ESTIMATION OF SAR SIGNAL PENETRATION DEPTH OVER SNOW/ICE LAND COVER AREAS USING VOLUME DECORRELATION COMPUTED FROM GEOCODED TANDEM-X PRODUCTS

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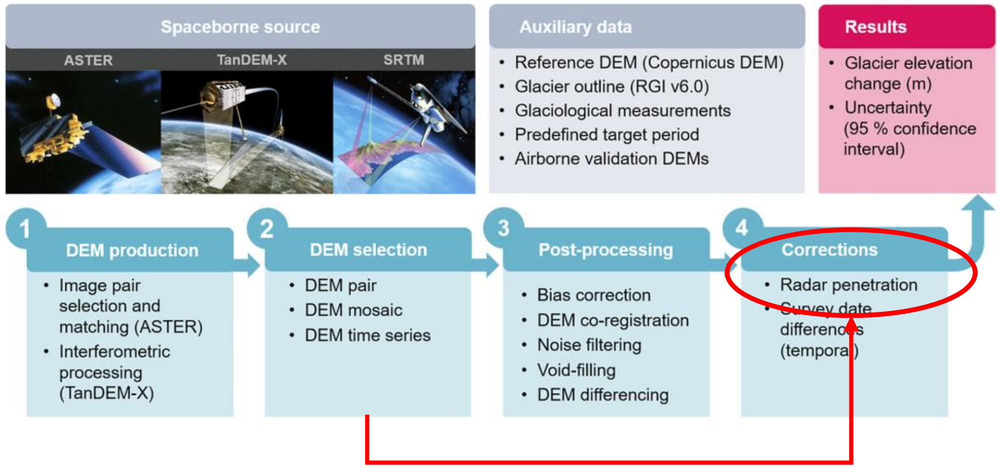
Motivation

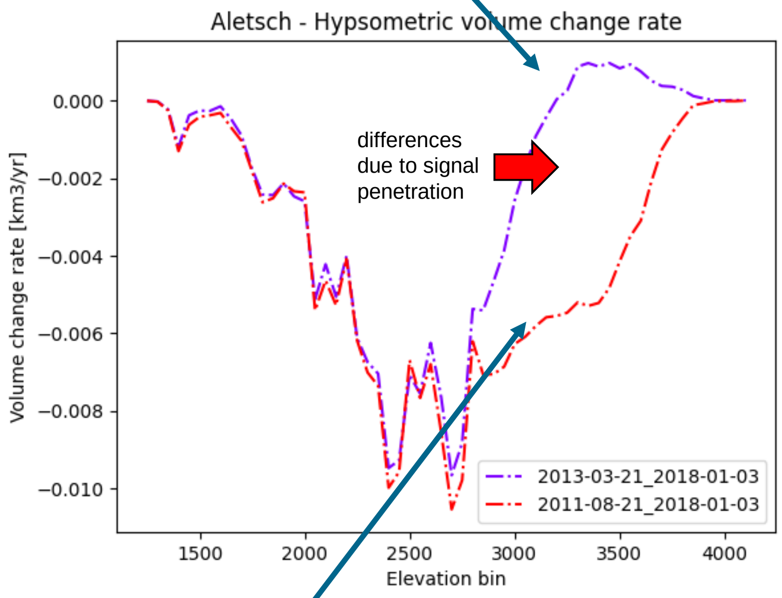
Glacier mass balance from DEM differencing



(Piermattei, 2024)

Unfavorable TanDEM-X scene combinations might cause a bias in volume change estimates

Mar. 2013 – Jan. 2018 (similar season – similar signal penetration)



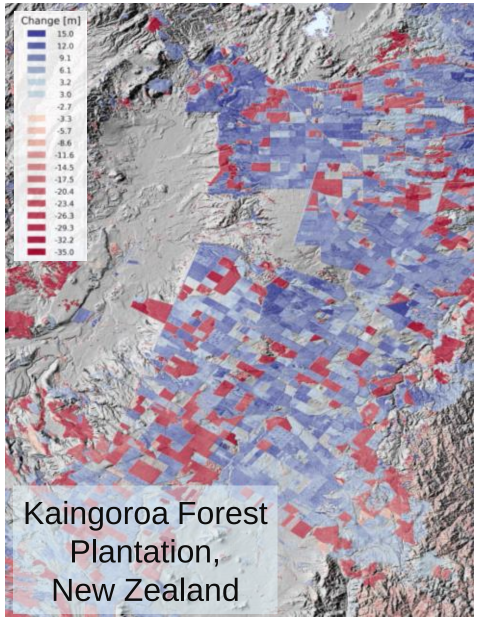
Aug. 2011 – Jan. 2018 (different season – different signal penetration)

A penetration bias correction increases the potential for TanDEM-X scene combinations and leads to increased temporal and spatial coverage of the world's glaciers

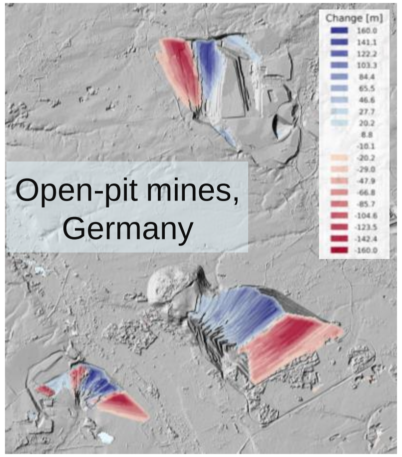
TanDEM-X DEM Change Maps (30m)

- TanDEM-X Mission (bistatic mission started in 2010):
  - Global DEMs of unprecedented accuracy and quality
  - Copernicus DEM derived from TanDEM-X Global DEM

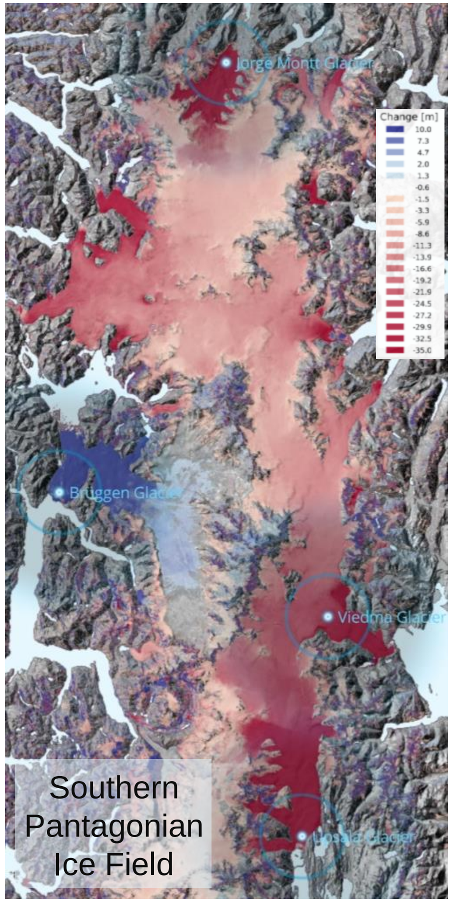
- TanDEM-X DEM Change Maps (Lachaise, 2023):
  - Global DEM differences between:
    - global TanDEM-X DEM (average of DEMs from 2010-2014)
    - time-tagged DEMs from 2016-2022
  - Enable global monitoring of height changes over forest, glacier melting, etc.
  - Freely available for scientific and non-commercial usage



Kaingoroa Forest Plantation, New Zealand



Open-pit mines, Germany

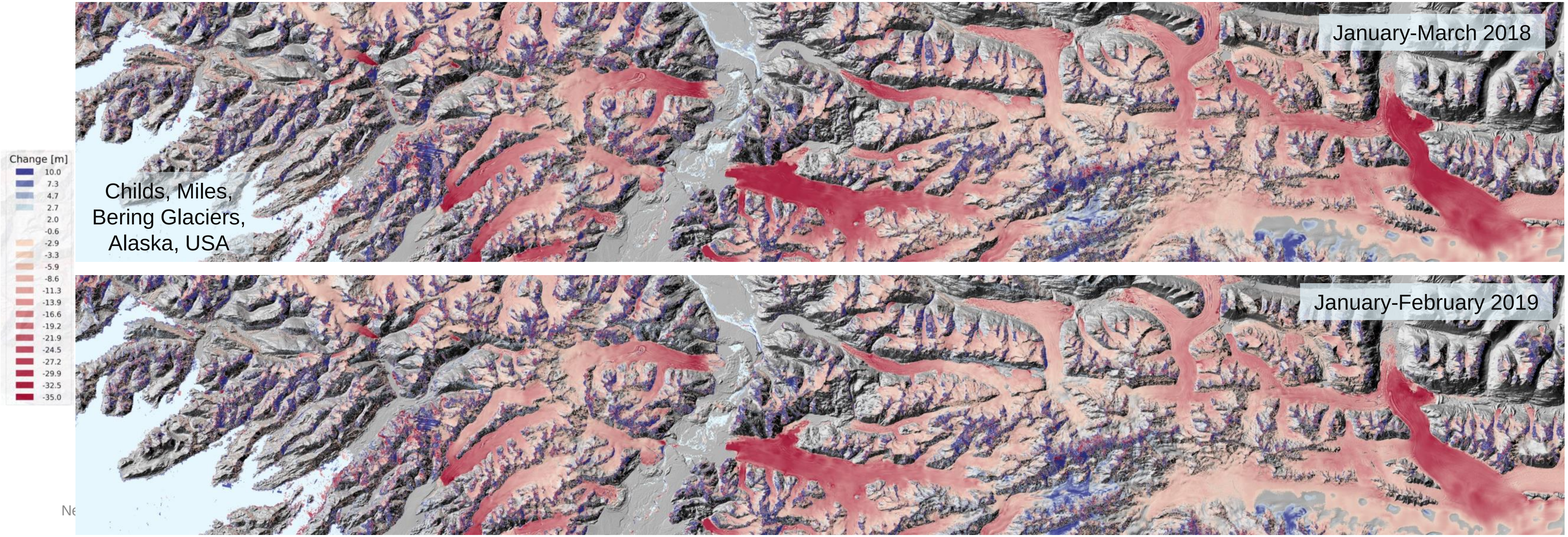


Southern Pantagonian Ice Field

TanDEM-X DEM Change Maps
Time Series (current developments)

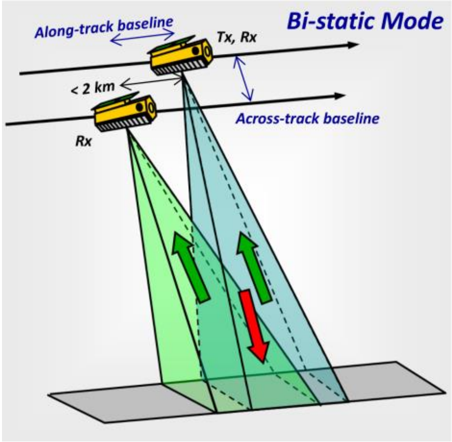
- Shall allow to quantify changes and their volume over time worldwide
- Improvements compared to the released DEM Change Maps
  - Comparison of time-tagged DEM mosaics ➔ precise time knowledge
  - X-band penetration corrections

(Schweisshelm, 2023)
(Lachaise, 2024)



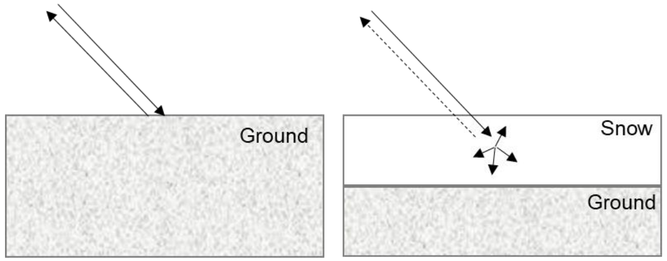
Methodology

TanDEM-X InSAR Measurement



Source: TanDEM-X Science DLR

Interferometric Coherence



High Coherence Lower Coherence

Volume Decorrelation

In **bistatic radar** systems like TanDEM-X, volume decorrelation can be derived from the interferometric total coherence by considering various decorrelation sources affecting the overall coherence.

$$\gamma_{vol} = \frac{\gamma_{Tot}}{\gamma_{SNR}\,\gamma_{Quant}\,\gamma_{Amb}\,\gamma_{Rg}\,\gamma_{Az}\,\gamma_{Temp}} \qquad \text{(Rizzoli, 2022)}$$

- temporal decorrelation $\gamma_{Temp} = 1.0$
- decorrelation factors of SAR ambiguities γ_{Amb}, and of range and azimuth effects $\gamma_{Rg}\ \gamma_{Az}$ are set to 0.98
- decorrelation due to quantization effects γ_{Quant} is provided by a lookup table. (Rizzoli, 2022)
- 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. (Breit, 2010) (Airbus, 2014)

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

Signal Penetration Correction

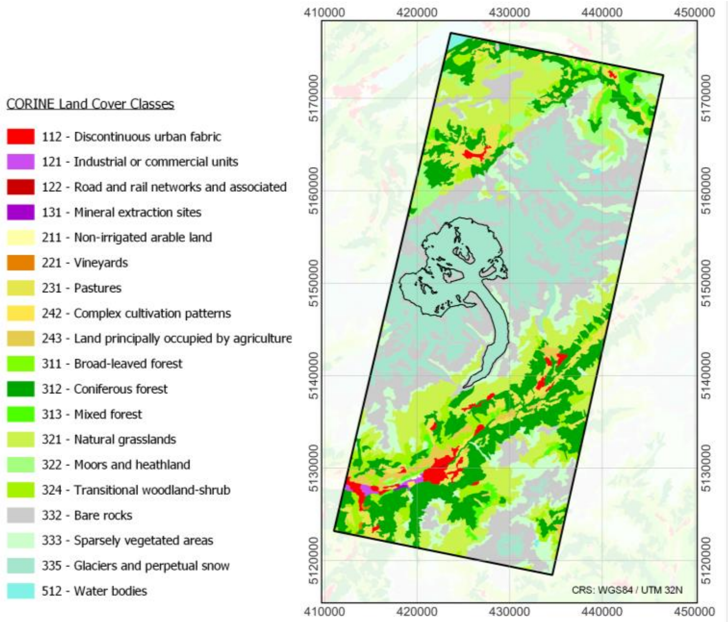
Used method to correct for SAR signal penetration bias: estimating volumetric coherence and inverting a simple physical model (Dall, 2007). This method allows estimating the penetration bias directly from the measured InSAR coherence, by assuming a uniform lossy scattering volume. The height of ambiguity is denoted as h_a.

$$\Delta_h = -\frac{|h_a|}{2\pi}\arctan\left(\sqrt{|\gamma_{vol}|^{-2} - 1}\right) \qquad \text{(Dall, 2007)}$$

Aletsch Glacier Test Site

TanDEM-X Scene Information	
r_acquisition_start_time	2021-03-30T05:45:10.957079
r_acquisition_item_id	1772010
r_acquisition_swath	stripFar_007
r_interferometric_mode	Bistatic
r_itp_version	2.3.1
g_equator_crossing_direction	D
g_incidence_angle_center	31.730339050

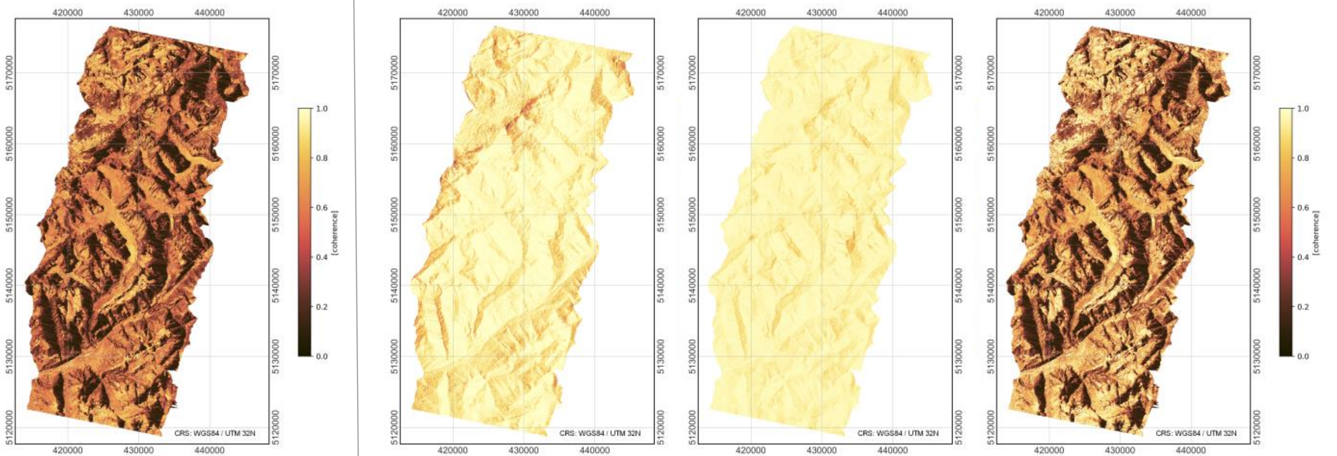
15 %
15 %
22 %
9 %
22 %



Volume Decorrelation Computation

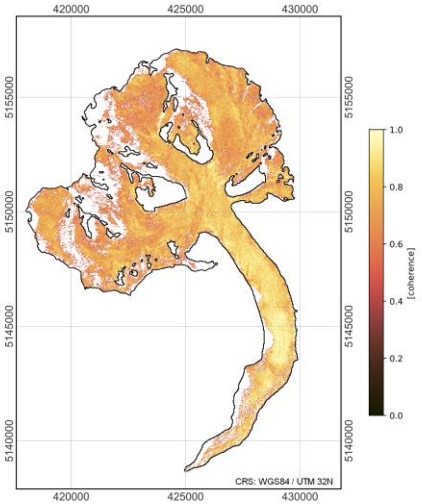
Measured from data

Interferometric Coherence | SNR Coherence | Quantization Coherence | Volumetric Coherence



Application: Signal Penetration Correction over a Glacier Area

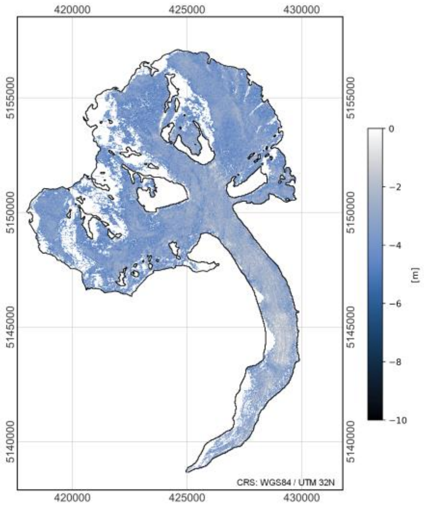
Volumetric Coherence



$$\Delta_h = -\frac{|h_a|}{2\pi}\arctan\left(\sqrt{|\gamma_{vol}|^{-2} - 1}\right)$$

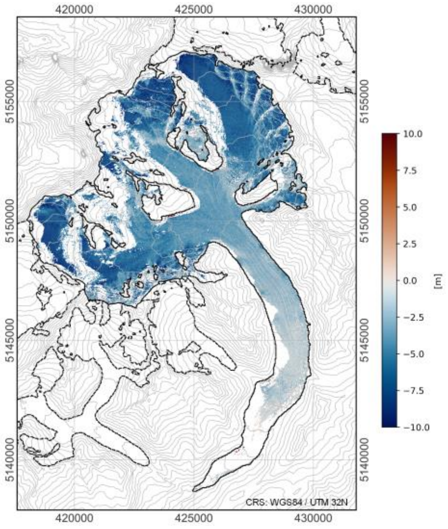
(Dall, 2007)

Signal Penetration

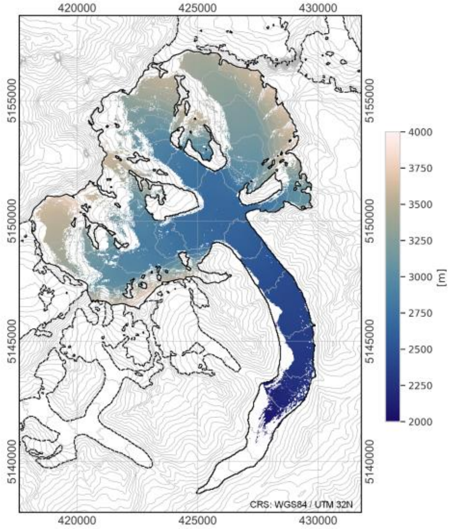


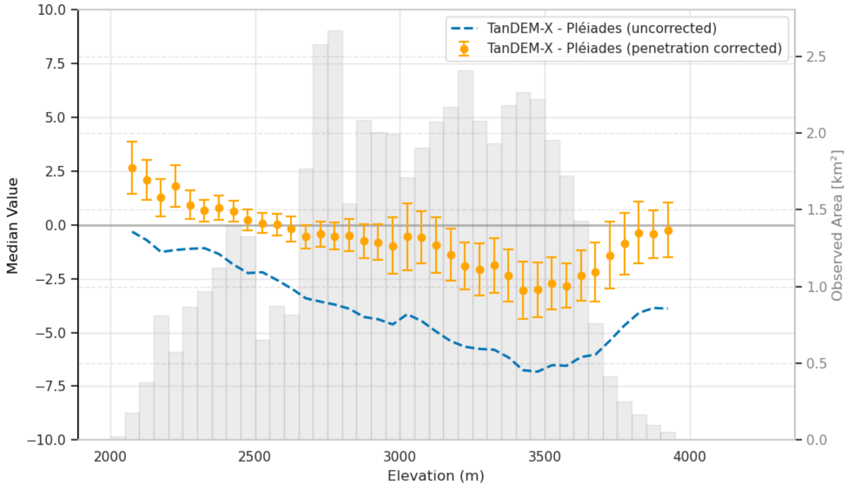
Verification – TanDEM-X vs Pléiades DEMs

dDEM: TanDEM-X – Pléiades (Bannwart, 2024)

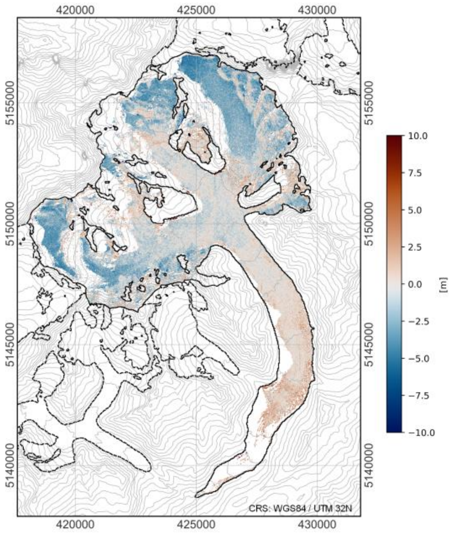


Elevation

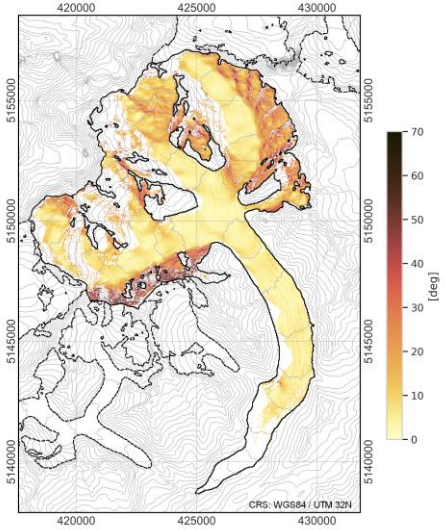


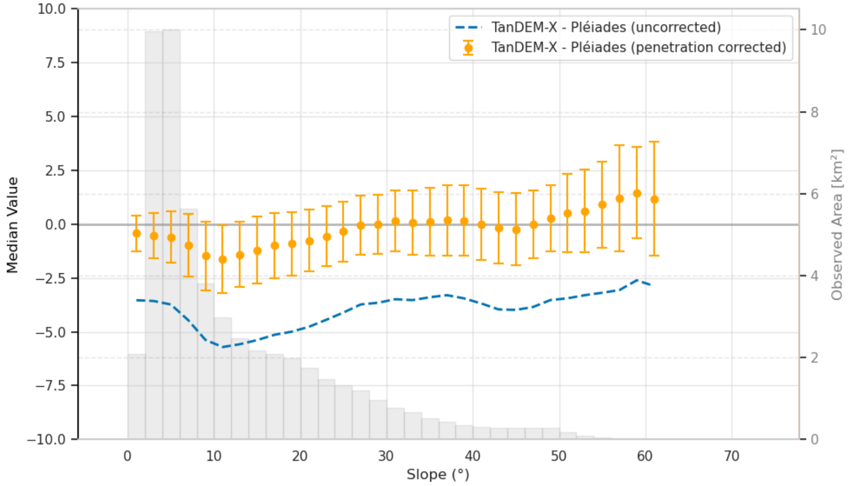


dDEM: TanDEM-X – Pléiades (signal penetration corrected)



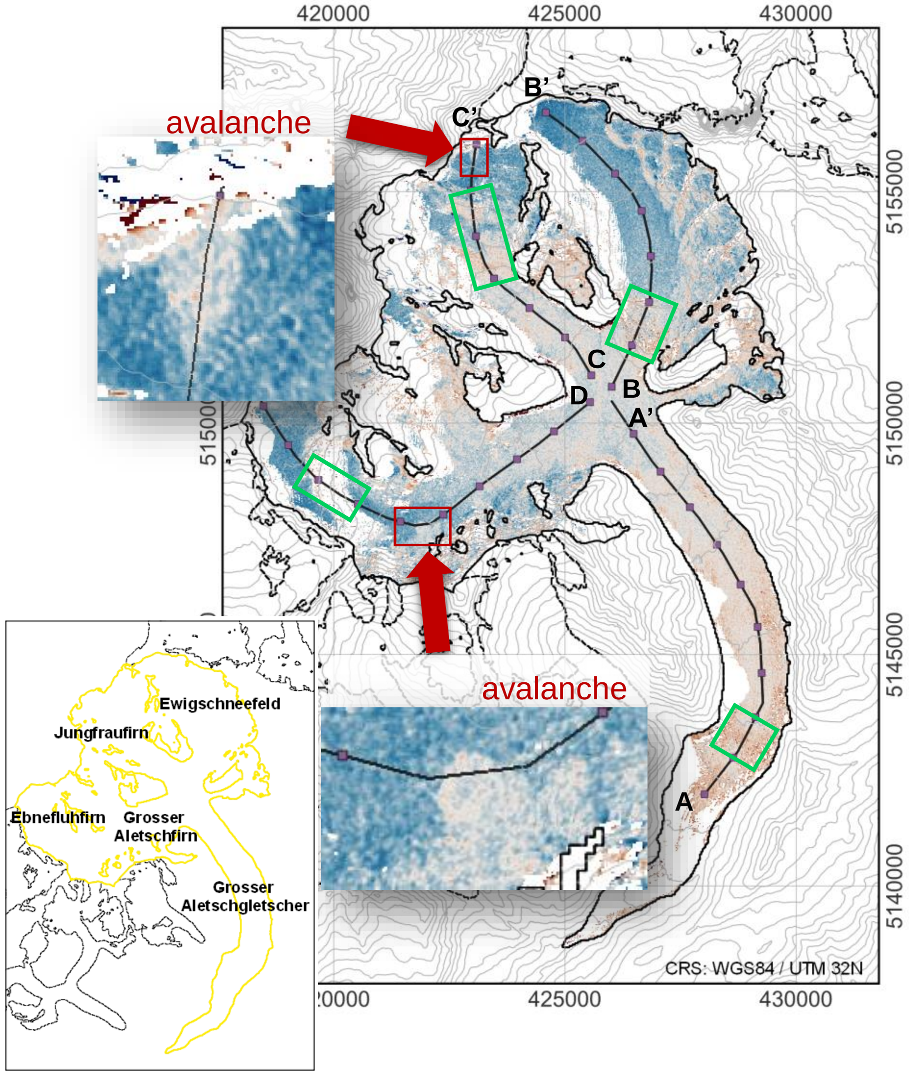
Slope

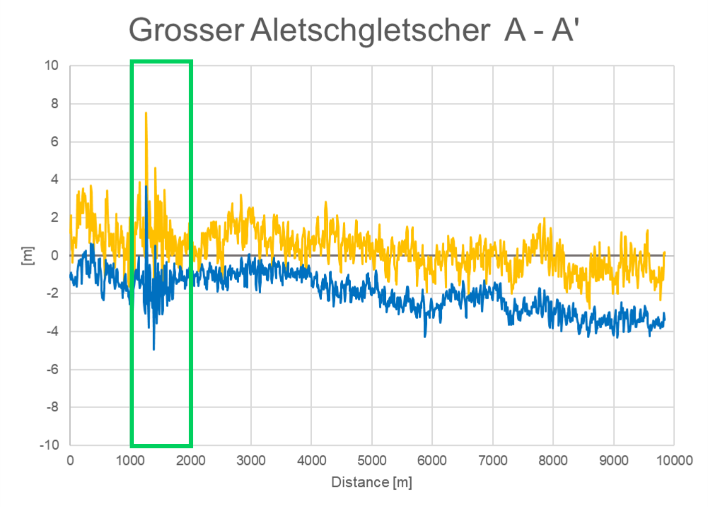


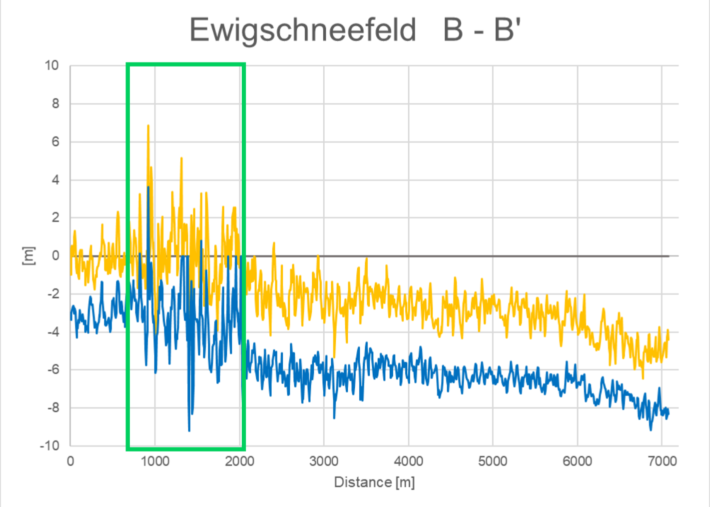


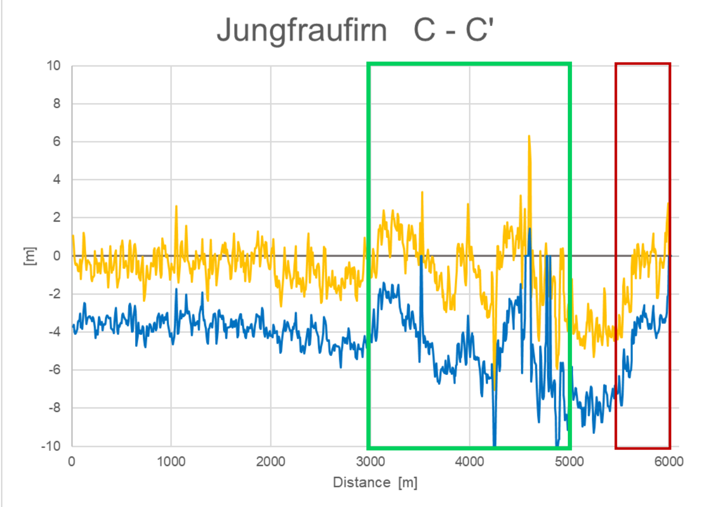
Verification – TanDEM-X vs Pléiades DEMs

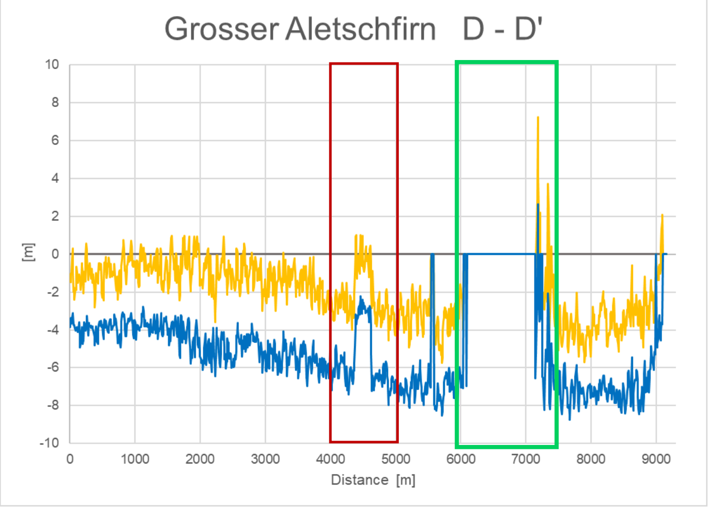
dDEM — dDEM + correction









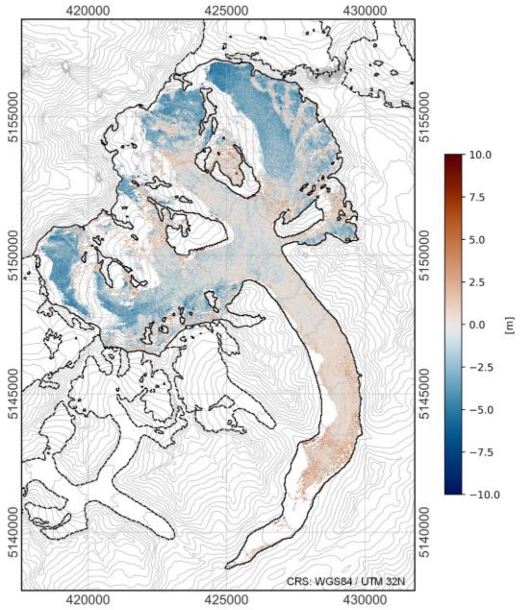


Conclusions and Next Steps

Conclusion

- A workflow to compute volume decorrelation layer has been implemented → DEM Change Maps Processing chain
- Aletsch glacier test site
  - Overall, the application of the signal penetration correction reduces the difference between TanDEM-X and Pléiades DEMs
  - Performance varies with elevation and terrain characteristics:
    - in the lower glacier regions below 2300 m, the correction tends to overestimate the elevation bias, leading to overcorrection.
    - 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.
    - areas with steep slopes yield unrealistic penetration correction values, likely due to geometric distortions or decorrelation effects.

dDEM: TanDEM-X – Pléiades
(signal penetration corrected)



Next Steps

- Verification of results in other sites – use of Pléiades Glacier Observatory (Berthier, 2024) and TanDEM-X Science Archive databases
- Application of signal penetration correction to DEM pairs → does it improve results when computing the difference?
- TanDEM-X DEM Change Map Products - Include a volume decorrelation layer → Useful to different applications

References

- Piermattei, L., Zemp, M., Sommer, C., Brun, F., Braun, M.H., Andreassen, L.M., Belart, J.M.C., Berthier, E., Bhattacharya, A., Boehm Vock, L., Bolch, T., Dehecq, A., Dussaillant, I., Falaschi, D., Florentine, C., Floricioiu, D., Ginzler, C., Guillet, G., Hugonnet, R., Huss, M., Kääb, A., King, O., Klug, C., Knuth, F., Krieger, L., La Frenierre, J., McNabb, R., McNeil, C., Prinz, R., Sass, L., Seehaus, T., Shean, D., Treichler, D., Wendt, A., Yang, R., (2024). Observing glacier elevation changes from spaceborne optical and radar sensors – an inter-comparison experiment using ASTER and TanDEM-X data. The Cryosphere 18, 3195–3230. https://doi.org/10.5194/tc-18-3195-2024

- Lachaise, M., Schweißhelm, B., (2023). TD-GS-PS-0216 TanDEM-X 30m DEM Change Maps Product Description, Version 1. Available online: https://geoservice.dlr.de/web/dataguide/tdm30/ (accessed on 17 June 2025)

- Lachaise, M., Schweisshelm, B., (2024). The TanDEM-X 30m DEM Change Maps: applications and further developments. EUSAR 2024; 15th European Conference on Synthetic Aperture Radar, Munich, Germany, 2024, pp. 901-906. https://elib.dlr.de/202478/1/TDM30m_DCM_applications_further_dev_EUSAR2024_Lachaise.pdf

- Schweisshelm, B., Lachaise, M. (2023). Tandem-X Dem Change Maps Stacks: Towards Tandem-X 4D. IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium, Pasadena, CA, USA, 2023, pp. 1329-1332, doi: https://doi.org/10.1109/IGARSS52108.2023.10282397

- 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

- Breit, H., Fritz, T., Balss, U., Lachaise, M., Niedermeier, A., Vonavka, M., (2010). TerraSAR-X SAR Processing and Products. IEEE Transactions on Geoscience and Remote Sensing 48, 727–740. https://doi.org/10.1109/TGRS.2009.2035497

- Airbus Defence & Space (2014). Radiometric calibration of TerraSAR-X Data. Beta Naught and Sigma Naught coefficient calculation. Airbus Defence & Space. SXX-ITD-TN-0049-radiometric_calculations_I3.00.doc. Available online: https://dep1doc.gfz-potsdam.de/attachments/download/365/r465_9_tsx-x-itd-tn-0049-radiometric_calculations_i3.00.pdf (accessed on 17 June 2025)

- Dall, J., (2007). InSAR Elevation Bias Caused by Penetration Into Uniform Volumes. IEEE Transactions on Geoscience and Remote Sensing 45, 2319–2324. https://doi.org/10.1109/TGRS.2007.896613

- Krieger, L., Ibarrola Subiza, N., Floricioiu, D., Fischer, G., Abdullahi, S., (2025). Assessing the TanDEM-X elevation bias due to SAR signal penetration for glacier mass balance measurements, Poster. Presented at the EGU General Assembly 2025. https://doi.org/10.5194/egusphere-egu25-16658

- Bannwart, J., Piermattei, L., Dussaillant, I., Krieger, L., Floricioiu, D., Berthier, E., Roeoesli, C., Machguth, H., Zemp, M., (2024). Elevation bias due to penetration of spaceborne radar signal on Grosser Aletschgletscher, Switzerland. *Journal of Glaciology,* 1–15. https://doi.org/10.1017/jog.2024.37

- Berthier, E., Lebreton, J., Fontannaz, D., Hosford, S., Belart, J.M.-C., Brun, F., Andreassen, L.M., Menounos, B., Blondel, C., (2024). The Pléiades Glacier Observatory: high-resolution digital elevation models and ortho-imagery to monitor glacier change. The Cryosphere 18, 5551–5571. https://doi.org/10.5194/tc-18-5551-2024

THANK YOU!

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