviations of 2.3° and 2.7°, respectively.

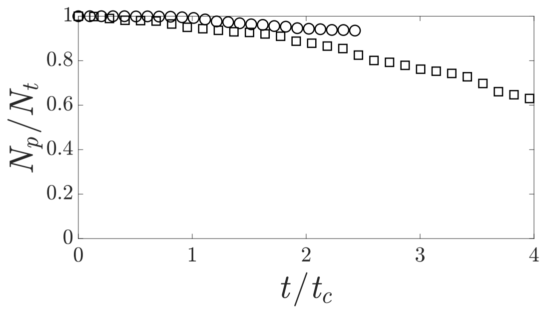

Figure S7. Time evolution of the ratio between the numbers of particles lost by the barchan N_p and the initial number of particles. Circles correspond to a barchan developed from a conical pile and squares to a barchan undergoing flow reversal.

t (s)	N_{mv}	N_t	N_{mv}/N_t
1	573	11261	5.1%
5	220	11015	2.0%
10	135	9415	1.4%
15	12	9104	0.1%
20	153	8815	1.7%
25	30	8587	0.3%
30	3118	8323	37.5%
35	275	7957	3.5%
40	306	7801	3.9%
45	69	7809	0.9%
50	189	7766	2.4%
55	11	7533	0.1%
60	397	7441	5.3%
65	25	7485	0.3%
70	262	7483	3.5%
75	248	7422	3.3%
80	79	7373	1.1%
85	27	7239	0.4%
90	1441	7182	20.1%
95	264	7165	3.7%
100	6	7073	0.1%
105	38	6976	0.5%
110	51	6970	0.7%
115	89	7022	1.3%
120	72	6944	1.0%

Figure S8. Table listing the number of grains moving as bedload in the central slice at each instant, for the initial heap being developed into a barchan dune. In the table, t is the time, N_{mv} is the number of moving grains in the central slice, N_t is the total number of grains in the central slice, and N_{mv}/N_t is the ratio between the two.

t (s)	N_{mv}	N_t	N_{mv}/N_t
1	122	6726	1.8%
5	74	6365	1.2%
10	46	6427	0.7%
15	197	6463	3.0%
20	28	6168	0.5%
25	101	6151	1.6%
30	1212	6144	19.7%
35	66	6076	1.1%
40	39	6103	0.6%
45	26	6091	0.4%
50	5	5959	0.1%
55	92	5910	1.6%
60	0	5935	0.0%
65	85	5933	1.4%
70	16	5917	0.3%
75	174	5991	2.9%
80	376	5951	6.3%
85	8	6020	0.1%
90	64	6011	1.1%
95	49	5935	0.8%
100	8	6017	0.1%
105	121	5845	2.1%
110	4	5855	0.1%
115	0	5848	0.0%
120	6	5805	0.1%
125	1	5882	0.0%
130	6	5810	0.1%
135	95	5649	1.7%
140	46	5612	0.8%
145	806	5545	14.5%
150	63	5692	1.1%
155	666	5477	12.2%
160	270	5421	5.0%
165	29	5328	0.5%
170	1659	5093	32.6%
175	30	4855	0.6%
180	31	4936	0.6%
185	97	4933	2.0%
190	564	4769	11.8%
195	9	4740	0.2%
200	550	4633	11.9%
205	15	4712	0.3%
210	44	4310	1.0%
215	31	4314	0.7%
220	5	4310	0.1%
225	772	4246	18.2%
230	322	4146	7.8%
235	23	3818	0.6%
240	311	3802	8.2%

Figure S9. Table listing the number of grains moving as bedload in the central slice at each instant, for a barchan dune undergoing reversal. In the table, t is the time, N_{mv} is the number of moving grains in the central slice, N_t is the total number of grains in the central slice, and N_{mv}/N_t is the ratio between the two

(a)
(b)

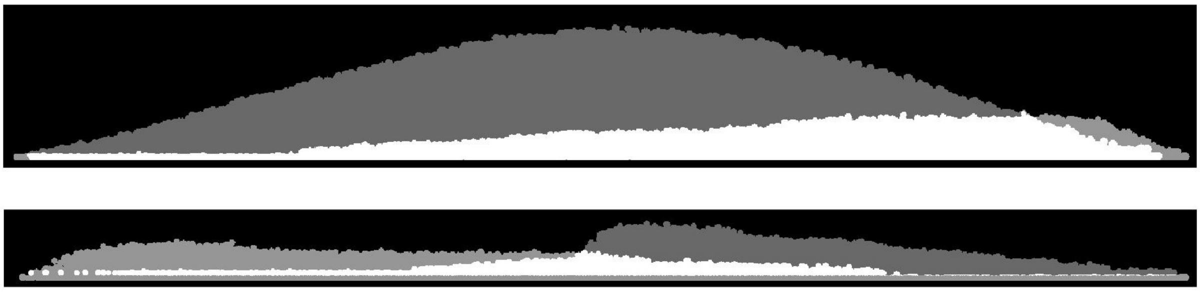

Figure S10. Superposition of the side view for (a) initial conical pile (t = 0 s, in darker gray) and developed (t = 120 s, in lighter gray) bedforms from figure 4 of the main manuscript (intersection appears in white) and (b) reversing flow direction (t = 1 s, in darker gray) and reversed dune (t = 160 s, in lighter gray) bedforms from figure 8 of the main manuscript (intersection appears in white).