Assessing the TanDEM-X elevation bias due to SAR signal penetration for glacier mass balance measurements

Krieger Lukas*[1], Ibarrola Subiza Nerea[1], Floricioiu Dana[1], Fischer Georg[2], Abdullahi Sahra[3]

[1]Remote Sensing Technology Institute (DLR), SAR Signal Processing, Oberpfaffenhofen, Germany
[2]Microwaves and Radar Institute (DLR), Radar Concepts, Oberpfaffenhofen, Germany
[3]German Remote Sensing Data Center (DLR), Land Surface Dynamics, Oberpfaffenhofen, Germany
*lukas.krieger@dlr.de

Introduction

The elevation bias due to signal penetration in InSAR DEMs is recognized as a main error source together with co-registration for estimating glacier mass balance with the DEM differencing method. For TanDEM-X DEMs, the elevation processed from X-band (9.65 GHz) SAR data can lie up to 4-8m lower than the actual snow/ice surface in alpine accumulation areas (Fig. 1) [1]. However, this bias can often be mitigated by differencing TanDEM-X acquisitions from the same season with unchanged SAR geometry, reducing penetration differences between DEMs. The relative importance of SAR signal penetration for accurate mass balance measurements also reduces with the length of the observation period.

Method

Common methods to correct for SAR signal penetration bias include estimating volumetric coherence and inverting a simple physical model [2] or predicting penetration corrections from an empirical model [3,4]. We use the former, which allows estimating the penetration bias directly from the measured InSAR coherence, by assuming a uniform lossy scattering volume (Fig. 2).

Here we validate the resulting penetration correction Δ_h, from inversion of volumetric coherence γ_{vol} across an entire TanDEM-X scene (30 March 2021 , 5:45 CET) of Aletsch glacier with a coincident DEM acquisition from Pléiades optical imagery (30 March 2021 , 10:40 CET) [1].

$$\Delta_h = -\frac{|h_a|}{2\pi}\arctan\left(\sqrt{|\gamma_{vol}|^{-2}-1}\right) \qquad \gamma_{vol} = \frac{\gamma_{Tot}}{\gamma_{SNR}\,\gamma_{Quant}\,\gamma_{Amb}\,\gamma_{Rg}\,\gamma_{Az}\,\gamma_{Temp}}$$

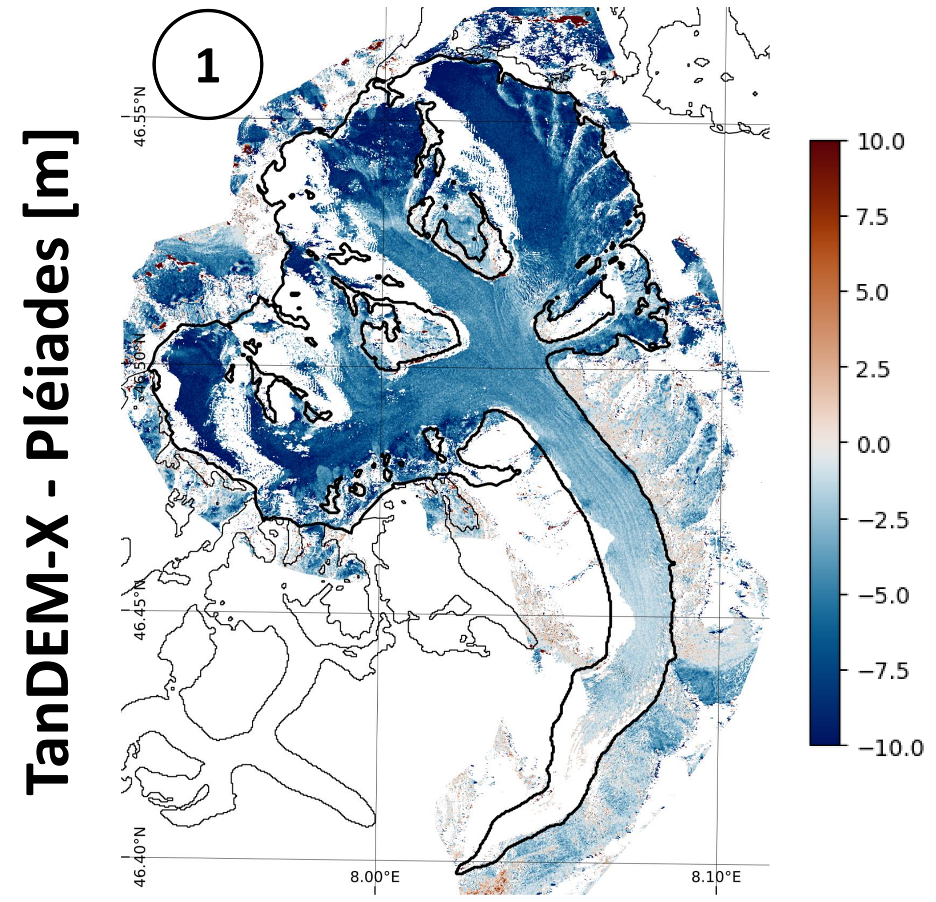
The height of ambiguity is denoted as h_a. As in [5] the decorrelation factors are: γ_{Amb}, γ_{Rg}, γ_{Az} = 0.98, γ_{Temp} = 1.0 and γ_{Quant} from a lookup table.

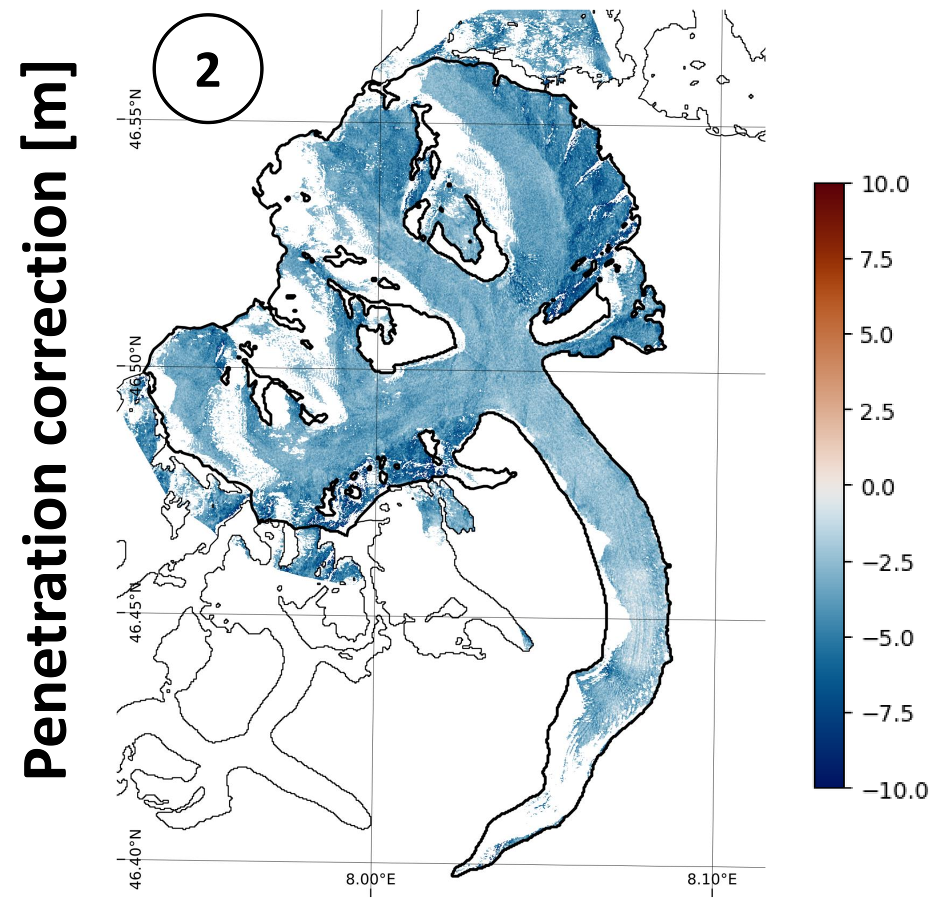
The decorrelation factor resulting from thermal noise γ_{SNR} is calculated from beta naught β^0 and noise equivalent beta naught $NEBN$ annotations of the TanDEM-X DEM product. It becomes significant in the low backscatter areas of the glacier (Fig. 4).

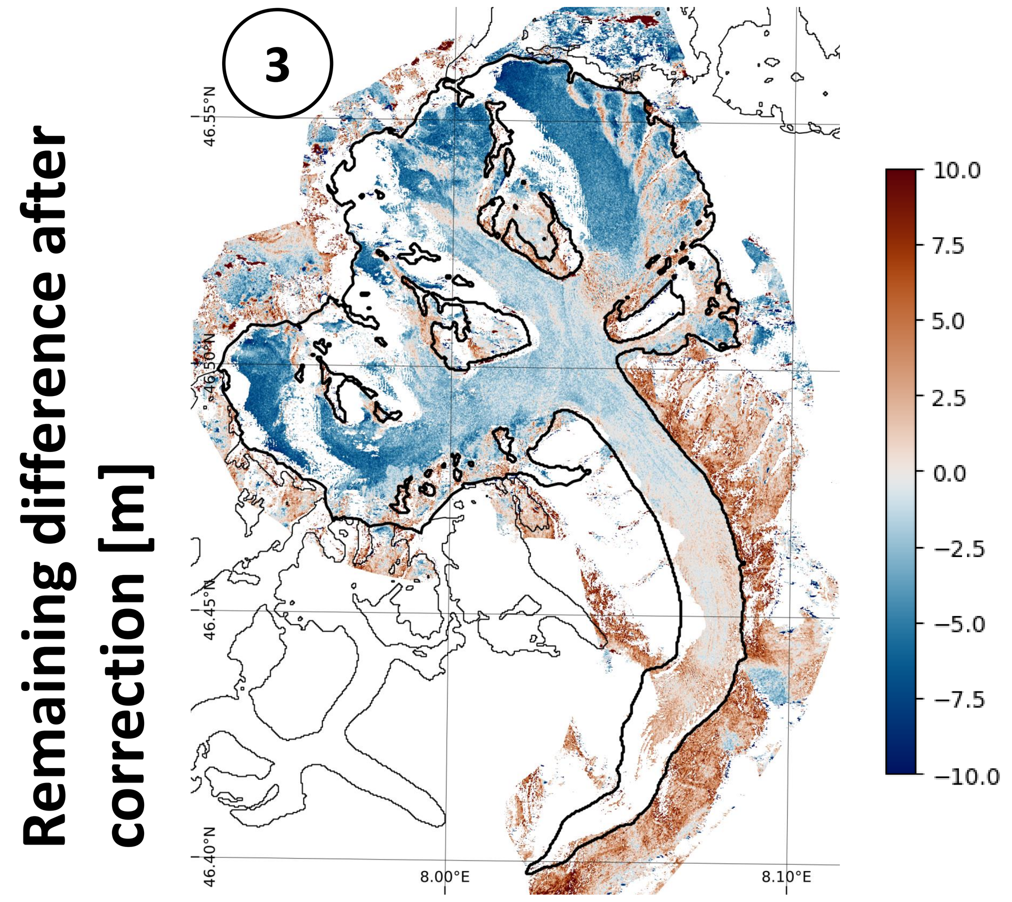
$$\gamma_{SNR} = \frac{1}{1+\frac{1}{SNR}} \qquad SNR = \frac{\beta^0 - NEBN}{NEBN}$$

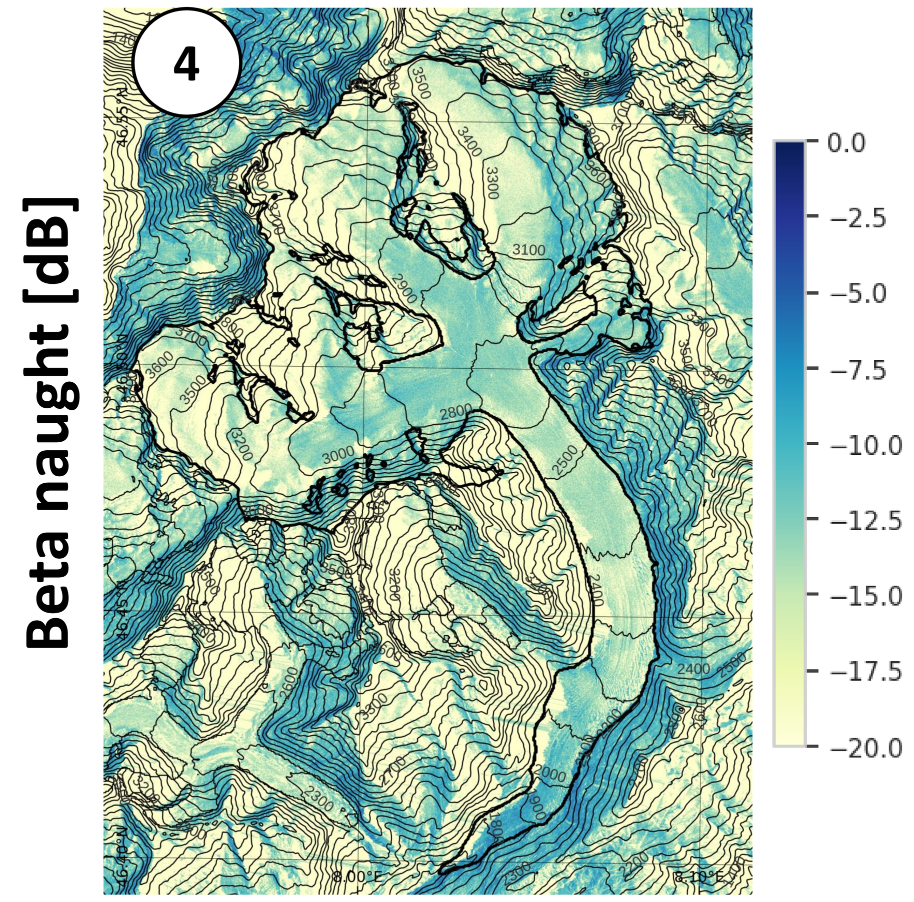
Results & Conclusion

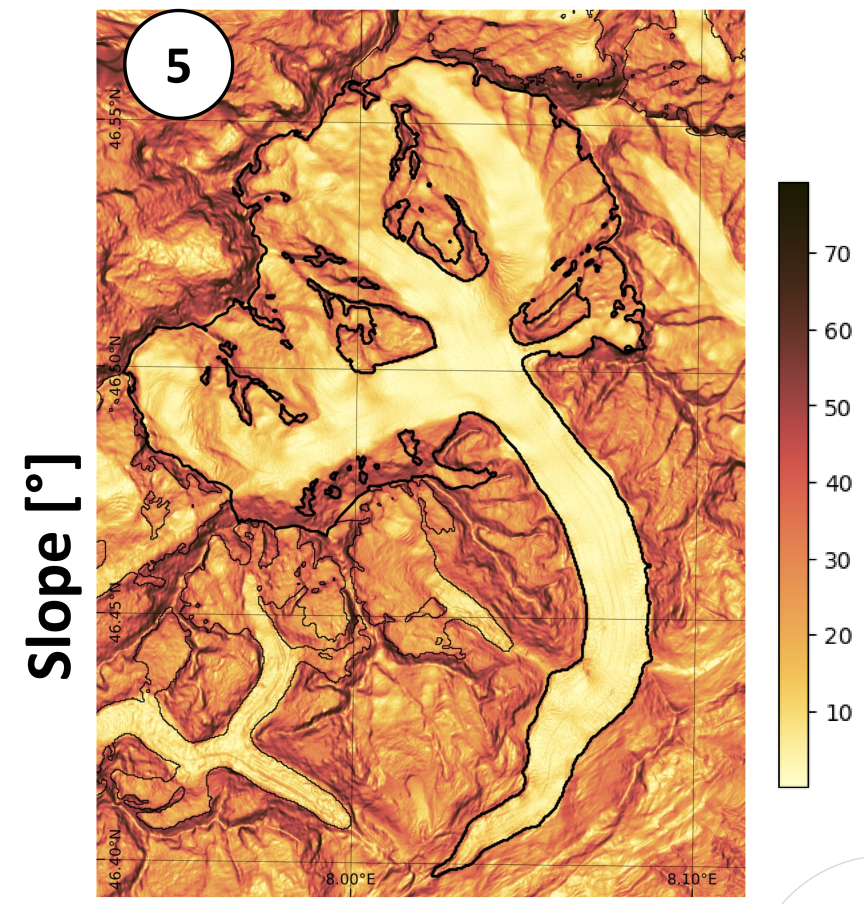
In this alpine test case over the Aletsch glacier, the applied correction based on volumetric coherence generally reduces the elevation bias due to SAR signal penetration and partly reduces the trend with elevation (Fig. 3&7). However, performance varies with elevation and terrain. In the higher accumulation areas above 3000 m, (fresh) snow appears to be partially transparent to X-band SAR, resulting in little to no impact on volumetric coherence and thus in an underestimation of the penetration bias. Conversely, in the lower glacier regions below 2300 m, where the scattering scenario likely deviates strongly from the model assumptions, the correction tends to overestimate the elevation bias, leading to overcorrection. Additionally, areas with steep slopes yield unrealistic penetration correction values, likely due to geometric distortions or decorrelation effects (Fig. 5&8).

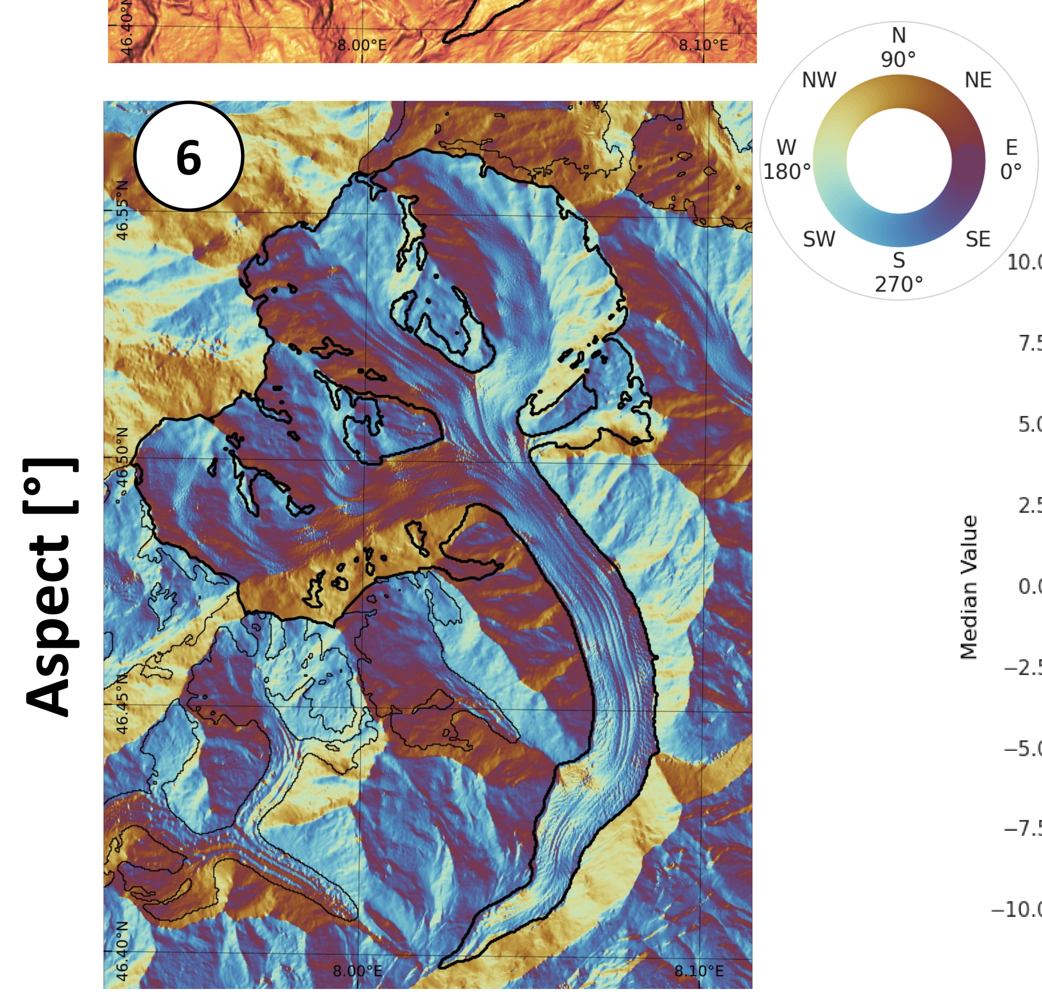


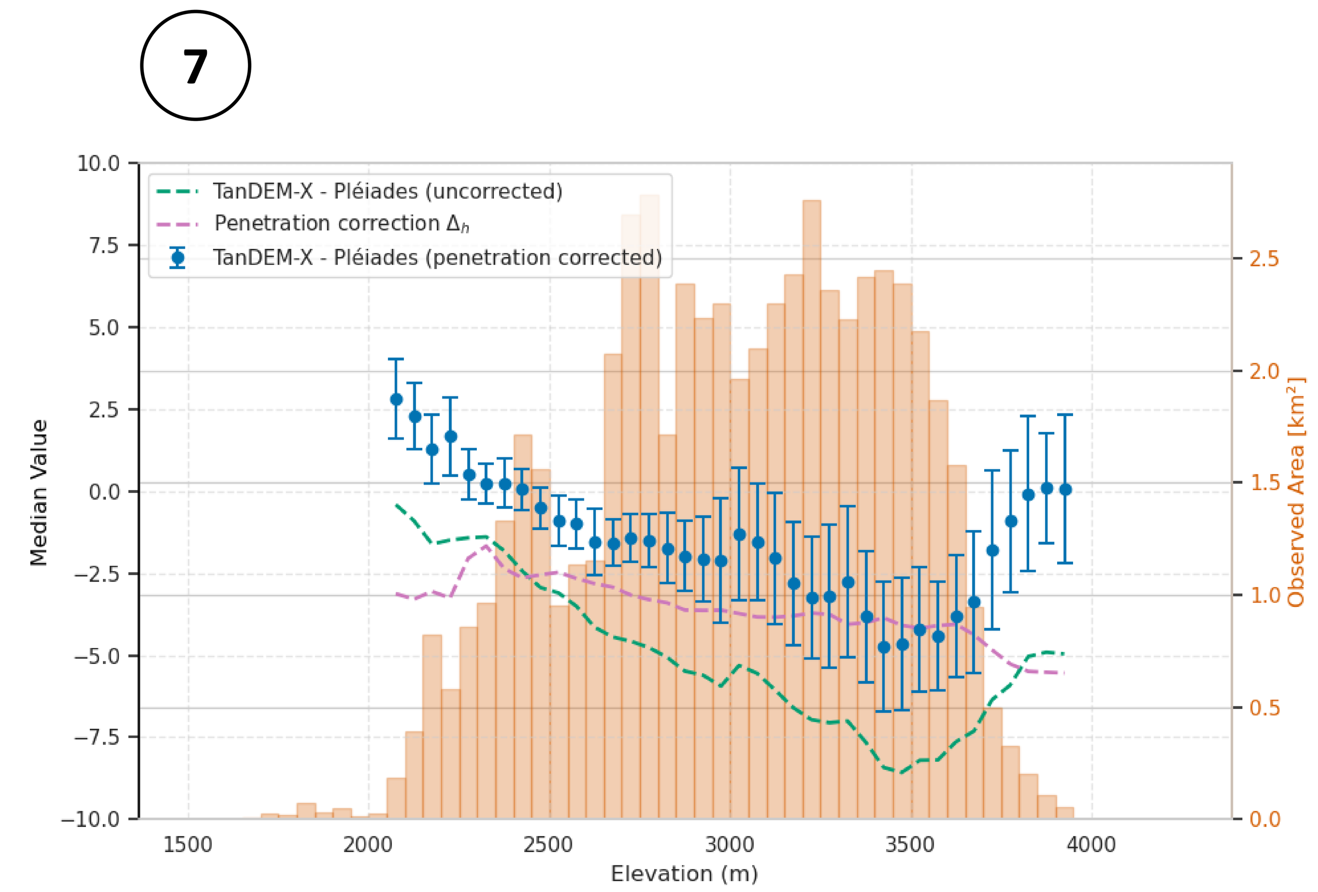


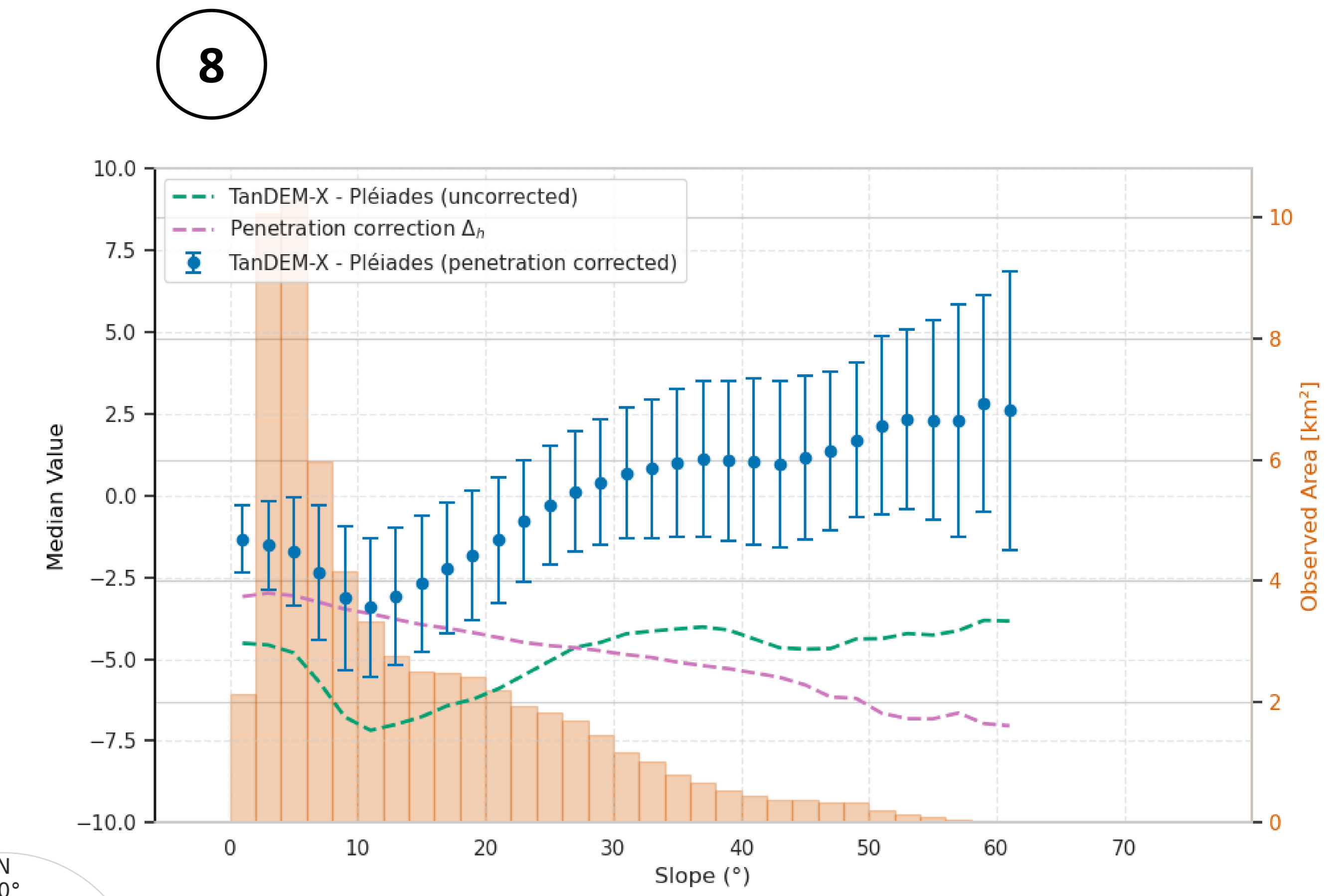


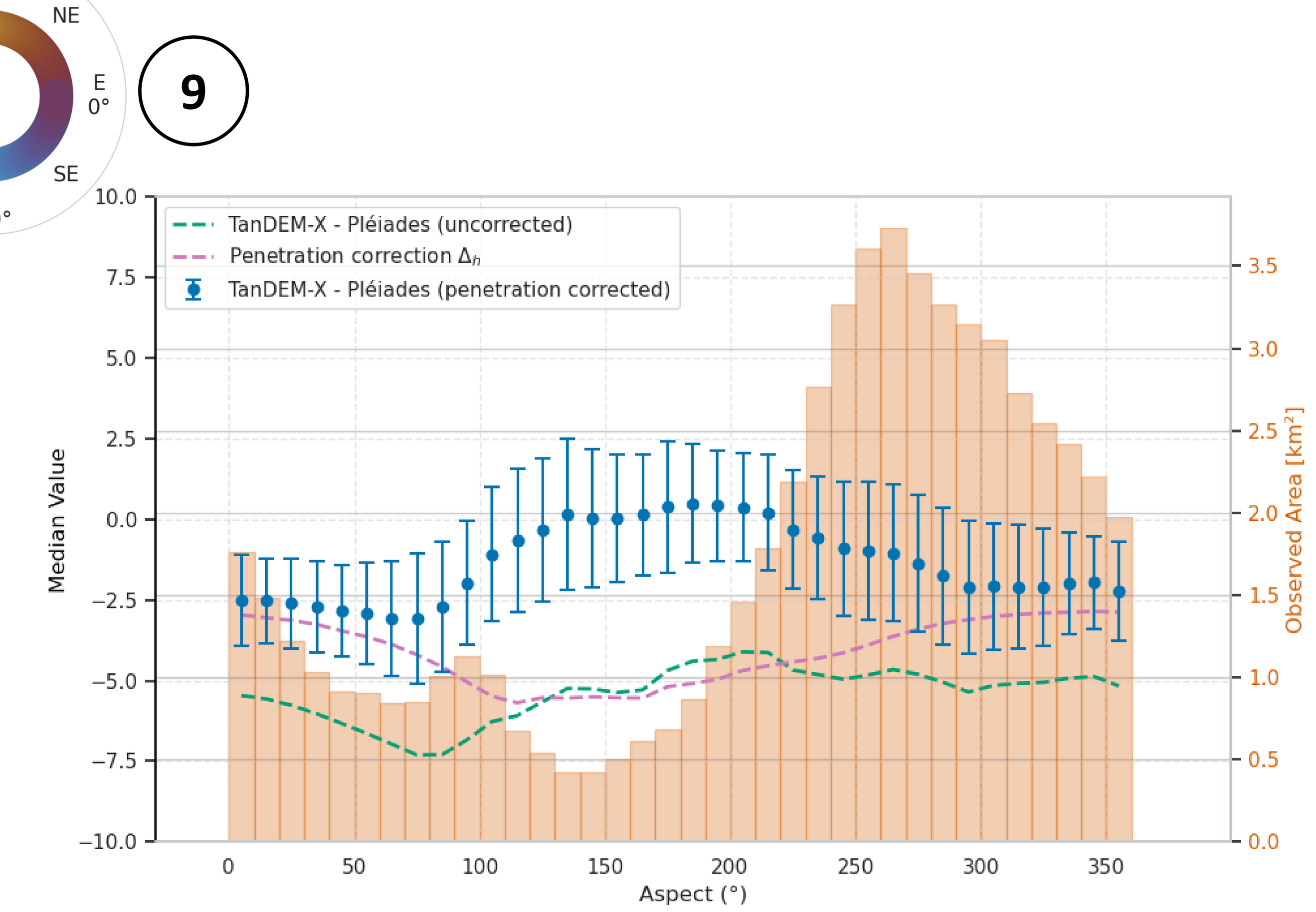












References

[1] Bannwart, Jacqueline, Livia Piermattei, Inés Dussaillant, Lukas Krieger, Dana Floricioiu, Etienne Berthier, Claudia Roeoesli, Horst Machguth, and Michael Zemp. 2024. "Elevation Bias Due to Penetration of Spaceborne Radar Signal on Grosser Aletschgletscher, Switzerland." *Journal of Glaciology*, April, 1–15. https://doi.org/10.1017/jog.2024.37.
[2] Dall, Jørgen. 2007. "InSAR Elevation Bias Caused by Penetration Into Uniform Volumes." *IEEE Transactions on Geoscience and Remote Sensing* 45 (7): 2319–24. https://doi.org/10.1109/TGRS.2007.896613.
[3] Abdullahi, Sahra, David Burgess, Birgit Wessel, Luke Copland, and Achim Roth. 2023. "Quantifying the Impact of X-Band InSAR Penetration Bias on Elevation Change and Mass Balance Estimation." *Annals of Glaciology* 64 (92): 396–410. https://doi.org/10.1017/aog.2024.7.
[4] Mansour, I., Fischer, G., Hänsch, R., Hajnsek, I., & Papathanassiou, K. (2024). Correction of The Penetration Bias for Insar Dem Via Synergetic Ai-Physical Modeling: A Greenland Case Study. *IGARSS 2024 - 2024 IEEE International Geoscience and Remote Sensing Symposium*, 138–142. https://doi.org/10.1109/IGARSS53475.2024.10642748
[5] Rizzoli, P., Dell Amore, L., Bueso Bello, J. L., Gollin, N., Carcereri, D., & Martone, M. (2022). On the Derivation of Volume Decorrelation from TanDEM-X Bistatic Coherence. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. https://ieeexplore.ieee.org/document/9763376

DLR Project
Polar Monitor II

Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center