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Supplement of

Glacial decline next to stable permafrost in the Dry Andes? Vertical glacier surface changes and rock glacier kinematics based on Pléiades imagery (Rodeo basin, 2019–2025)

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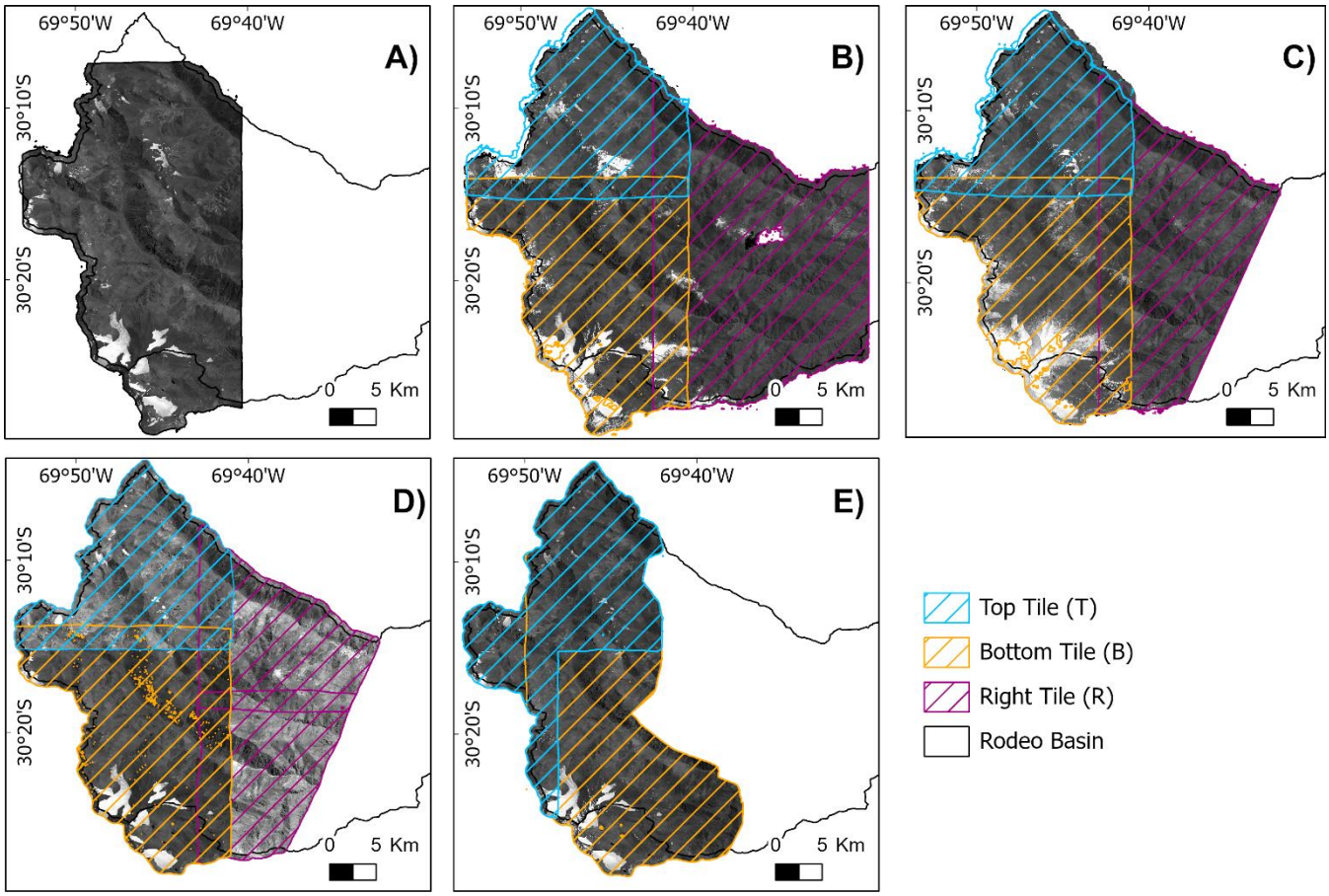


Fig. S1 Comparison of panchromatic Pléiades imagery with a focus on the distribution of acquisition tiles (T, B, R – see Tab. 1) and differences in acquisition extent. Note that we do not separate in T, B and R for the 2019 acquisition as this imagery was acquired as one tile only. In addition, snow cover distribution at the respective date of the acquisitions is visible from the imagery. For the processing of the Pléiades imagery, see section 3.2 in the publication.

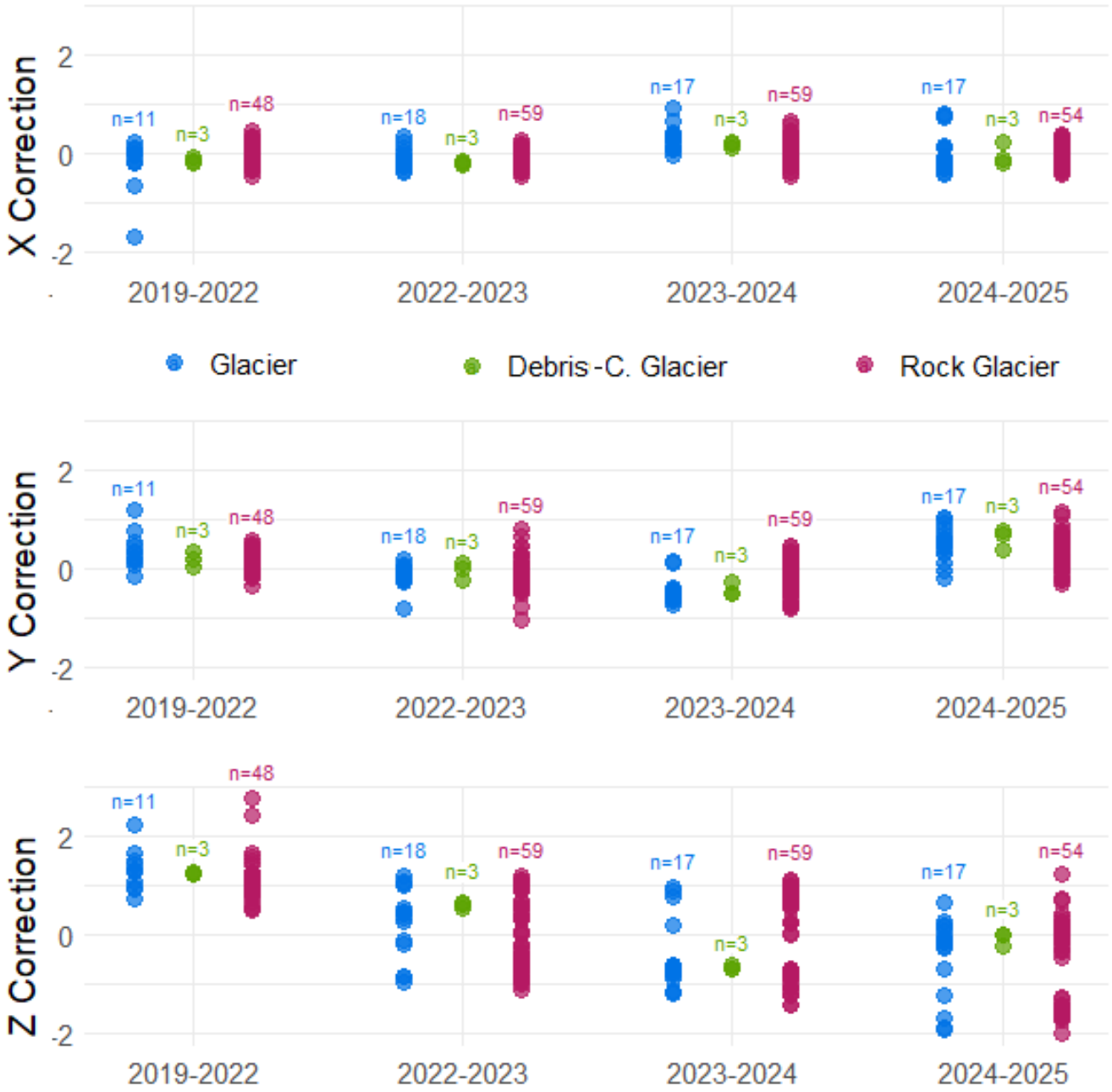


Fig. S2 Temporal and landform-specific analysis of the x, y and z correction factors (m) used during co-registration. For a full list of all correction factors, please see Tab. S1. Co-registration is achieved following the approach by Nuth and Kääb (2011) as applied in Demcoreg (Shean et al. 2016). The number of landforms in the respective category is given in each of the subplots and depends on the respective acquisition extents, see Fig. S1.

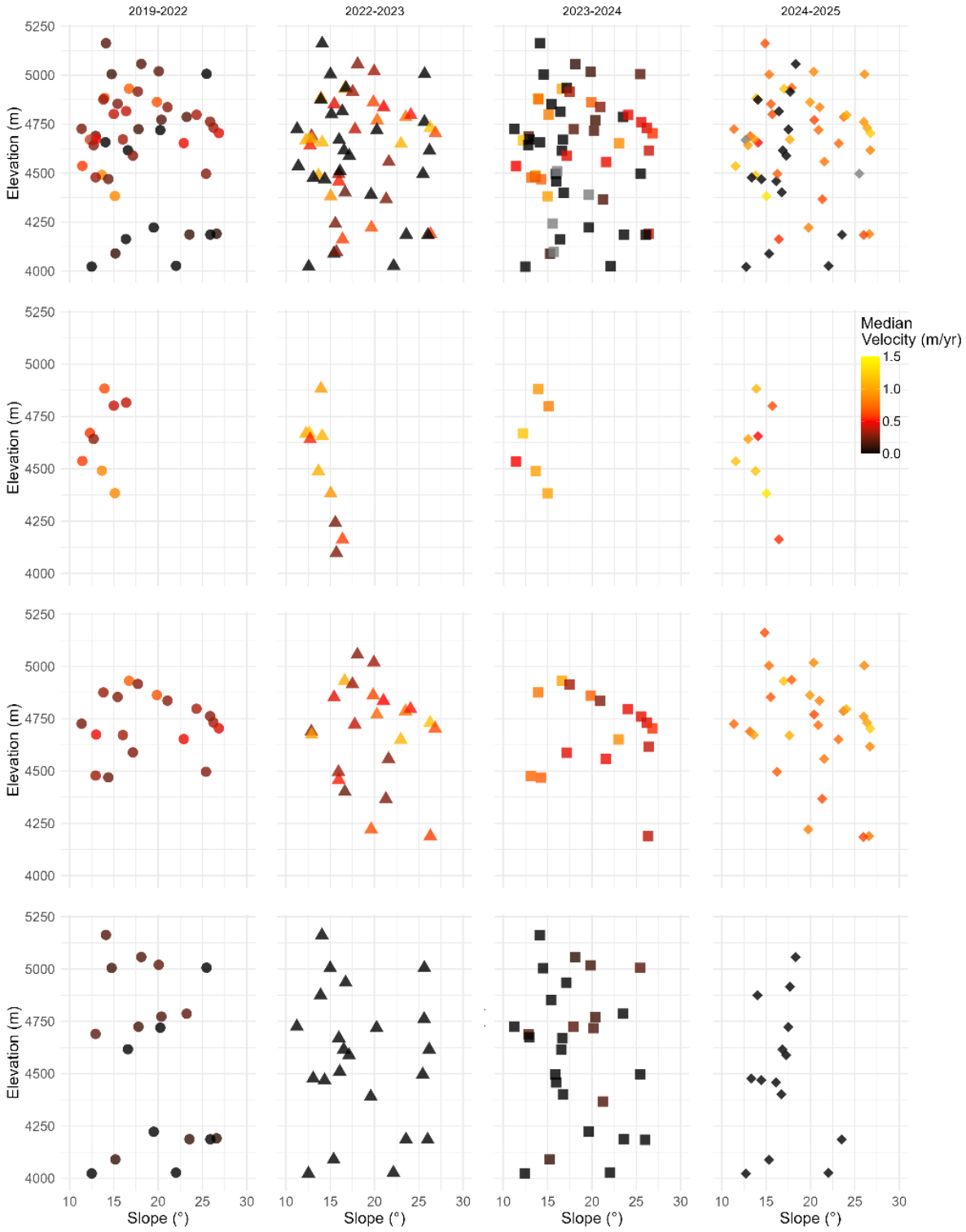


Fig. S3 The concurrence of elevation and slope for all rock glacier velocities (row 1), large and fast rock glaciers (row 2), small and fast rock glaciers (row 3), and small and slow rock glaciers (row 4), all coloured by median velocity (m/yr). The columns and symbols correspond to the different time episodes: circles (2019-2022), squares (2022-2023), triangles (2023-2024), and diamonds (2024-2025).

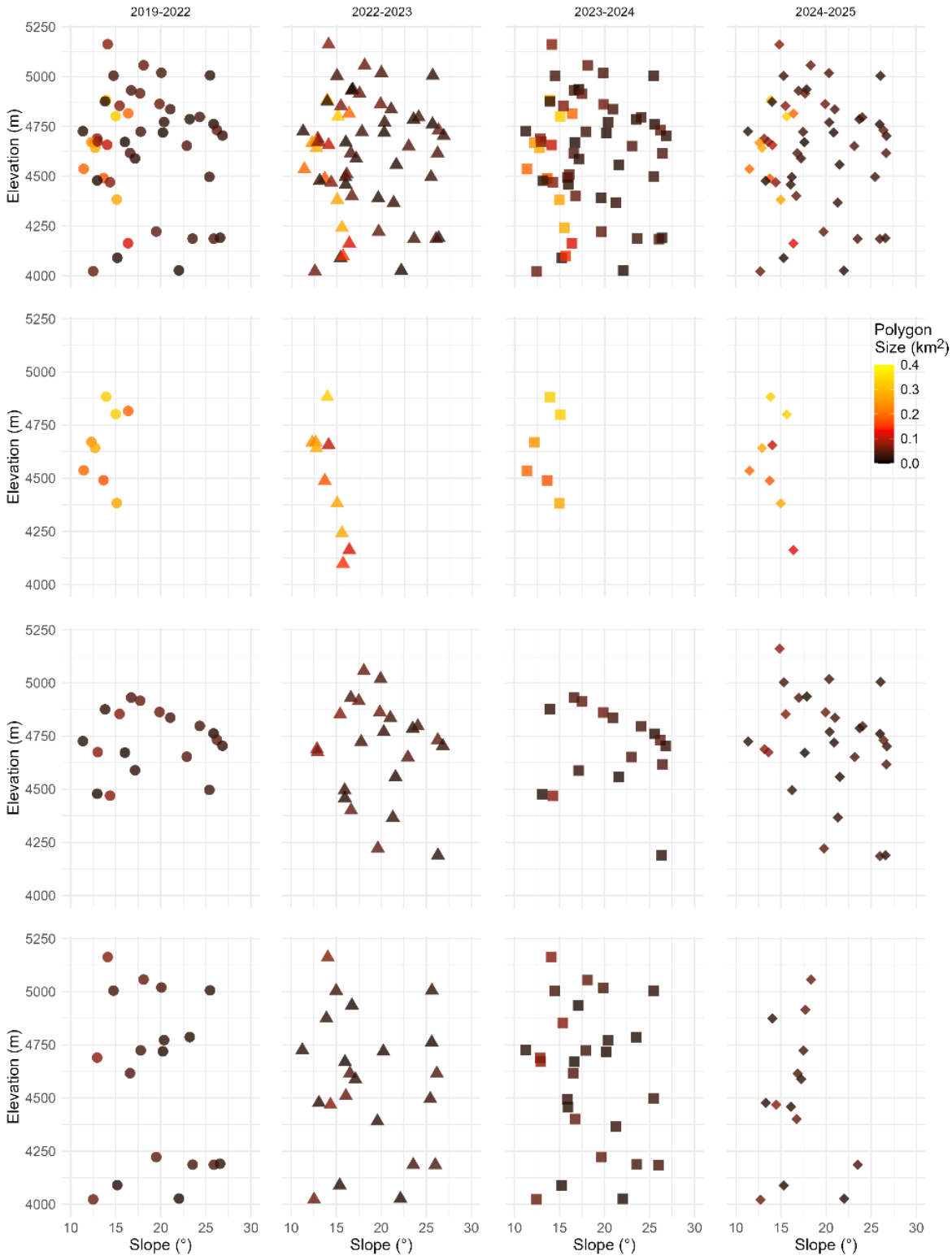
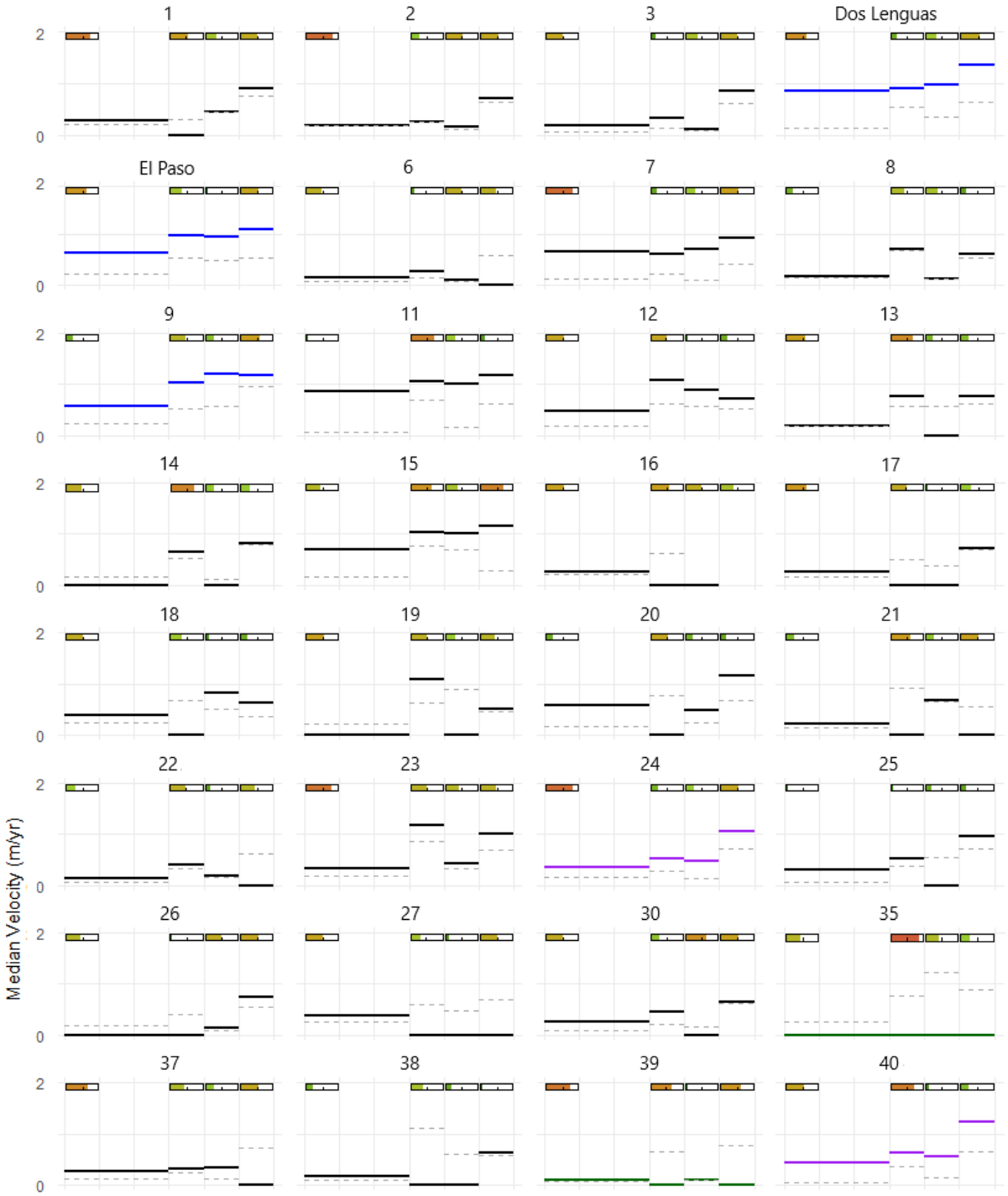


Fig. S4 The concurrence of elevation and slope for all rock glacier velocities (row 1), large and fast rock glaciers (row 2), small and fast rock glaciers (row 3), and small and slow rock glaciers (row 4), all coloured by polygon size (km^2) – equal to rock glacier surface area. The columns and symbols correspond to the different time episodes: circles (2019-2022), squares (2022-2023), triangles (2023-2024), and diamonds (2024-2025).


1
2
3
Dos Lenguas
El Paso
6
7
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19
20
21
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27
30
35
37
38
39
40
Median Velocity (m/yr)
2
0

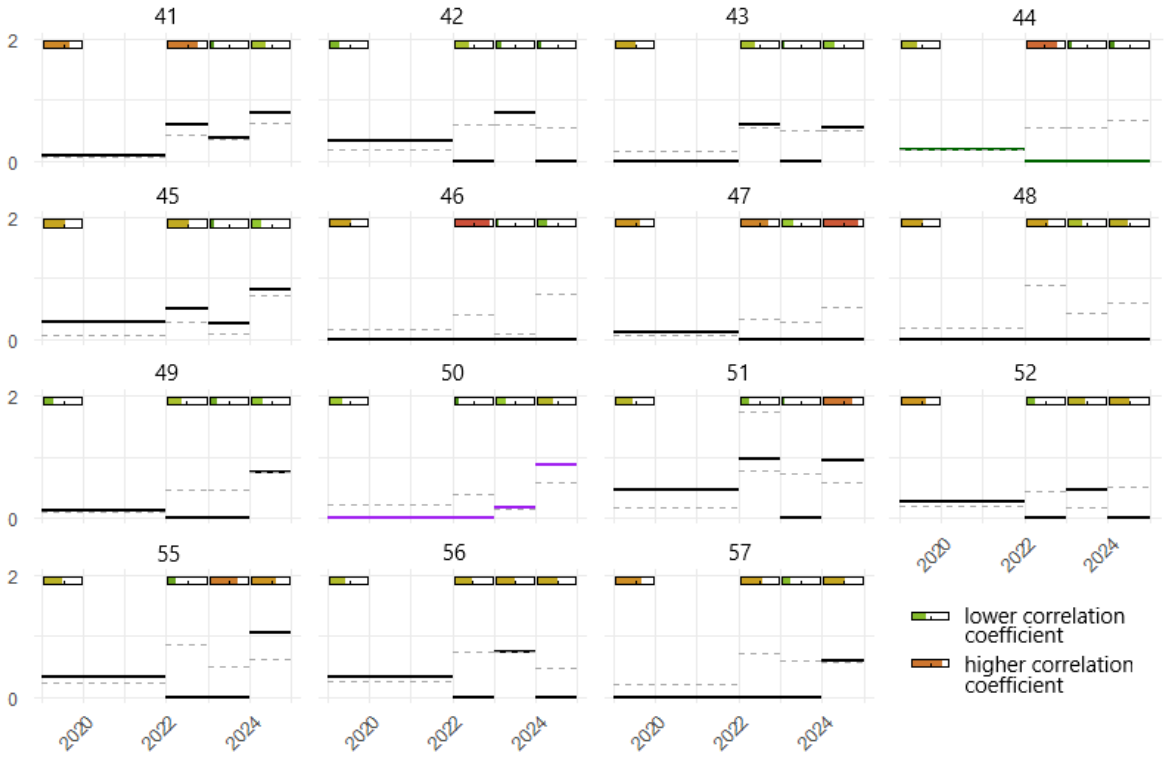
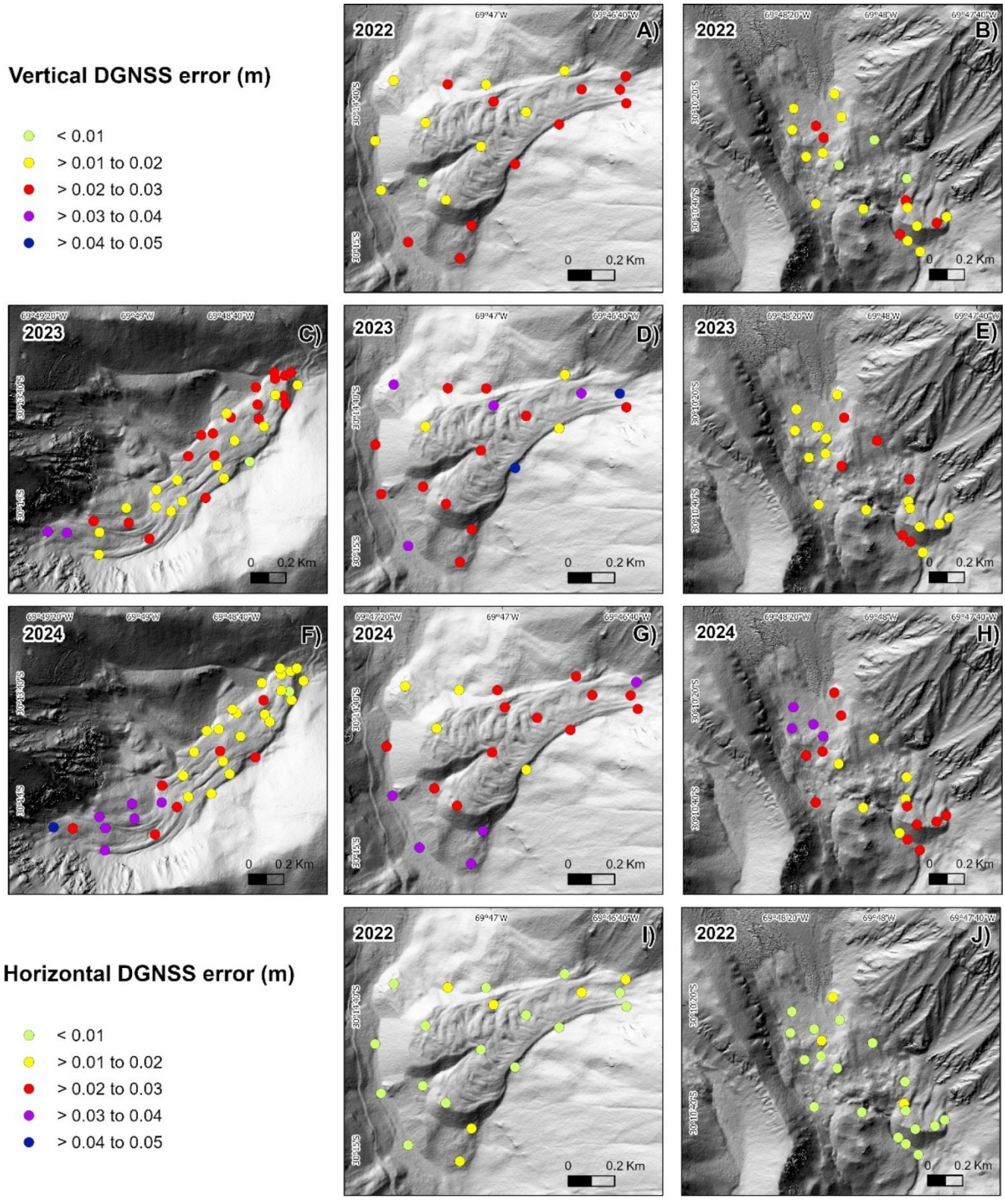


Fig. S5 continued Temporal evolution of median rock glacier horizontal surface velocities (m/yr) between 2019-2025 based on feature tracking on panchromatic Pléiades imagery (solid lines, colour-coding corresponds to Fig. 5). Median horizontal velocity is calculated for the rock glacier surface based on tracked velocity at 5 m resolution. LoDs are shown as dashed lines. Residue correlation coefficients, our quality control for our feature tracking approach, are included as bars – one each per time period.


Vertical DGNSS error (m)
< 0.01
> 0.01 to 0.02
> 0.02 to 0.03
> 0.03 to 0.04
> 0.04 to 0.05
2022
A)
2022
B)
2023
C)
2023
D)
2023
E)
2024
F)
2024
G)
2024
H)
Horizontal DGNSS error (m)
< 0.01
> 0.01 to 0.02
> 0.02 to 0.03
> 0.03 to 0.04
> 0.04 to 0.05
2022
I)
2022
J)
0
0.2 Km

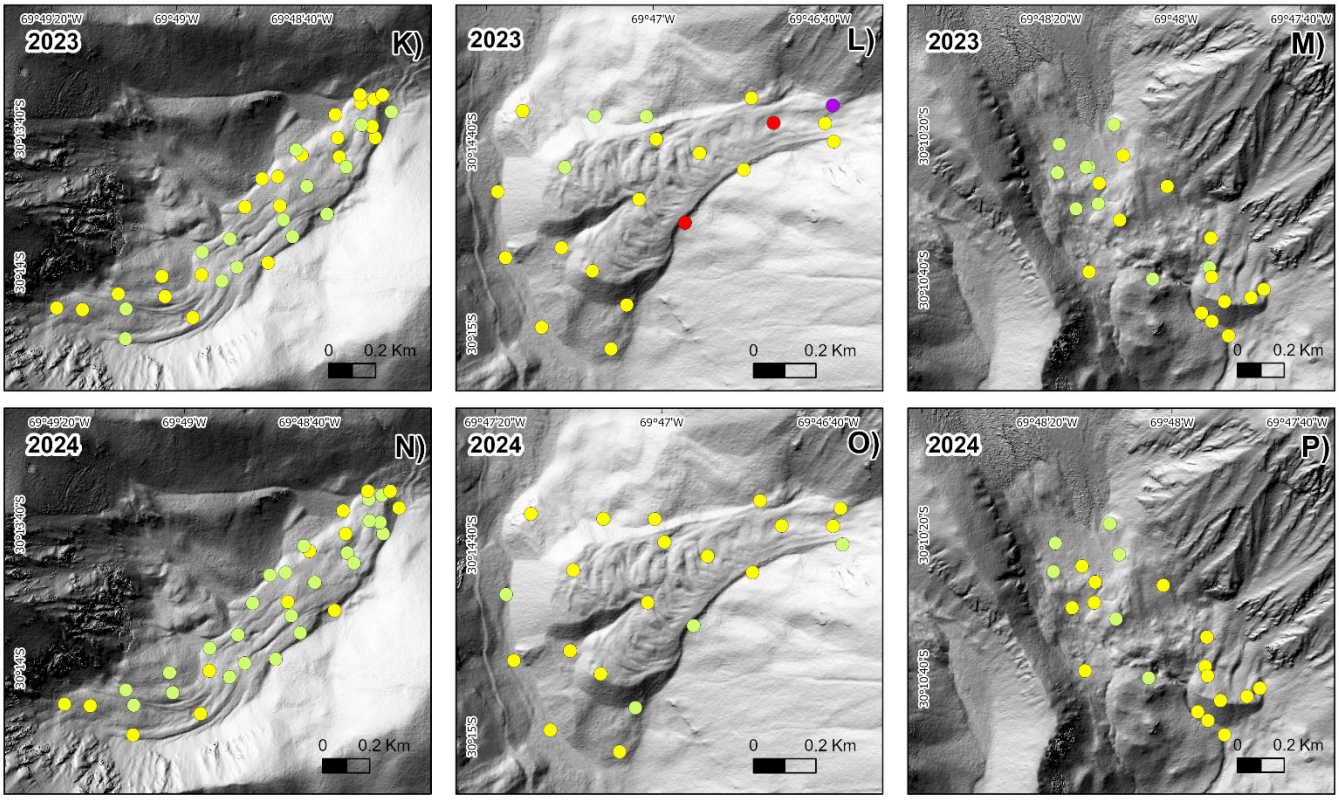


Fig. S6 continued Spatial distribution of the DGNSS errors (m) at El Paso rock glacier (left), Dos Lenguas rock glacier (centre) and the Agua Negra glacier forefield (right). Errors are provided for each acquisition (2022, 2023, 2024, as applicable) separated in vertical (A-H) and horizontal (I-P) error.

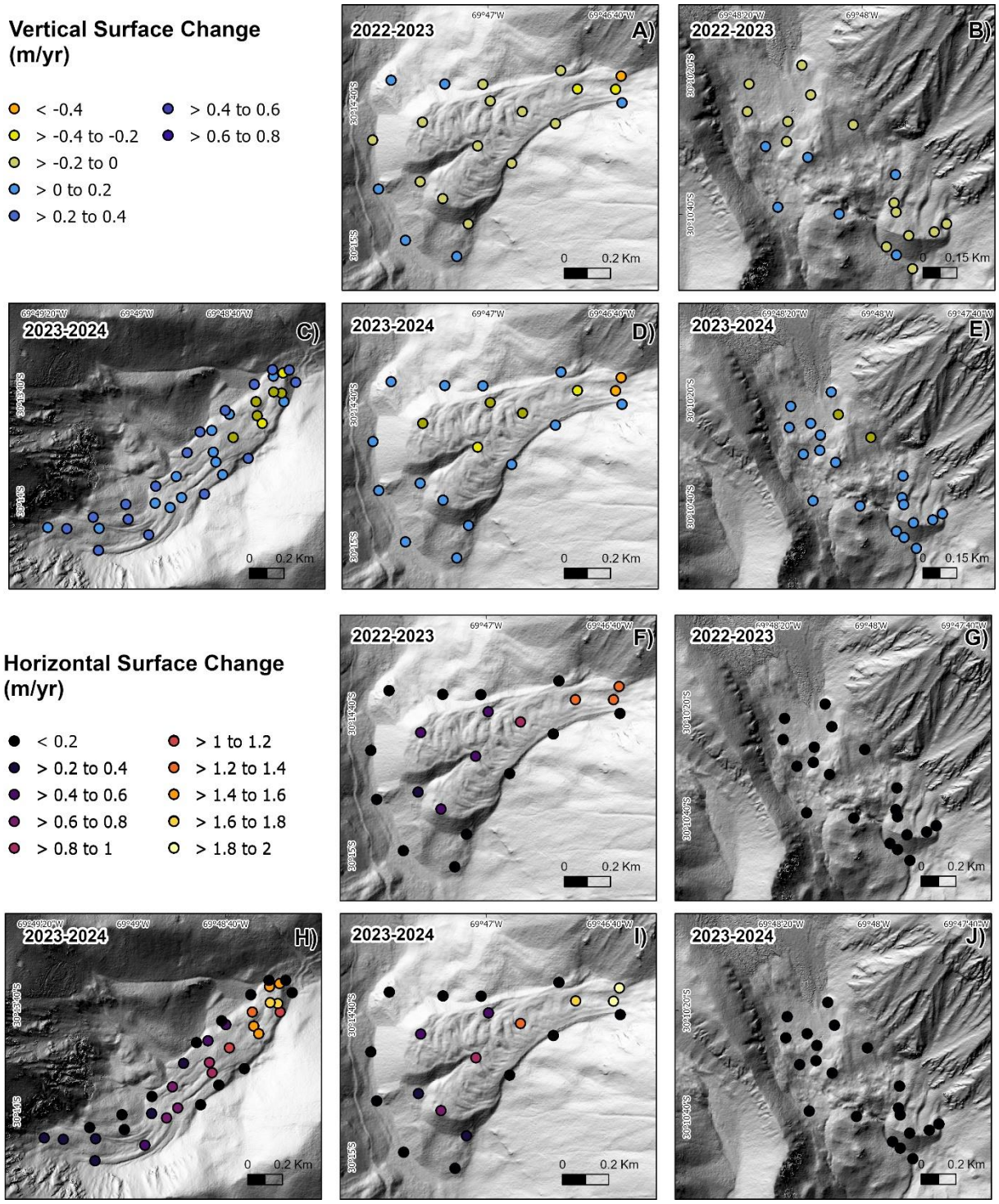


Fig. S7 Spatial distribution of the DGNSS-based surface changes (m/yr) at El Paso rock glacier (left), Dos Lenguas rock glacier (centre) and the Agua Negra glacier forefield (right). Surface changes are provided for each time period (2022-2023, 2023-2024, as applicable) separated in vertical (A-E) and horizontal (F-J) surface change.

Tab. S1 Co-registration correction factors (m) for all clipped rasters based on the approach by Nuth and Kääb (2011) as applied in Demcoreg (Shean et al. 2016).

Polygon ID	Tile	Start	End	X	Y	Z
1	T	19	22	-0.17	0.19	1.22
1	T	22	23	-0.21	-0.08	0.66
1	T	23	24	0.16	-0.47	-0.67
2	T	19	22	-0.16	0.43	1.24
2	T	22	23	-0.18	-0.18	0.72
2	T	23	24	0.31	-0.33	-0.69
3	T	19	22	-0.13	0.34	0.93
3	T	22	23	-0.25	-0.12	0.91
3	T	23	24	0.36	-0.35	-0.9
4	T	19	22	-0.16	0.14	1.05
4	B	19	22	0.27	0.29	1.02
4	T	22	23	-0.34	-0.06	1.15
4	B	22	23	-0.17	-0.16	-0.47
4	B	23	24	-0.08	-0.05	0.72
5	T	19	22	-0.31	0.23	1.2
5	B	19	22	0.21	0.06	0.39
5	T	22	23	-0.26	-0.03	1.05
5	T	23	24	0.58	-0.44	-1.23
6	T	19	22	-0.12	0.3	0.91
6	T	22	23	-0.2	-0.07	0.89
6	T	23	24	0.24	-0.34	-0.87
7	T	19	22	0.01	0.41	1.04
7	T	22	23	-0.19	-0.03	1.12
7	T	23	24	0	-0.72	-1.21
8	R	19	22	-0.02	0.4	2.7
8	B	19	22	0.32	-0.12	1.28
8	R	22	23	-0.02	-0.22	-0.93
8	B	22	23	-0.18	0.46	0.38
8	R	23	24	0.04	0.15	0.33
8	B	23	24	-0.01	-0.22	0.01
9	R	19	22	-0.16	0.38	2.78
9	B	19	22	0.08	-0.23	1.35
9	R	22	23	0.01	-0.28	-0.96
9	B	22	23	0.03	0.55	0.25
9	R	23	24	0.2	0.34	0.28
10	R	22	23	0.08	-0.35	-0.91
10	B	22	23	-0.15	0.73	0.2
10	R	23	24	0.24	0.48	0.23
11	R	19	22	-0.19	0.49	2.45
11	B	19	22	0.14	0.23	1.08
11	R	22	23	-0.03	-0.2	-0.8
11	B	22	23	0.09	0.03	0.17
11	R	23	24	0.11	-0.04	0.26
12	R	19	22	-0.25	0.56	2.44
12	B	19	22	0.14	0.44	0.92
12	B	22	23	0.21	0.26	0.09
12	R	23	24	0.15	-0.4	0.65
12	B	23	24	-0.08	0.48	0.04
13	B	19	22	0.04	-0.04	1.29
13	B	22	23	-0.47	0.05	-0.62
13	B	23	24	-0.12	-0.17	0.95
14	B	19	22	0.46	0.41	0.84
14	B	22	23	-0.37	-0.26	-0.98
14	B	23	24	0.08	0.08	1.12
15	B	19	22	0.12	0.37	0.53
15	B	22	23	-0.29	0.01	-0.21
15	B	23	24	-0.25	-0.17	0.92
16	T	19	22	-0.36	0.03	0.86
16	B	19	22	0.02	-0.02	1.04
16	B	22	23	-0.17	-0.32	-0.76
16	B	23	24	0.27	-0.12	0.81
17	T	19	22	0.21	0.06	1.22
17	B	19	22	0.23	0.6	1.04
17	T	22	23	-0.26	-0.15	1.07
17	B	22	23	0.15	-0.8	-0.22
17	B	23	24	0.15	0.06	0.59
18	T	19	22	0.08	0.19	1.28
18	B	19	22	0.49	0.67	0.83
18	T	22	23	-0.24	-0.17	1.08
19	T	22	23	-0.26	-0.11	1.13
19	B	22	23	-0.17	-1.09	-0.26
19	B	23	24	0	0.13	0.67
20	T	19	22	-0.32	0.03	1.06
20	B	19	22	0.27	0.34	1.08
20	T	22	23	-0.14	-0.21	1.17
20	B	22	23	-0.34	-0.77	-0.48
20	B	23	24	0.33	-0.08	0.68
21	T	19	22	-0.35	0.02	0.93
21	B	19	22	0.06	0.03	1.06
21	T	22	23	-0.15	-0.17	1.23
21	B	22	23	-0.17	-0.5	-0.69
21	B	23	24	0.28	-0.12	0.76
22	B	19	22	0.26	0.05	1.19
22	B	22	23	0.14	0.21	-0.88
22	B	23	24	-0.07	-0.18	0.92
23	T	19	22	-0.27	0.5	1.31
23	B	19	22	0.16	0.65	1.26

23	T	22	23	-0.39	-0.1	1.07
23	B	22	23	-0.13	-0.38	-0.54
23	B	23	24	0.66	-0.78	0.24
24	T	19	22	-0.11	0.34	1.29
24	B	19	22	0.34	-0.33	0.66
24	T	22	23	-0.38	-0.11	1.06
24	B	22	23	-0.04	0.26	0.06
24	B	23	24	-0.14	0.12	0.72
25	B	19	22	0.35	-0.18	1.06
25	B	22	23	-0.08	0.67	-0.67
25	B	23	24	-0.17	-0.34	0.82
26	T	19	22	-0.18	0.47	1.08
26	T	22	23	-0.28	0.03	1.19
26	T	23	24	0.48	-0.82	-1.4
27	T	19	22	-0.09	0.43	0.8
27	T	22	23	-0.2	-0.18	1.04
27	T	23	24	0.26	-0.55	-1.05
28	R	23	24	-0.04	0.29	1.03
29	T	22	23	0.05	-0.04	0.32
29	T	23	24	0.41	-0.5	-0.75
30	T	19	22	-0.08	0.15	1.59
30	T	22	23	-0.09	-0.19	0.55
30	T	23	24	0.22	-0.31	-0.75
31	T	22	23	-0.15	-0.05	0.4
31	T	23	24	0.22	-0.36	-0.69
32	T	22	23	-0.14	-0.02	0.38
32	T	23	24	0.22	-0.6	-0.77
33	T	22	23	-0.19	-0.02	0.35
33	T	23	24	0.21	-0.54	-0.8
34	T	22	23	-0.12	-0.2	0.36
34	T	23	24	0.22	-0.5	-0.74
35	B	19	22	0.29	0.39	0.86
35	B	22	23	-0.22	-0.41	-0.57
35	B	23	24	-0.39	0.18	0.97
36	R	22	23	-0.01	-0.46	-0.88
36	R	23	24	0.44	0.37	0.58
37	T	19	22	-0.3	0.29	1.2
37	T	22	23	-0.32	-0.06	1.05
37	T	23	24	0.41	-0.67	-1.18
38	B	19	22	0.2	-0.03	1.13
38	B	22	23	-0.2	0.33	0.02
38	B	23	24	0.03	-0.3	0.54
39	B	19	22	0.04	0.43	0.98
39	B	22	23	0.08	-0.28	-0.36
39	B	23	24	-0.39	0.31	0.77
40	B	19	22	0	0.1	0.98

40	B	22	23	-0.01	0.04	-0.37
40	B	23	24	-0.04	-0.05	0.68
41	B	19	22	0.3	-0.07	1.07
41	B	22	23	-0.18	0.81	-0.93
41	B	23	24	0.06	-0.51	0.95
42	B	19	22	0.21	0.23	0.54
42	B	22	23	-0.35	0.05	-0.18
42	B	23	24	-0.27	-0.22	0.89
43	B	19	22	0.33	-0.07	1.09
43	B	22	23	-0.02	0.48	-0.65
43	B	23	24	-0.06	-0.42	0.86
44	B	19	22	0.28	0.41	0.83
44	B	22	23	-0.16	-0.42	-0.54
44	B	23	24	-0.23	0.1	0.95
45	B	19	22	8.9	5	-9.47
45	B	22	23	0.14	0.11	-0.6
45	B	23	24	-0.47	-0.31	1.03
46	B	19	22	0.09	0.21	0.56
46	B	22	23	0.11	-0.31	-0.21
46	B	23	24	-0.27	0.26	0.81
47	B	19	22	0.05	0.6	1.14
47	B	22	23	0.09	-0.19	-1.1
47	B	23	24	-0.13	-0.22	1.1
48	T	22	23	-0.28	-0.11	1.17
48	B	22	23	-0.09	-1.02	-0.32
48	B	23	24	0.21	0.12	0.65
49	B	19	22	0.09	0.1	1.19
49	B	22	23	0.26	0.13	-0.66
49	B	23	24	-0.28	-0.15	0.95
50	T	19	22	0.07	0.32	1.12
50	B	19	22	0.11	0.12	0.34
50	T	22	23	-0.33	-0.08	1.11
50	T	23	24	0.26	-0.7	-1.42
51	T	19	22	-0.23	0.23	0.85
51	T	22	23	-0.05	0.01	0.94
51	T	23	24	0.34	-0.46	-1.06
52	T	19	22	-0.22	0.29	0.85
52	T	22	23	-0.21	-0.11	0.99
52	T	23	24	0.22	-0.32	-1.04
53	R	23	24	0.2	0.37	1
54	R	23	24	0.03	0.19	0.95
55	T	19	22	-0.47	0.39	1.65
55	T	22	23	-0.37	0.05	0.57
55	T	23	24	0.02	-0.33	-0.68
56	T	19	22	-0.35	-0.14	1.5
56	T	22	23	-0.3	-0.03	0.59

56	T	23	24	0.21	-0.39	-0.74
57	T	19	22	-0.25	0.04	1.44
57	T	22	23	-0.21	0.04	0.56
57	T	23	24	0.32	-0.44	-0.8
58	T	22	23	-0.21	-0.1	0.31
58	T	23	24	0.22	-0.43	-0.78
59	T	22	23	-0.3	0.03	0.52
59	T	23	24	0.27	-0.54	-0.73
60	T	19	22	-0.19	0.37	1.43
60	T	22	23	-0.16	-0.28	0.48
60	T	23	24	0.34	-0.61	-0.69
61	T	19	22	-0.04	0.46	1.08
61	T	22	23	-0.34	0.02	1.08
61	T	23	24	0.65	-0.71	-1.2
62	T	19	22	0	-0.13	1.3
62	T	22	23	-0.21	0.18	0.56
62	T	23	24	0.06	-0.45	-0.6
64	B	22	23	0.23	-0.03	-0.11
65	B	19	22	-1.68	1.21	2.25
65	B	22	23	0.35	-0.24	-0.19
65	R	23	24	0.6	-0.08	-0.06
65	B	23	24	0.08	0.17	0.22
66	T	19	22	0.1	0.21	1.33
66	B	19	22	0.24	0.16	0.56
66	T	22	23	-0.28	-0.06	1.03
66	T	23	24	0.37	-0.56	-1.16
67	B	22	23	-0.03	-0.07	-0.96
67	B	23	24	0.31	-0.64	0.97
68	T	19	22	-0.67	0.1	0.75
68	T	22	23	-0.23	-0.23	1.19
68	T	23	24	0.92	-0.47	-0.86
69	B	19	22	0.09	0.54	1.34
69	B	22	23	0.1	-0.8	-0.83

69	B	23	24	0.27	0.12	0.77
70	T	19	22	-0.37	0.69	0.79
70	B	19	22	-0.01	0.79	0.94
70	B	22	23	-0.08	0.06	-0.83
70	B	23	24	-0.05	-0.41	0.9
71	T	19	22	-0.14	0.34	0.96
71	T	22	23	-0.38	-0.23	1.07
71	T	23	24	0.38	-0.48	-1.15
72	T	19	22	-0.21	0.24	1.53
72	T	22	23	-0.04	-0.11	0.45
72	T	23	24	0.28	-0.39	-0.75
73	T	19	22	0.25	0.16	1.65
73	T	22	23	-0.09	0.09	0.48
73	T	23	24	0.42	-0.48	-0.81
74	T	22	23	0.04	-0.09	0.29
74	T	23	24	0.37	-0.54	-0.76
75	T	22	23	-0.03	-0.09	0.36
75	T	23	24	0.29	-0.49	-0.7
76	T	22	23	-0.19	-0.1	0.46
76	T	23	24	0.13	-0.42	-0.66
77	T	22	23	-0.07	-0.05	0.48
77	T	23	24	0.16	-0.41	-0.6
78	T	22	23	-0.1	-0.17	0.47
78	T	23	24	0.13	-0.41	-0.6
79	T	19	22	-0.06	0.03	1.27
79	T	22	23	-0.18	0.13	0.57
79	T	23	24	0.11	-0.51	-0.62
80	T	19	22	-0.15	0.37	1.26
80	T	22	23	-0.16	-0.24	0.68
80	T	23	24	0.21	-0.28	-0.67
81	T	19	22	-0.19	0.2	1.25
81	T	22	23	-0.23	-0.01	0.64
81	T	23	24	0.23	-0.49	-0.68

Tab. S2 Correlation coefficients of the affine transformation residues of the feature tracking approach, for all object IDs. For an interpretation of the coefficients, see section 3.5.

Polygon ID	2019-2022	2022-2023	2023-2024	2024-2025	Median
ID1	0.73	0.57	0.35	0.50	0.53
ID2	0.79	0.28	0.52	0.53	0.53
ID3	0.52	0.15	0.38	0.51	0.45
ID4	0.64	0.20	0.33	0.51	0.42
ID5	0.62	0.34	0.02	0.53	0.43
ID6	0.48	0.01	0.49	0.48	0.48
ID7	0.79	0.18	0.32	0.56	0.44
ID8	0.22	0.41	0.37	0.17	0.30
ID9	0.21	0.45	0.26	0.57	0.35
ID11	0.06	0.70	0.31	0.15	0.23
ID12	0.54	0.53	0.10	0.20	0.37
ID13	0.57	0.66	0.23	0.25	0.41
ID14	0.49	0.69	0.28	0.29	0.39
ID15	0.43	0.62	0.37	0.70	0.53
ID16	0.56	0.56	0.50	0.38	0.53
ID17	0.61	0.51	0.09	0.30	0.40
ID18	0.50	0.33	0.12	0.20	0.27
ID19	0.56	0.48	0.30	0.45	0.47
ID20	0.20	0.54	0.22	0.19	0.21
ID21	0.24	0.58	0.27	0.56	0.42
ID22	0.31	0.48	0.17	0.44	0.37
ID23	0.76	0.47	0.44	0.47	0.47
ID24	0.79	0.22	0.29	0.53	0.41
ID25	0.07	0.04	0.19	0.17	0.12
ID26	0.43	0.05	0.50	0.54	0.46
ID27	0.55	0.35	0.14	0.50	0.43
ID30	0.51	0.27	0.64	0.56	0.54
ID35	0.44	0.85	0.41	0.29	0.42
ID37	0.67	0.41	0.28	0.53	0.47
ID38	0.22	0.37	0.19	0.07	0.20
ID39	0.74	0.66	0.08	0.61	0.64
ID40	0.55	0.72	0.12	0.25	0.40
ID41	0.67	0.73	0.13	0.36	0.52
ID42	0.24	0.38	0.17	0.10	0.20
ID43	0.53	0.37	0.09	0.28	0.33
ID44	0.42	0.80	0.12	0.13	0.27
ID45	0.54	0.51	0.14	0.28	0.39
ID46	0.56	0.89	0.00	0.23	0.40
ID47	0.62	0.69	0.30	0.86	0.66
ID48	0.56	0.57	0.39	0.48	0.52
ID49	0.24	0.37	0.21	0.28	0.26
ID50	0.32	0.11	0.29	0.44	0.30
ID51	0.44	0.24	0.04	0.75	0.34
ID52	0.61	0.24	0.47	0.52	0.49
ID55	0.46	0.19	0.72	0.62	0.54
ID56	0.41	0.50	0.53	0.52	0.51
ID57	0.65	0.57	0.25	0.53	**0.55**
Median	**0.53**	**0.47**	**0.28**	**0.47**	**0.47**

Tab. S3 Correlation coefficients between the rock glacier characteristics elevation, slope, median horizontal velocity and surface area.

	Elevation	Slope	Mdn. hor. velocity	Surface Area
Elevation	1.00	0.02	0.20	-0.00
Slope	0.02	1.00	-0.00	**-0.47**
Mdn. hor. velocity	**0.20**	-0.00	1.00	**0.21**
Surface Area	-0.00	**-0.47**	**0.21**	1.00