

1 **Supplementary Material: Inferring on-glacier meteorology from physical**
2 **modeling and remote sensing**

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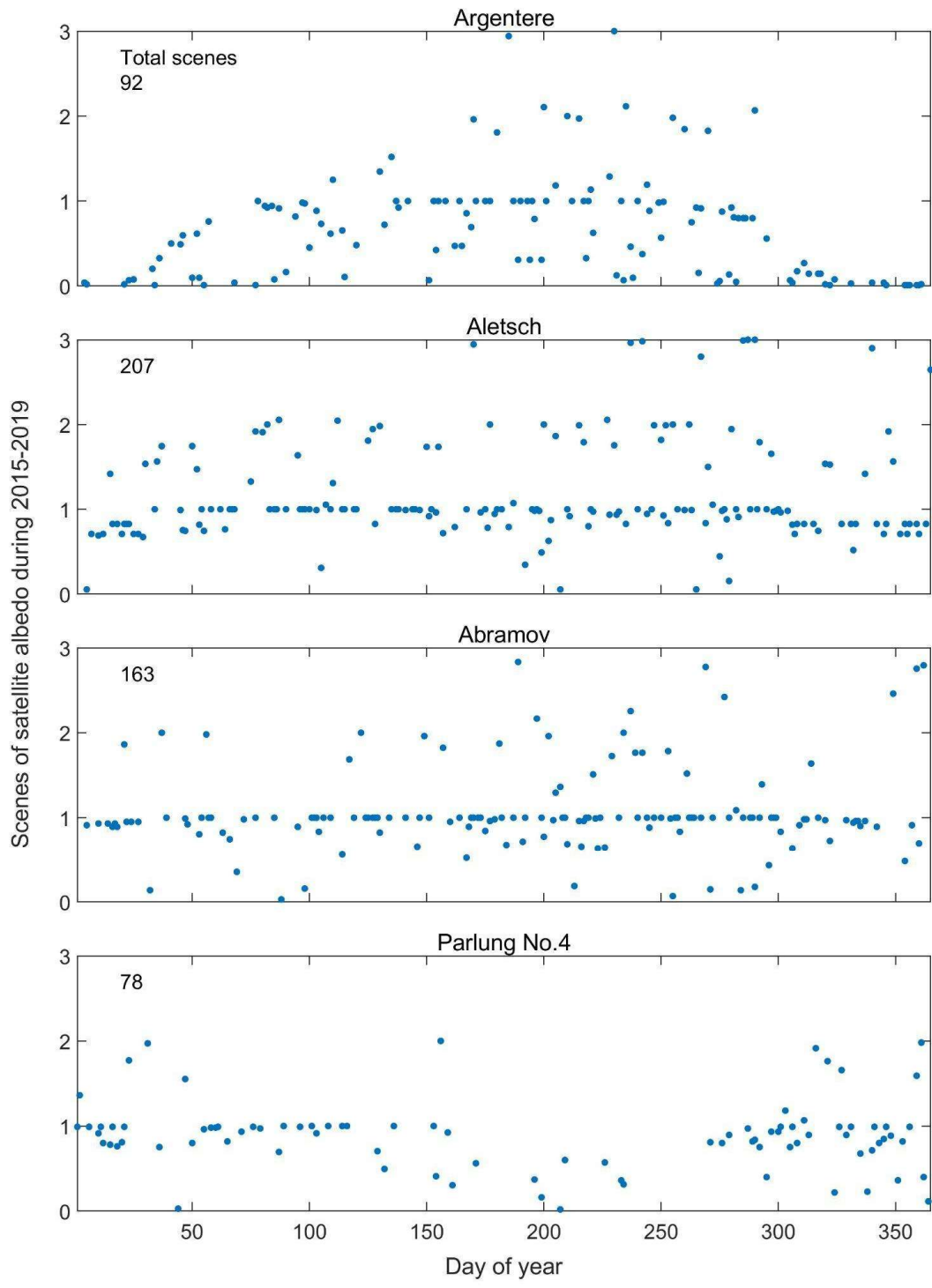
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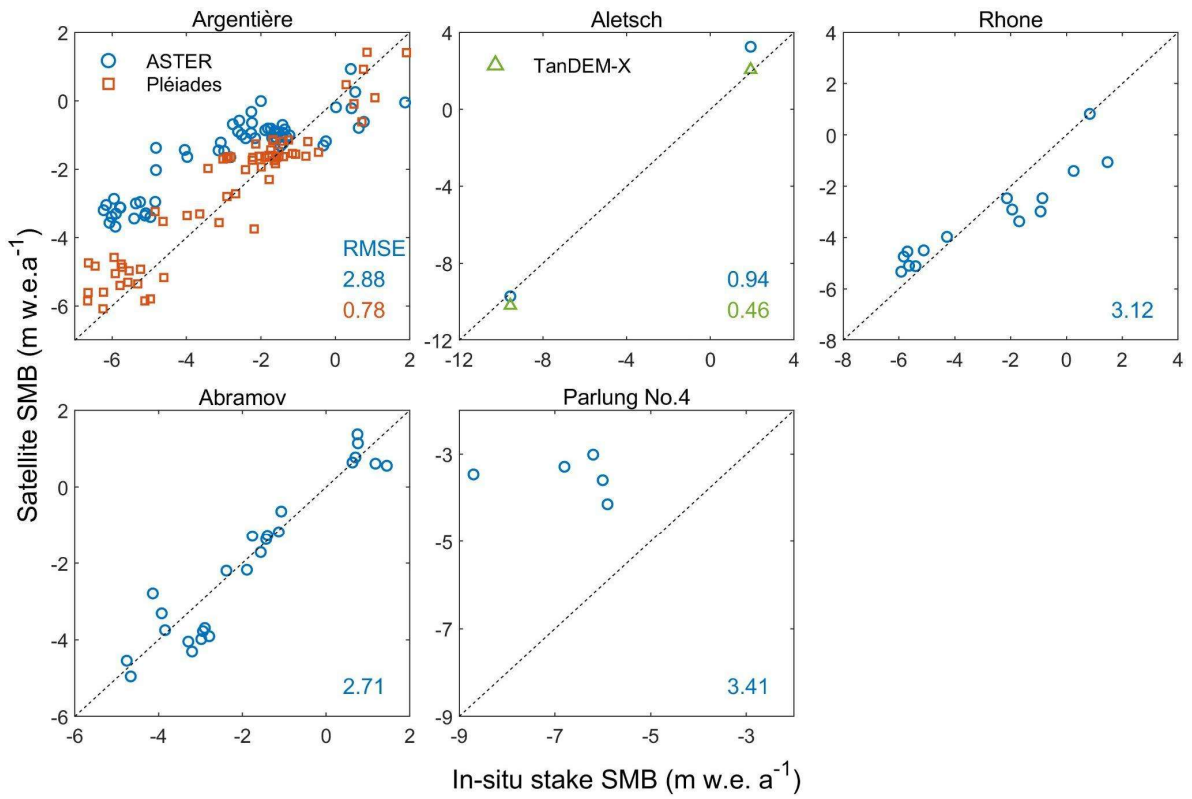
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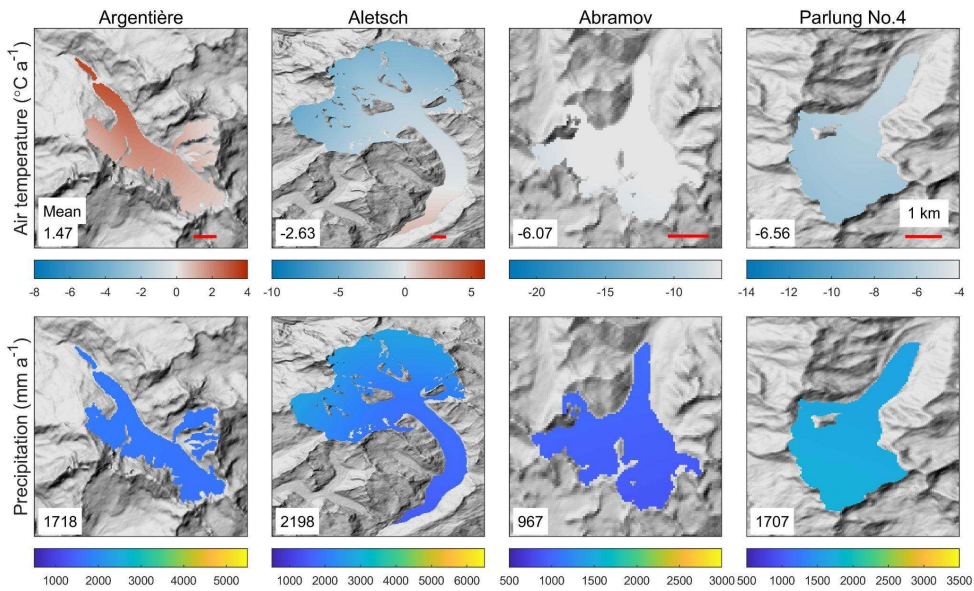


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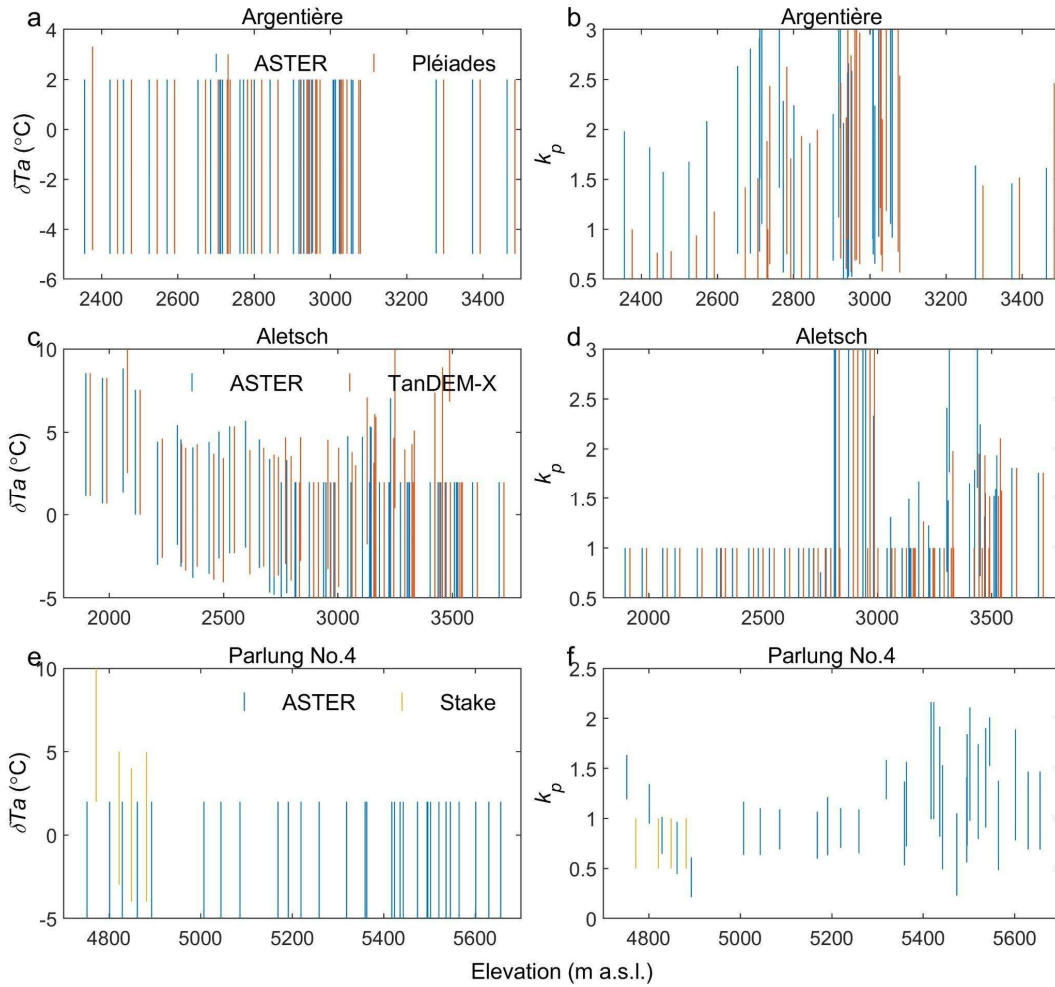
Figure S1. Total number of scenes of Landsat-8 and Sentinel-2 satellites during 2015-2019. Note that the scene is calculated by the area percent of the clear region when the glacier is partially covered by cloud and mountain shadow.



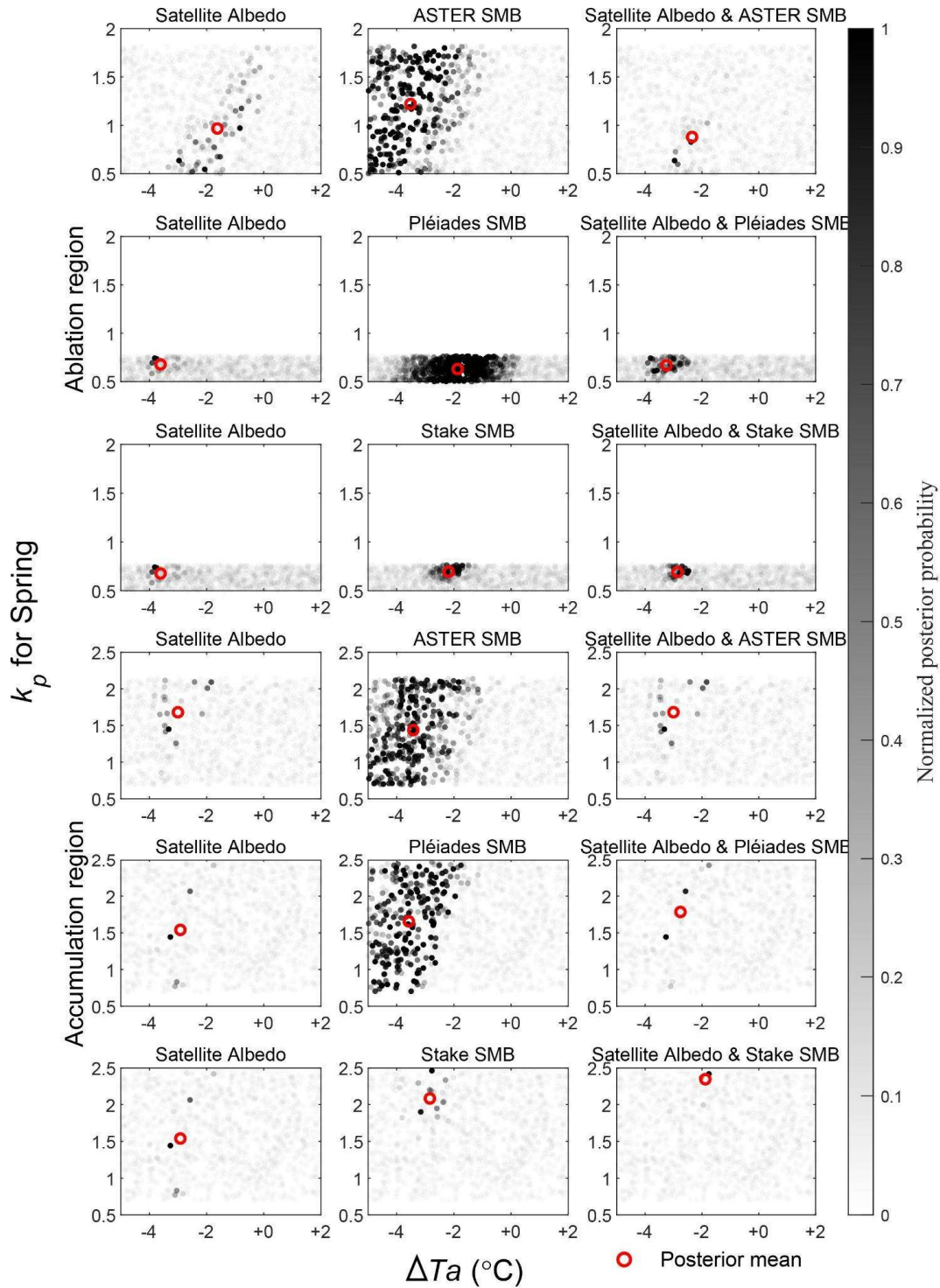
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 21 **Figure S2.** Satellite against in-situ stake SMB measurements across five glaciers. Note that this is not a “real”
 22 evaluation since some stake SMB do not cover the whole period of satellite SMB due to data absence.
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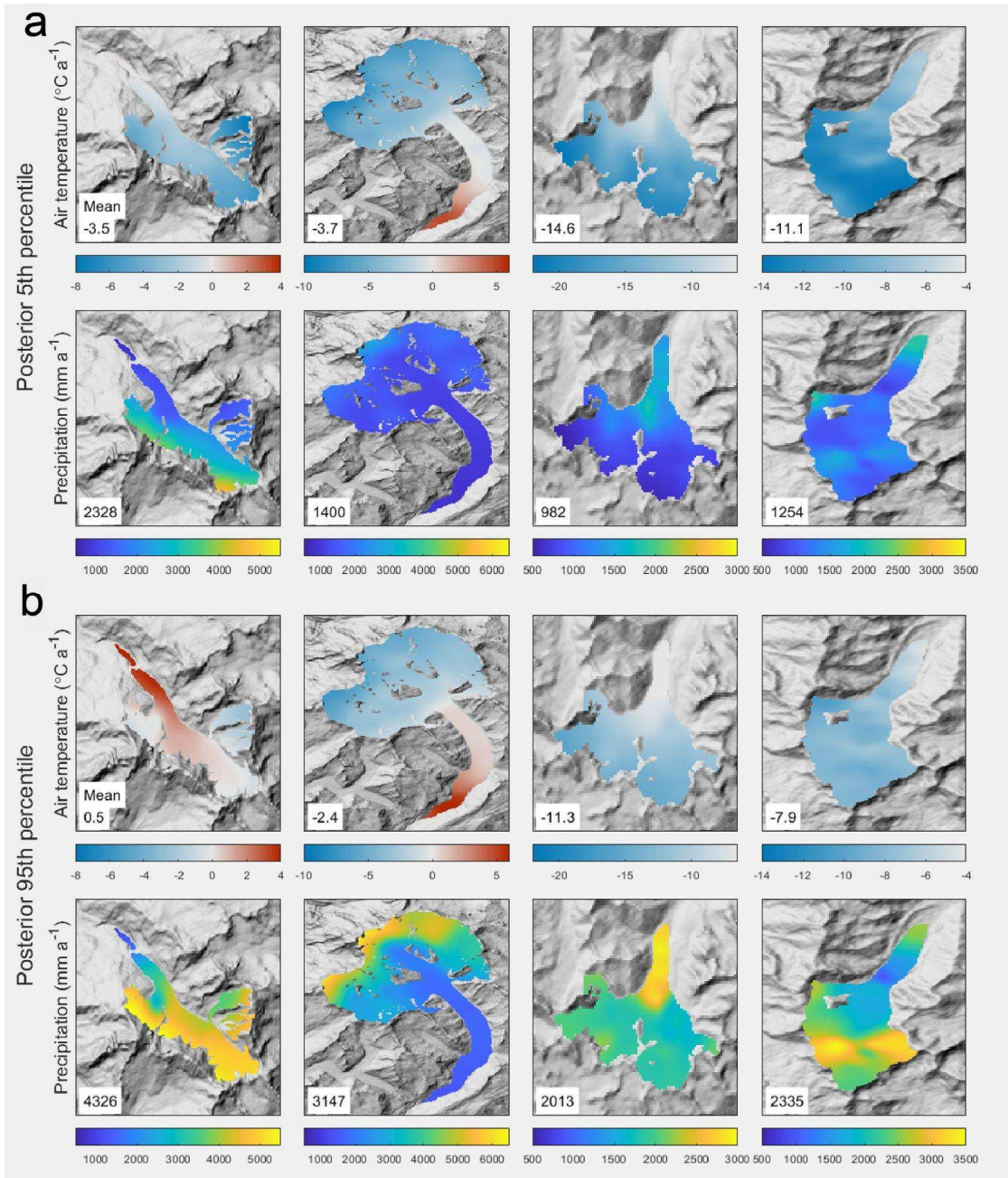
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 25 **Figure S3.** Multi-year average air temperature and precipitation from statistically downscaled ERA5-Land
 26 reanalysis data over 2015-2019. The number in each panel is glacier-wide average. The colorbar is the same as
 27 Fig. S6 for comparison.
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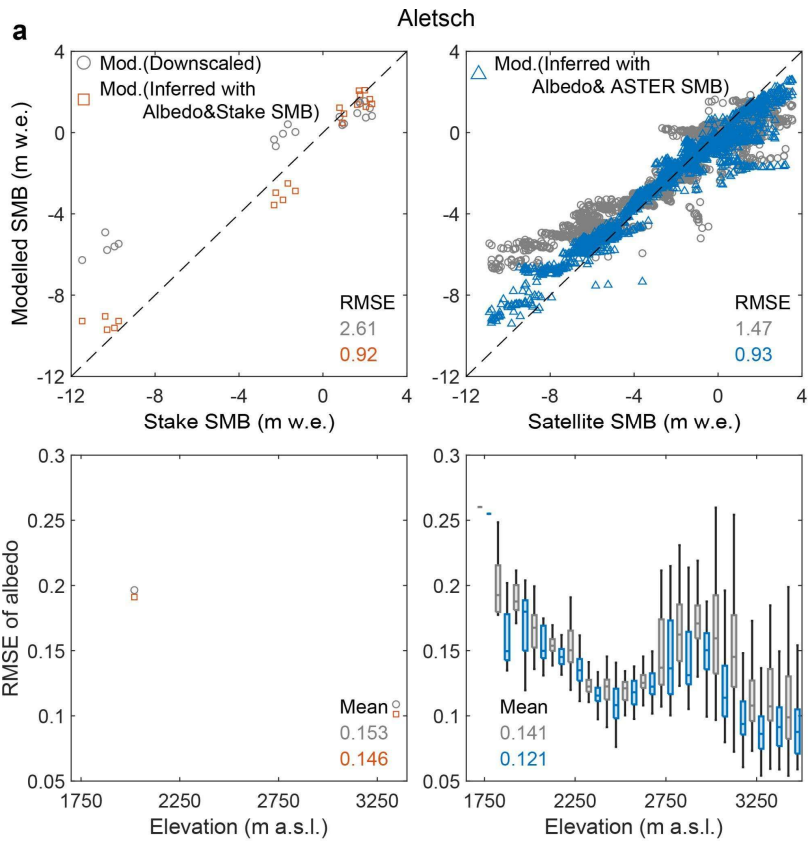
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 30 **Figure S4.** Prior range determined by ASTER against other SMB datasets across the three glaciers. a-b, ASTER
 31 against Pléiades SMB for Argentière Glacier; c-d, ASTER against TanDEM-X SMB for Aletsch Glacier; e-f,
 32 ASTER against Stake SMB for Parlung No.4 Glacier. The first column is for air temperature prior (ΔTa , °C)
 33 and the second column is for precipitation correction factor (k_p).
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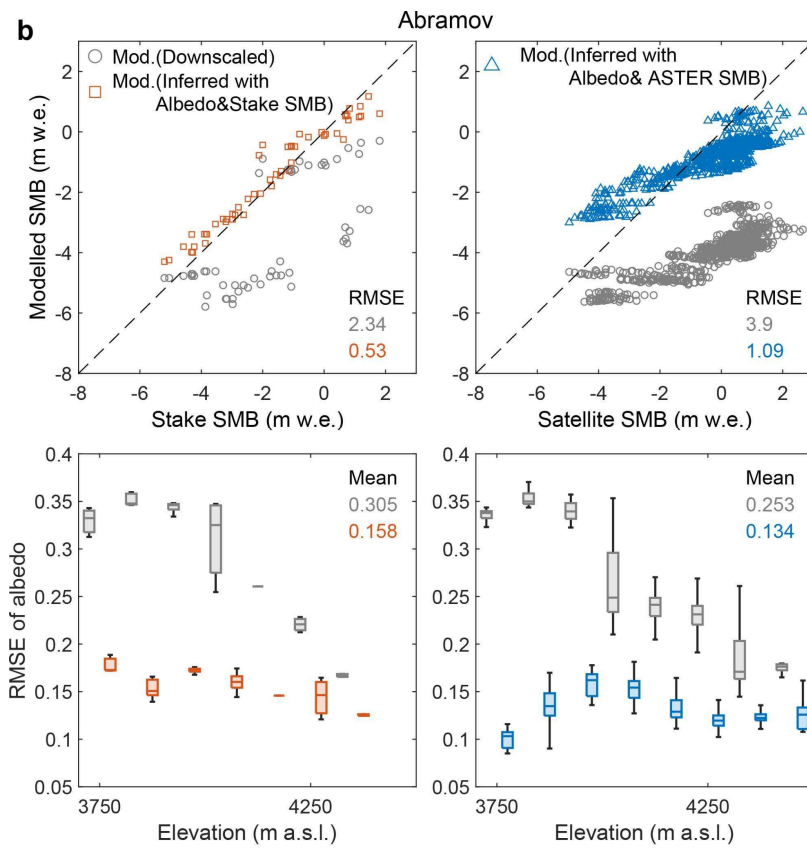
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 36 **Figure S5.** Two examples of Monte Carlo posterior samples (intensity-coded by their normalized posterior
 37 probability) distributions and inferred (posterior mean) bias-correctors for nine different combinations of targets
 38 at two stake SMB measurements at the ablation and accumulation region of Argentière Glacier (marked P_{Ar_abl}
 39 and P_{Ar_acc} in Fig. 1c, same as Fig. 4). Black points are 1000 Monte Carlo simulations. Note that the period of
 40 ASTER SMB is 2015-2019, while Pléiades SMB is 2013-2022. Correction spaces are narrow when using
 41 Pléiades/Stake SMB as a target due to narrow prior of k_p (Fig. S4b).
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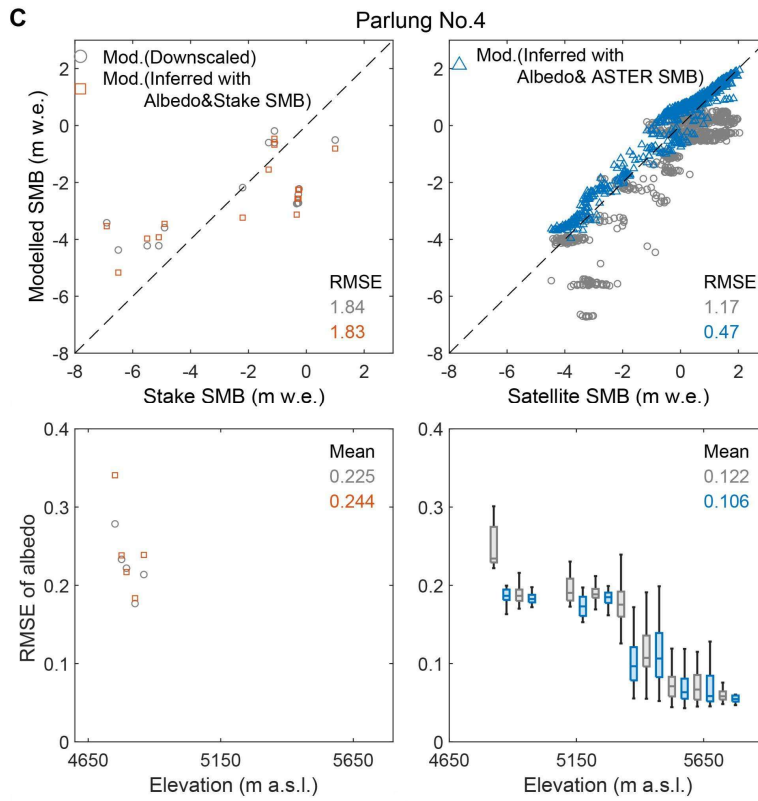
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 44 **Figure S6.** Inferred uncertainties of multi-year average air temperature and precipitation with 5th (a) and 95th
 45 (b) posterior percentile by ASTER SMB and satellite albedos during 2015-2019. The number in each panel is
 46 glacier-wide average.
 47



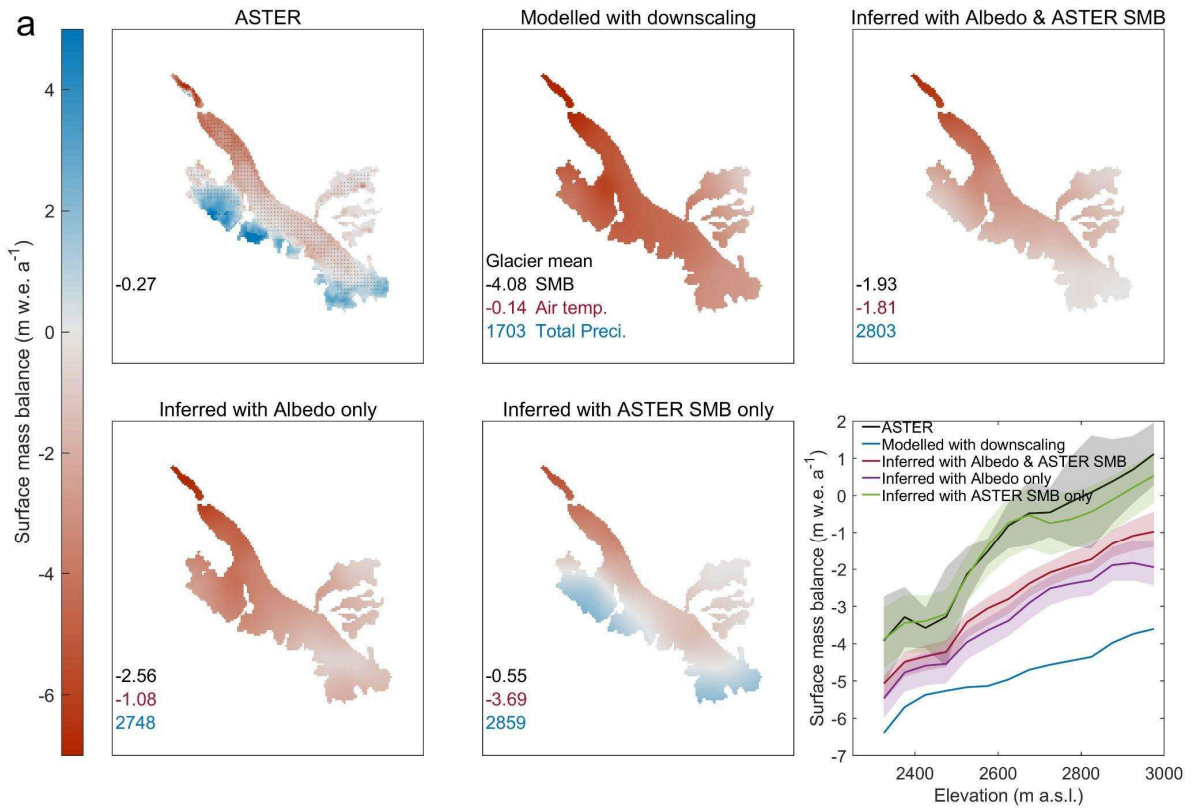
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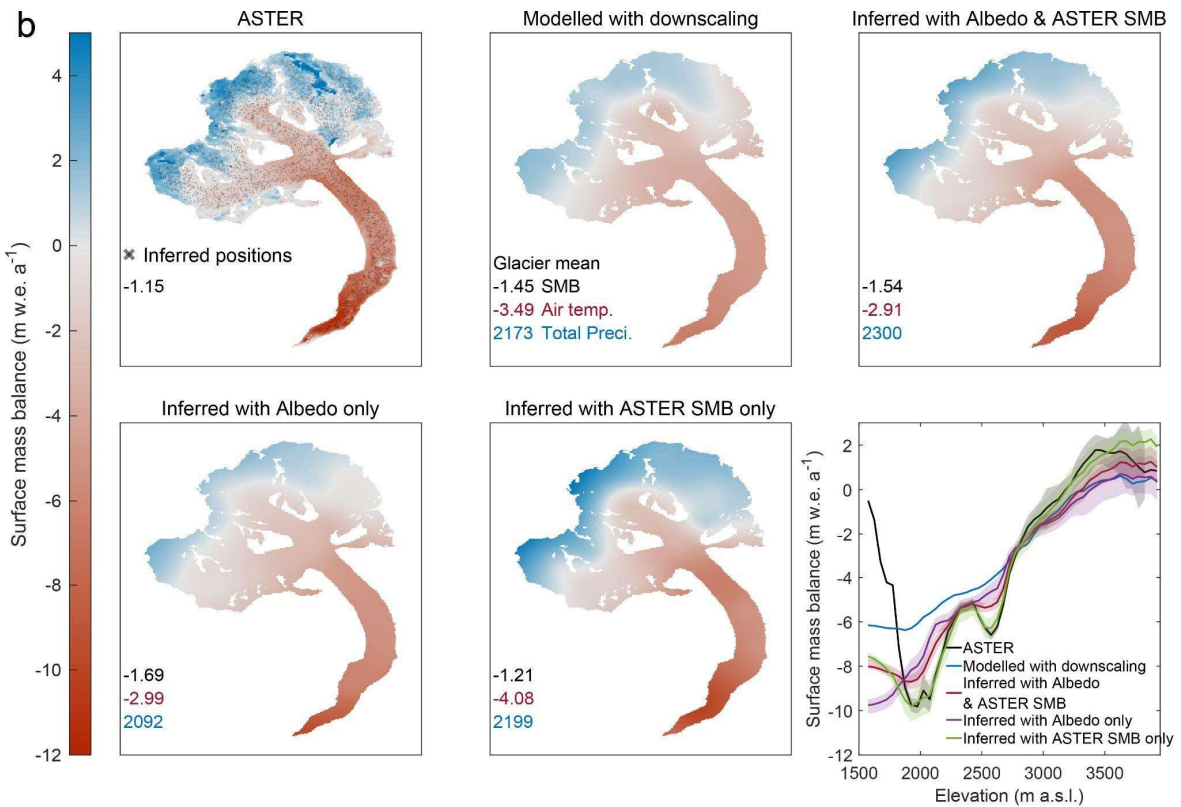
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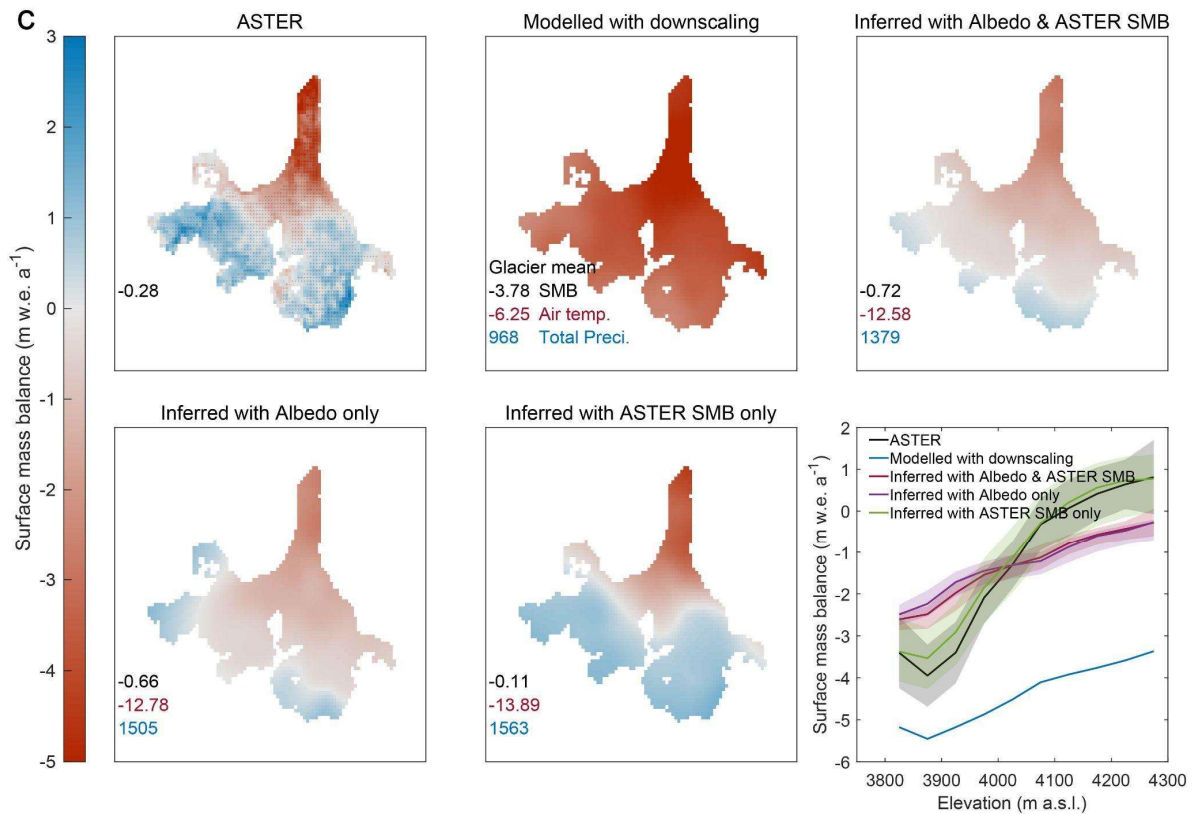
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 51 **Figure S7.** modelled SMB (first row of each panel) and glacier albedo (second row of each panel) against used
 52 targets at Aletsch (a), Abramov (b) and Parlung No.4 (c) Glacier (same as Fig. 5 but for other glaciers). Grey
 53 represents modelled with downscaling ERA5-Land, red is inferred with satellite albedo and stake SMB, and
 54 blue is inferred with satellite albedo and SMB. Note that the points in the first subpanel represent all
 55 measurements from stakes, while in the second subpanel they represent all locations used for inference (black
 56 points in Fig. 7b-d).
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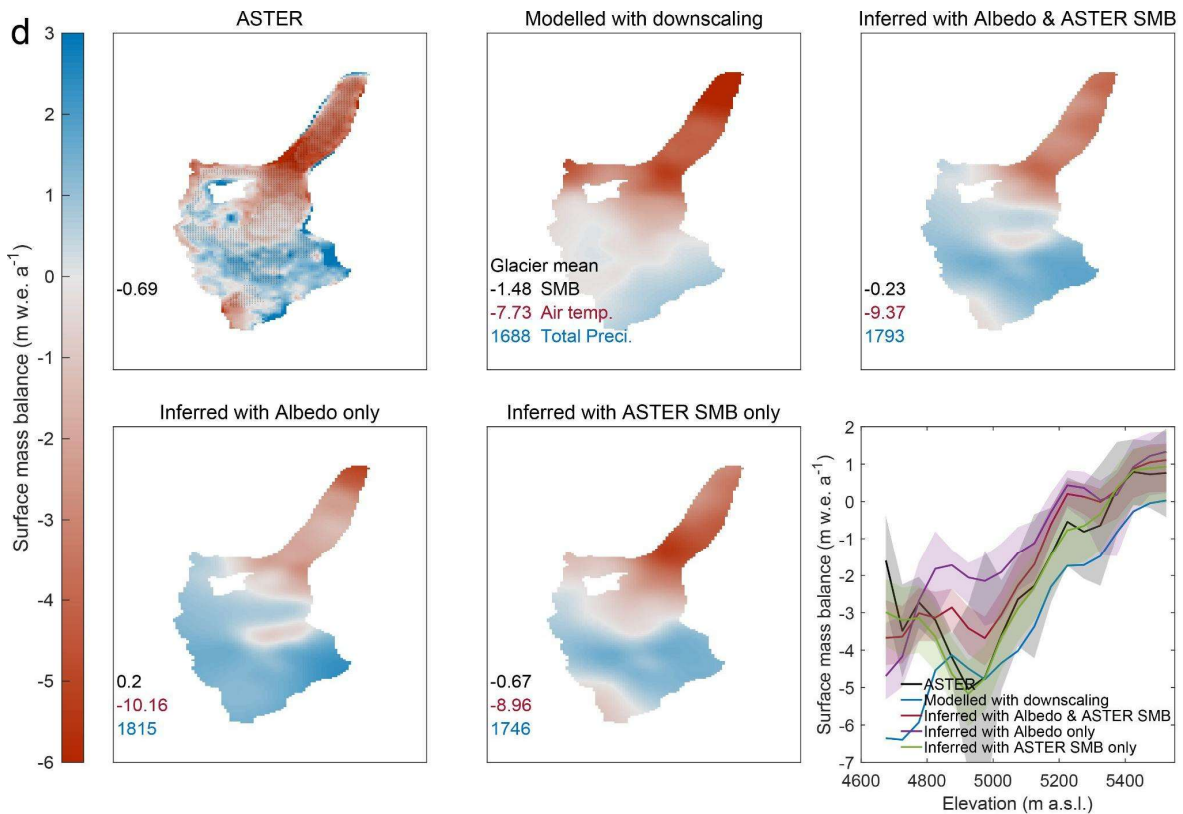
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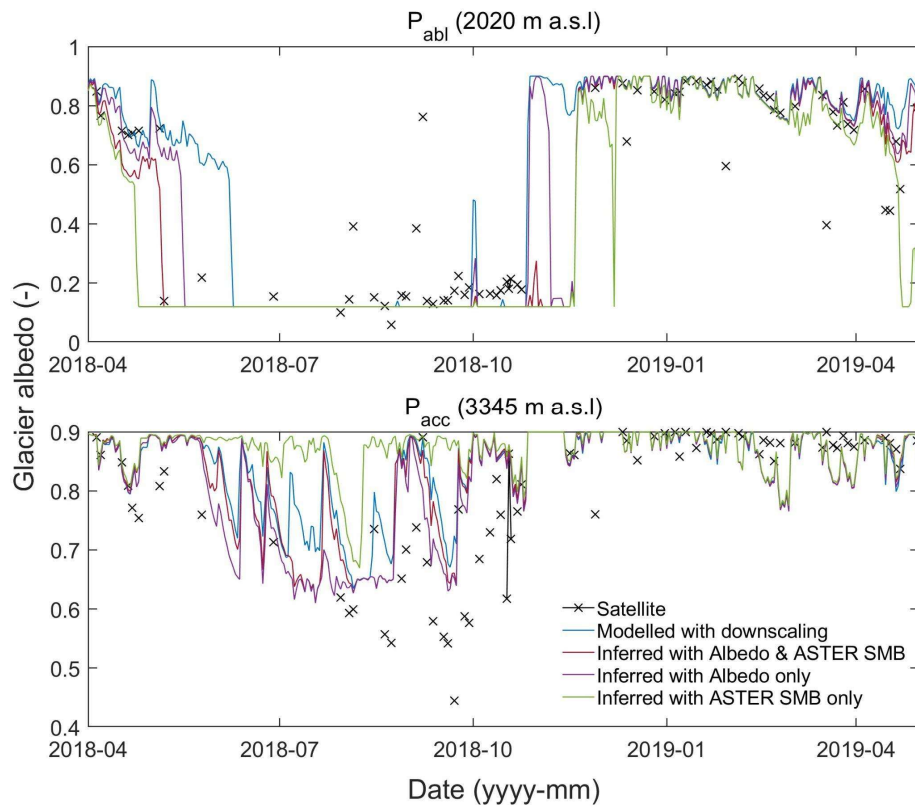


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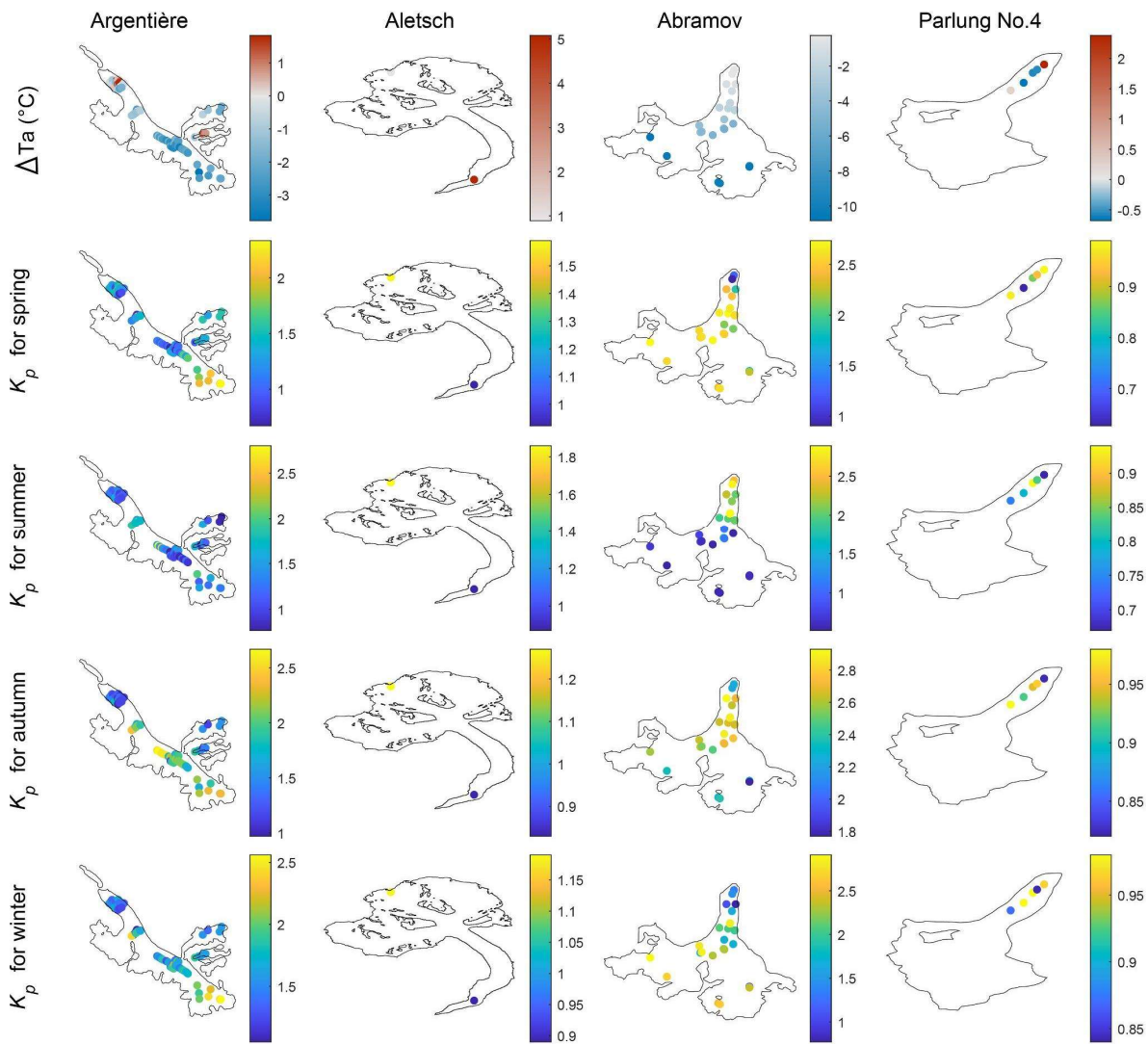
62 **Figure S8.** Comparison of modelled and ASTER SMB at Argentière (a), Aletsch (b), Abramov (c) and Parlung
 63 No.4 (d) Glaciers. Black points in the first subpanel are inferred locations. Black numbers are glacier-wide mean
 64 SMB, red and blue numbers are glacier-wide mean air temperature and precipitation used for SMB map
 65 generation. The shading area in the last panel is the uncertainty of SMB in each 50 m elevation bin.



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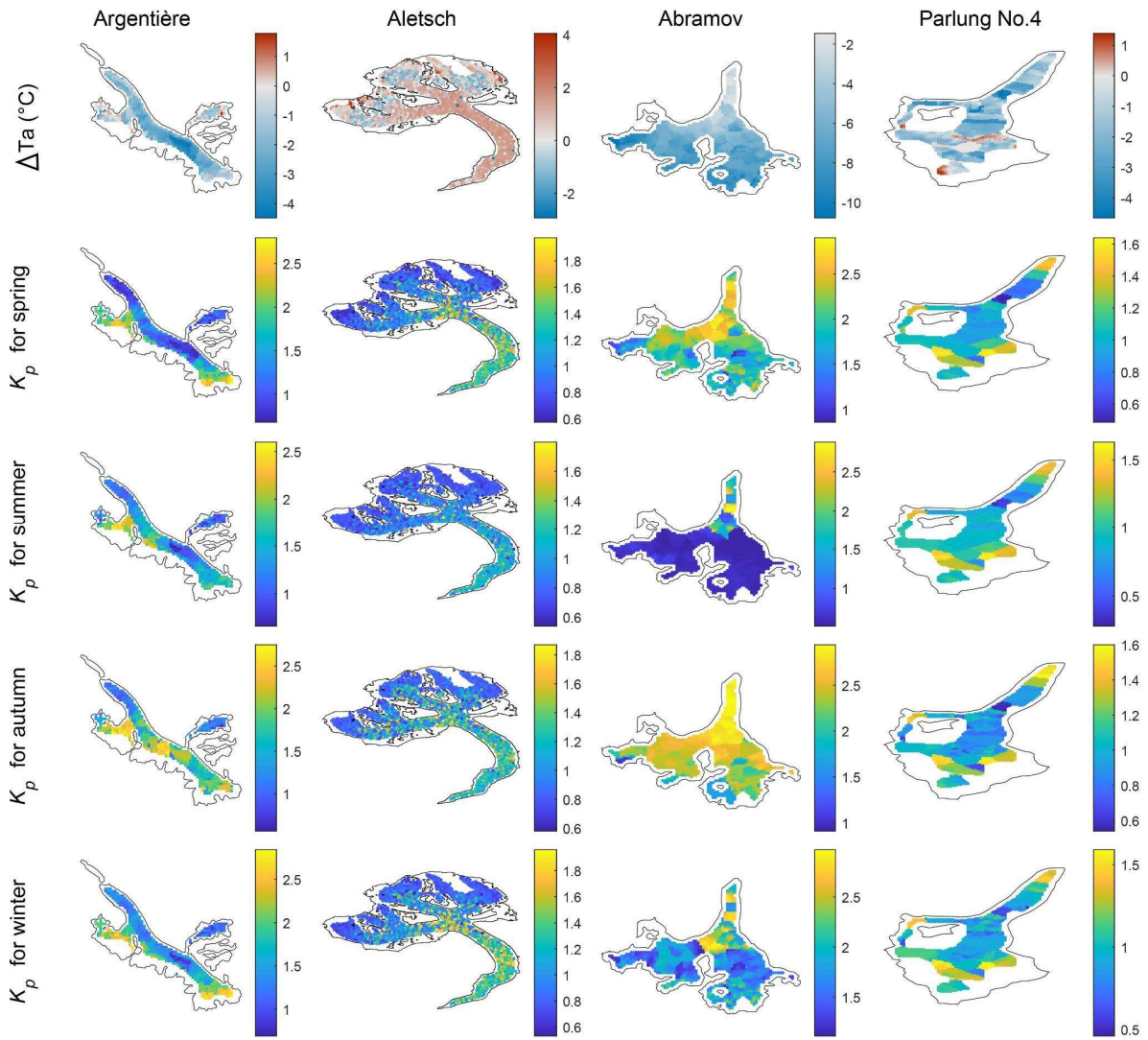
68 **Figure S9.** Two examples of temporal dynamics of glacier albedo derived from inference with satellite albedo
 69 & ASTER SMB against satellite observations at two stake SMB measurements at the ablation and accumulation
 70 region of Aletsch Glacier (marked P_{abl_Al} and P_{acc_Al} in Fig. 1d) during 2018-2019.

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 73 **Figure S10.** Inferred additive factor for air temperature (ΔT_a , first row) and multiplicative factor for seasonal
 74 precipitation (k_p , second-fifth rows) with satellite albedo and stake SMB at the locations of stakes for four
 75 tested glaciers over 2015-2019. The points in each panel are the locations of stake SMB measurements and their
 76 colors indicate correction factors. Note that these factors are relative to their nearest downscaled meteorology
 77 (purple points in Fig. 1c-f)

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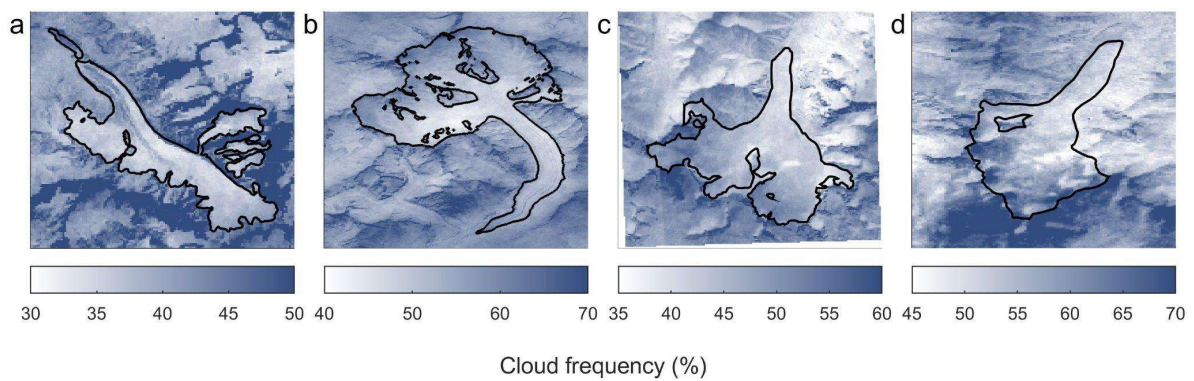


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Figure S11. Same as Fig. 8 but for inference with satellite albedo and ASTER SMB.

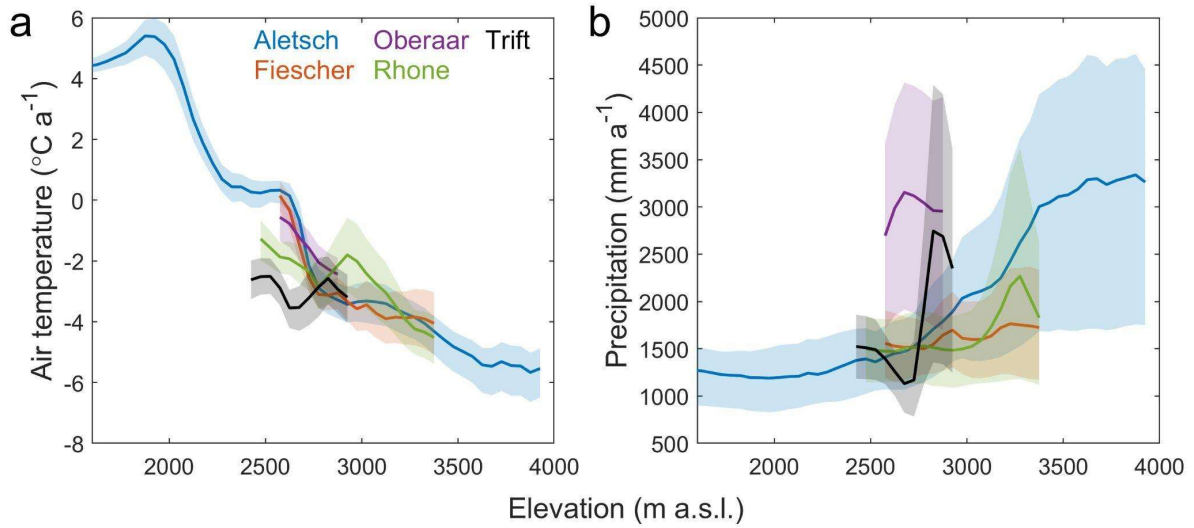


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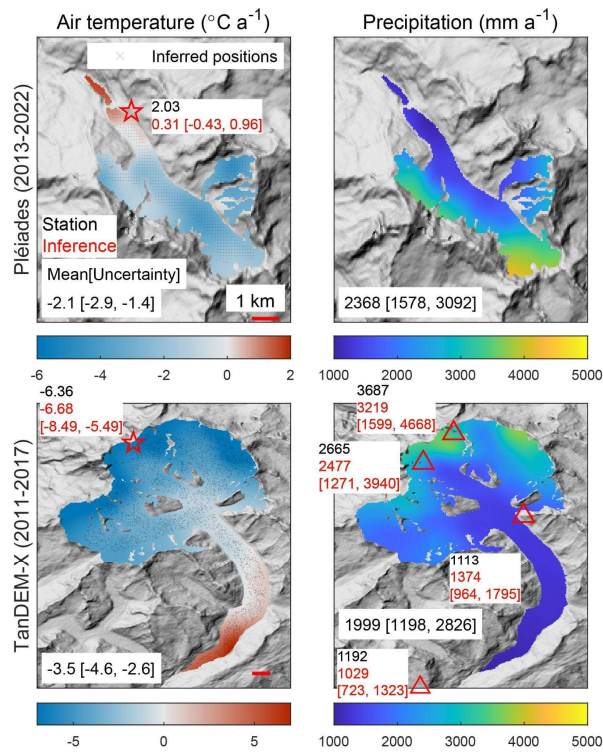
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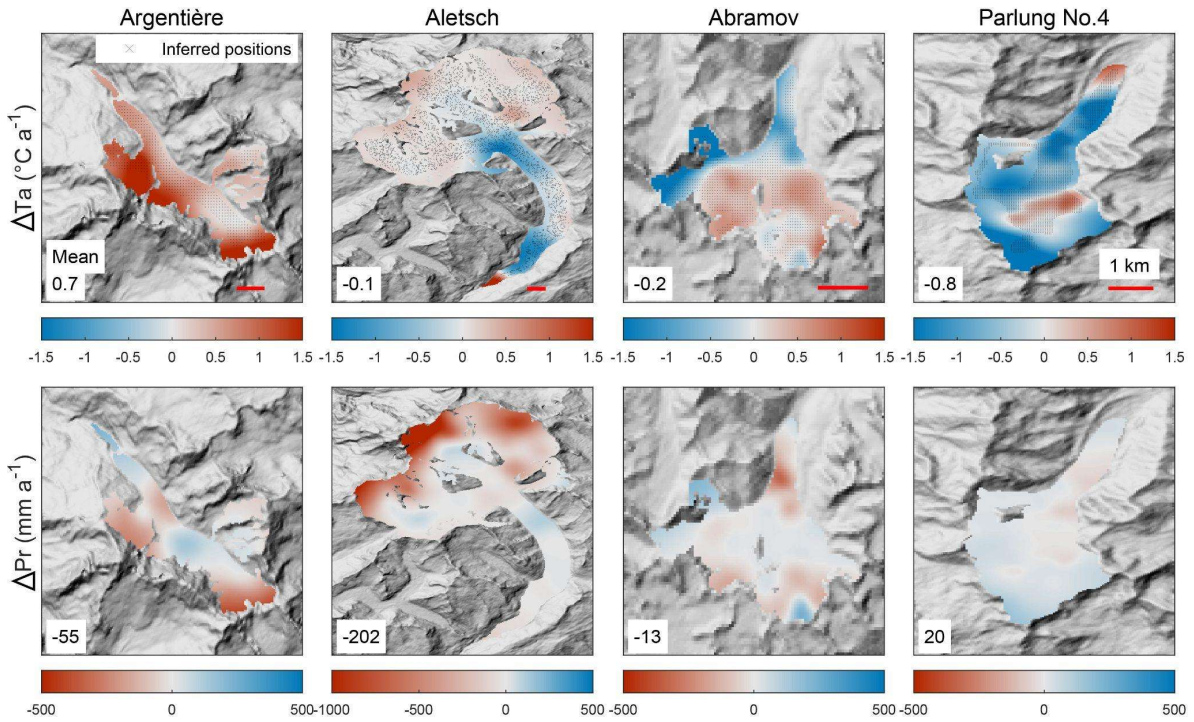
Figure S12. Cloud frequency maps derived with Sentinel-2 over the four glaciers for 2015–2019.



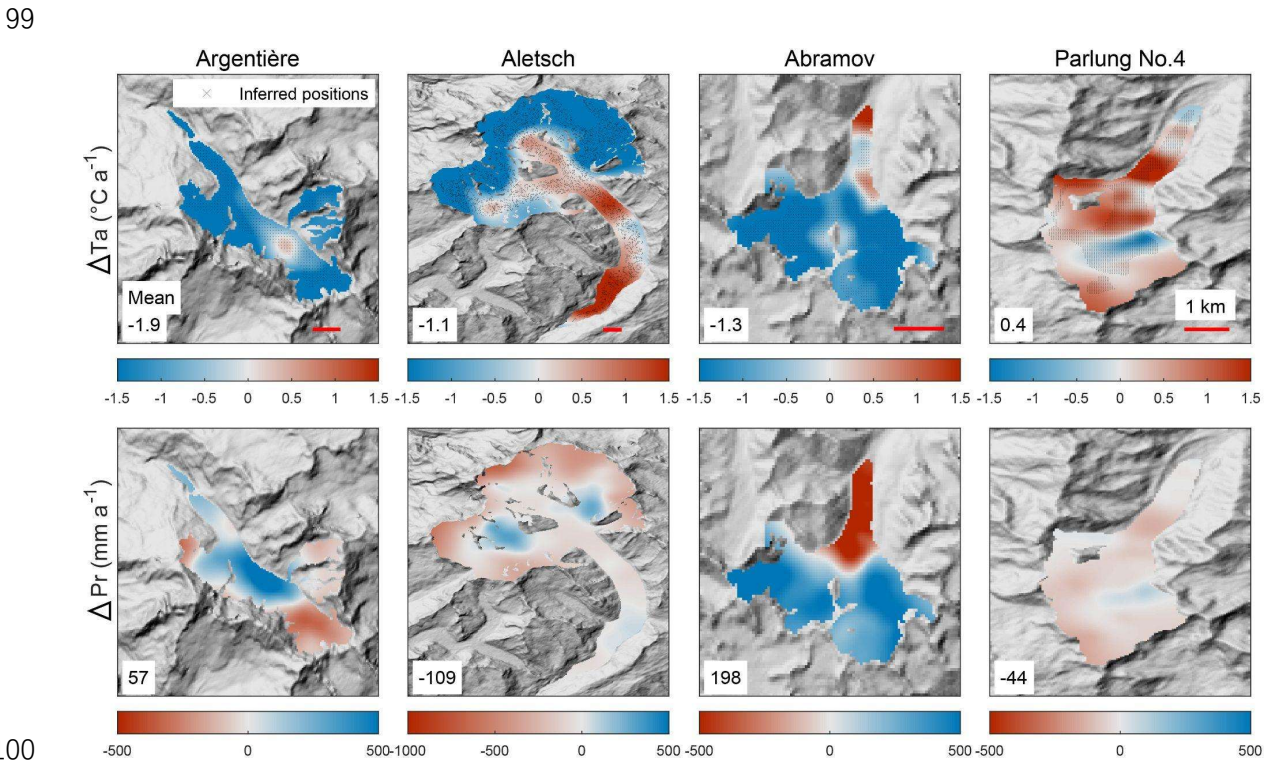
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 86 **Figure S13.** Inferred multi-year average meteorology by satellite albedo and ASTER SMB datasets as a
 87 function of elevation at the five glaciers of Upper Valais. The shaded area represents the uncertainty within
 88 each elevation bin. The dataset used for aggregation is the same as in Fig. 9.
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 91 **Figure S14.** Same as Fig. 6 but inferred by satellite albedo and high-quality SMB datasets (Pléiades/
 92 TanDEM-X). The colorbar is the same as Fig. 6.
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94
 95 **Figure S15.** Difference of inferred multi-year average air temperature (a) and precipitation (b) between using
 96 satellite albedo only and using satellite albedo and ASTER SMB across four glaciers over 2015-2019. A:
 97 $Ta_{\text{Albedo}} - Ta_{\text{Albedo\&ASTER SMB}}$; $Pr_{\text{Albedo}} - Pr_{\text{Albedo\&ASTER SMB}}$. The displayed numbers in the left corner represent the
 98 glacier-wide mean values.



100
 101 **Figure S16.** Same to Fig. S15 but for the difference between using ASTER SMB only and using satellite albedo
 102 and ASTER SMB.

105 **Table S1.** Datasets used in this study

Type	Parameter	Glacier	Period	Note	Reference
Forcing data (Meteorology)	ERA5-Land (Seven variables)	All	2014-2019, 2011-2022		Muñoz-Sabater, 2021
Target data (Remote sensing)	Glacier albedo (Landsat-8/9, Sentinel-2)	All	2014-2019, 2011-2022		Ren et al. (2021)
	Low-quantity SMB (ASTER)	All	2015-2019		Miles et al. (2021)
	High-quantity SMB (Pléiades)	Argentière	2013-2022, 2013-2018, 2019-2022	Comparison with ASTER inference	Kneib et al. (2024)
	High-quantity SMB (TanDEM- X)	Aletsch	2011-2017	Comparison with ASTER inference	Leinss et al. (2021)
Evaluation data	In-situ meteorology (Ta)	All	2014-2019, 2011-2022	Three off-glacier and one on-glacier station (Parlung No.4)	GLACIOCLIM , MeteoSwiss,
	In-situ meteorology (Pr)	Aletsch	2011-2019	Five stations	MeteoSwiss ,
	In-situ SMB	Argentière	2013-2022		GLACIOCLIM, GLAMOS,WGM S
		Aletsch	2011-2019		
		Abramov	2015-2019		
	Cloud frequency (Sentinel-2)	All	2017-2019	Qualitative check	

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