

Impact of the 25th Solar Cycle Ionospheric Activity on Sentinel-1 SAR Data – A Status Report by SAR-MPC

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Ionospheric Delay & Sentinel-1

Driven by the approximately 11-years solar cycle, the **impact of ionosphere dynamics** on Copernicus **Sentinel-1** satellites spans from **minor degradation of precise orbit solutions** to **meter-level path delays** in the **C-band SAR** (5.4 Ghz) image data.

SAR Mission Performance Cluster (SAR-MPC) routinely **monitors S-1 product quality**. During past years, we noticed **ionosphere-related limitations** with the S-1 **ETAD product** that aims to provide accurate layers for geometric SAR data correction [1].

A major **source of uncertainty** in the ETAD ionospheric correction layer stems from the **reduction of vertical total electron content (vTEC)** provided by GNSS for the **part below S-1 orbit height**, which is modelled via a **scaling factor**, see Fig. 1.

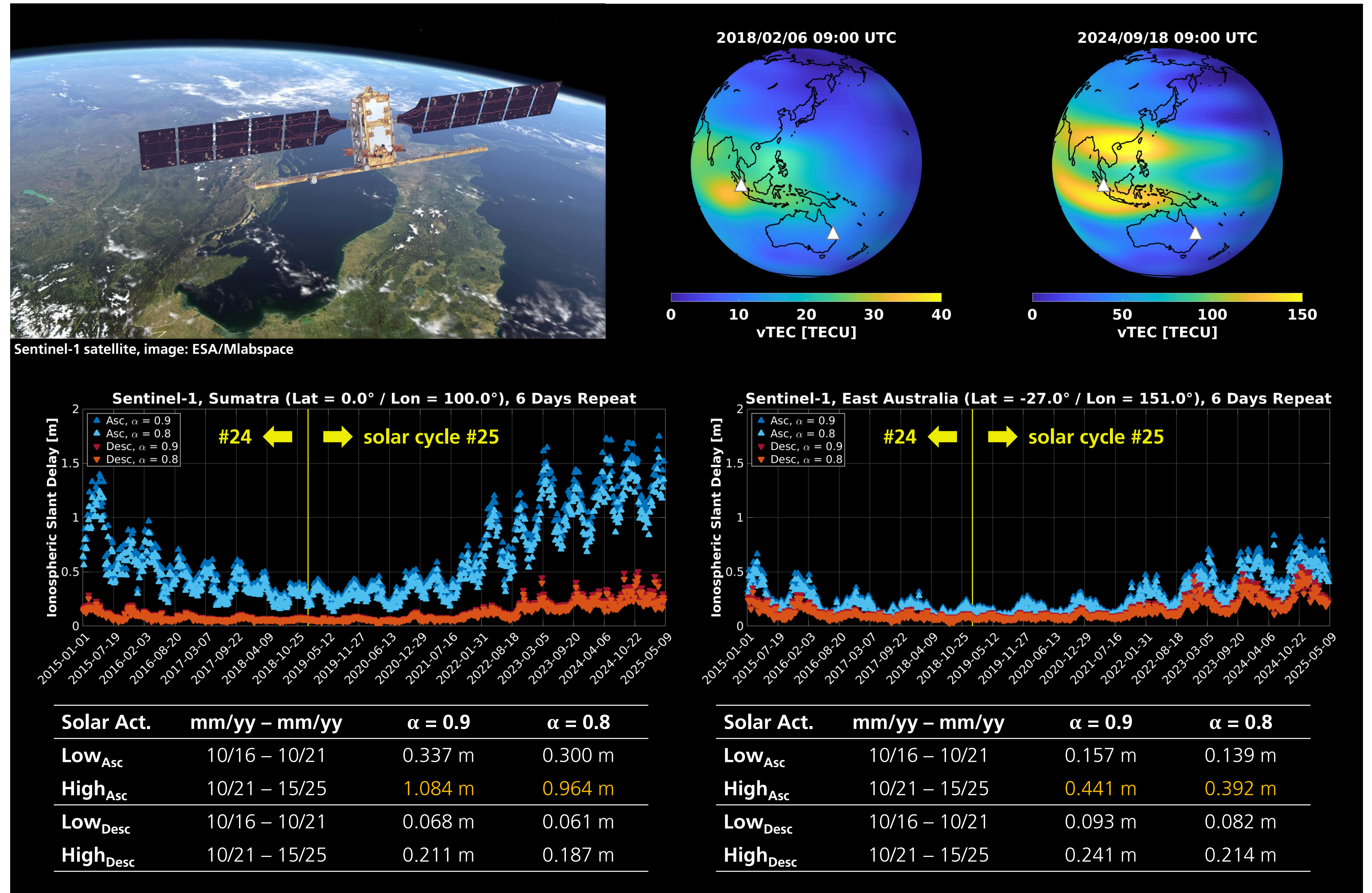


Fig. 1 Impact of TEC scaling factor on ionospheric path delay corrections for Sentinel-1. ETAD-type corrections based on CODE TEC maps computed for Sentinel-1 ascending and descending stacks located at Sumatra and Australia, assuming 6 day repeat acquisitions. Differences of up to 10 cm are found in ascending data during high solar activity.

Investigation of vTEC Scaling Factor and Empirical Adjustment

The MPC findings led to a **re-evaluation of the scaling factor**. Our analysis with the **3-D ionosphere model NEDM2020** [2] shows that **seasonal effects dominate** for Sentinel-1 **sun-synchronous orbits** (6h and 18h local passing time, see Fig. 2), whereas solar activity (F10.7 flux above 80) has marginal impact on the TEC ratio.

Contrarily, the **long-term residuals of S-1 IW geolocation analysis** of reference targets **indicate that ranging errors are dominated by solar activity**, see Fig 3.

From **S-1A/B/C IW data of reference targets**, we performed a **joint LSQ estimate of the scaling factor and SAR sensor timing offsets** which provided stable results:

Least-squares results of TEC factor and instrument timing calibration (ITC) from 8.5 years of Sentinel-1 data over 6 globally distributed calibration sites with stable corner reflectors. See [3] for details on our methods.

Sensor	TEC scaling α	Range ITC	Azimuth ITC
Sentinel-1A	0.78 ± 0.004	0.1061 ± 0.0012 m	0.0430 ± 0.0034 m
Sentinel-1B		-0.0183 ± 0.0010 m	-0.2175 ± 0.0046 m
Sentinel-1C		0.3435 ± 0.0042 m	-0.1339 ± 0.0220 m

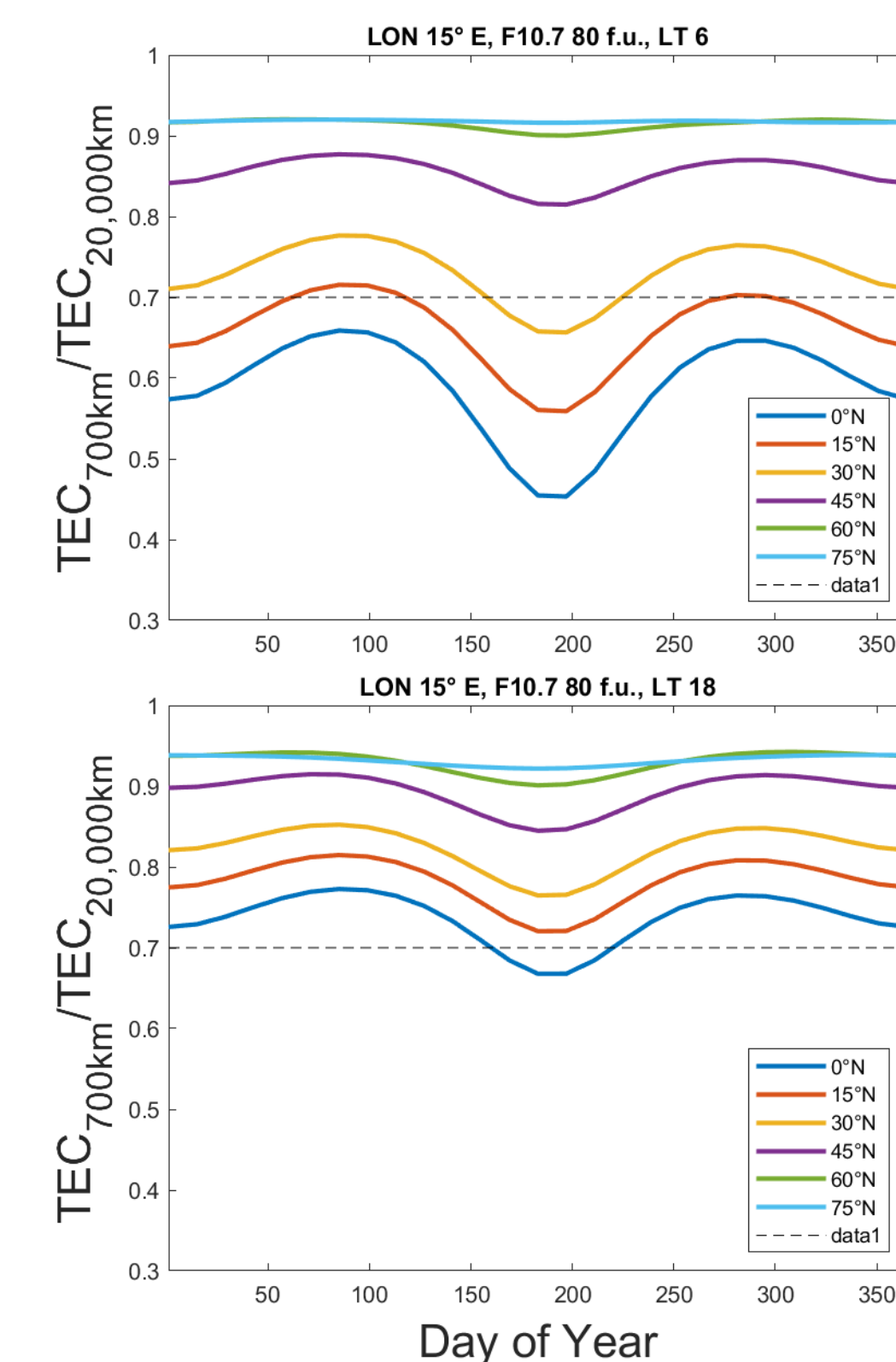


Fig. 2 Seasonal TEC ratio derived from NEDM2020 for descending (top) and ascending (bottom) Sentinel-1 pass configuration.

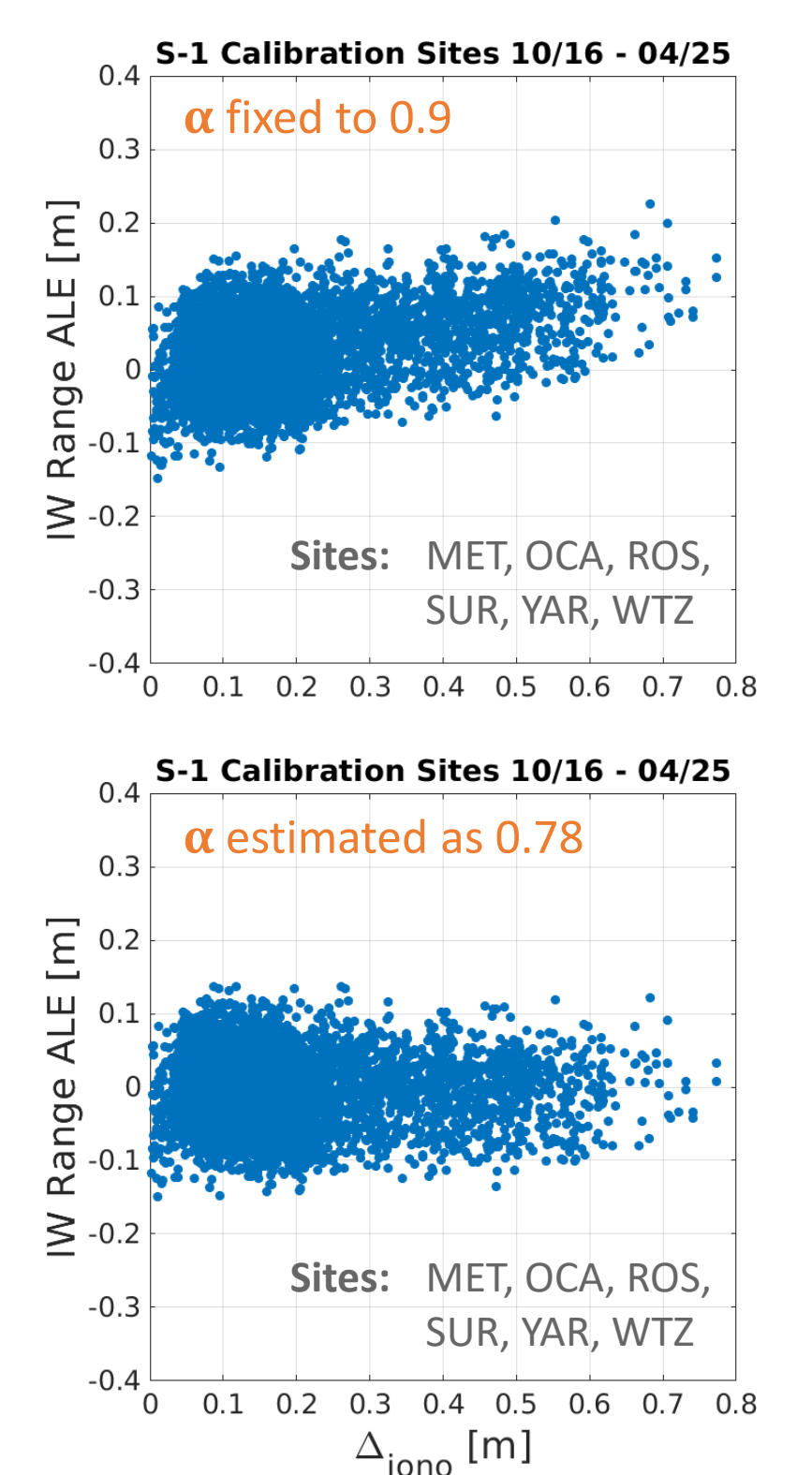


Fig. 3 Range localization error of CR targets versus ionospheric correction for different scaling factors.

Validation Results and Conclusions

Our **comparison of TEC scaling factors** derived from spatio-temporal modelling of NEDM2020 and from SAR data adjustment shows an **advantage for the data driven approach**, see Fig 4.

In conclusion, the TEC scaling factor **configuration for ETAD product generation** will be updated from **0.9 to 0.78** with the **new processor version 3.0** to be introduced in **June 2025**.

References

- [1] Hajduch et al., S-1 Annual Performance Report for 2024, Chapter 5.2 Geometric Validation, SAR-MPC-0715, issue 2.1, 02/04/2025
- [2] Hoque et al., A new climatological electron density model for supporting space weather services, J. Space Weather Space Clim., vol. 12, iss. 1, 2022
- [3] Gisinger et al., Update of S-1 Instrument Timing Calibration for ETAD, SAR-MPC-0622, issue 1.2, 27/10/2023

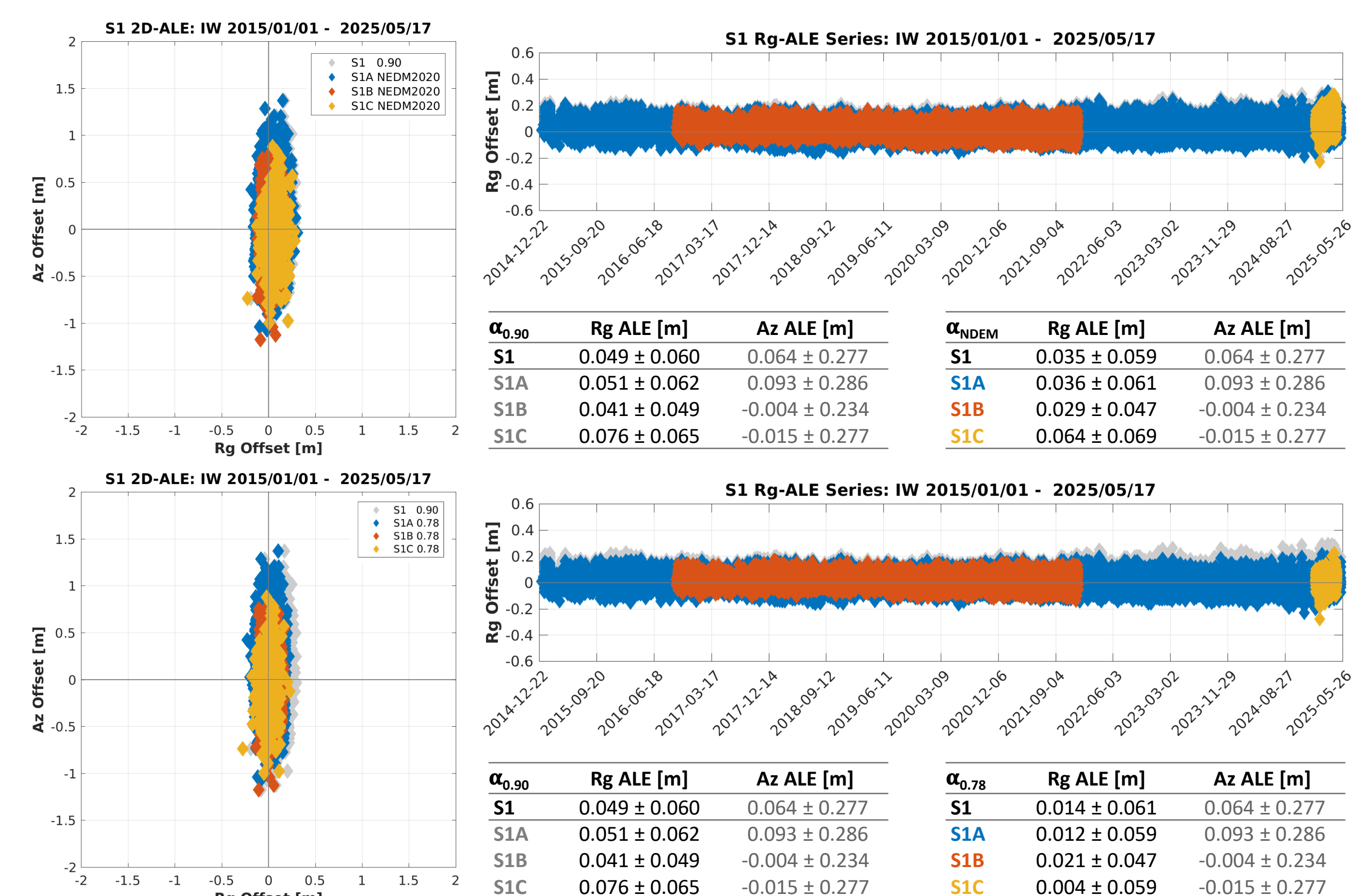


Fig. 4 Validation of TEC scaling factor methods over 8 test sites in Europe, Australia and North America, hosting a total of 84 CRs. Sentinel-1 A/B/C IW data covering 2015 to 2025. Geolocation results of nominal $\alpha=0.9$ configuration (background) versus dynamic α of NEDM2020 (top) and data driven $\alpha=0.78$ (bottom).