IGS 2026 WORKSHOP
SANTIAGO DE CHILE
33°26' S 70°39' O

1-5 June 2026

ETH zürich

TomoNet - deep learning–based GNSS tomography algorithm for tropospheric monitoring

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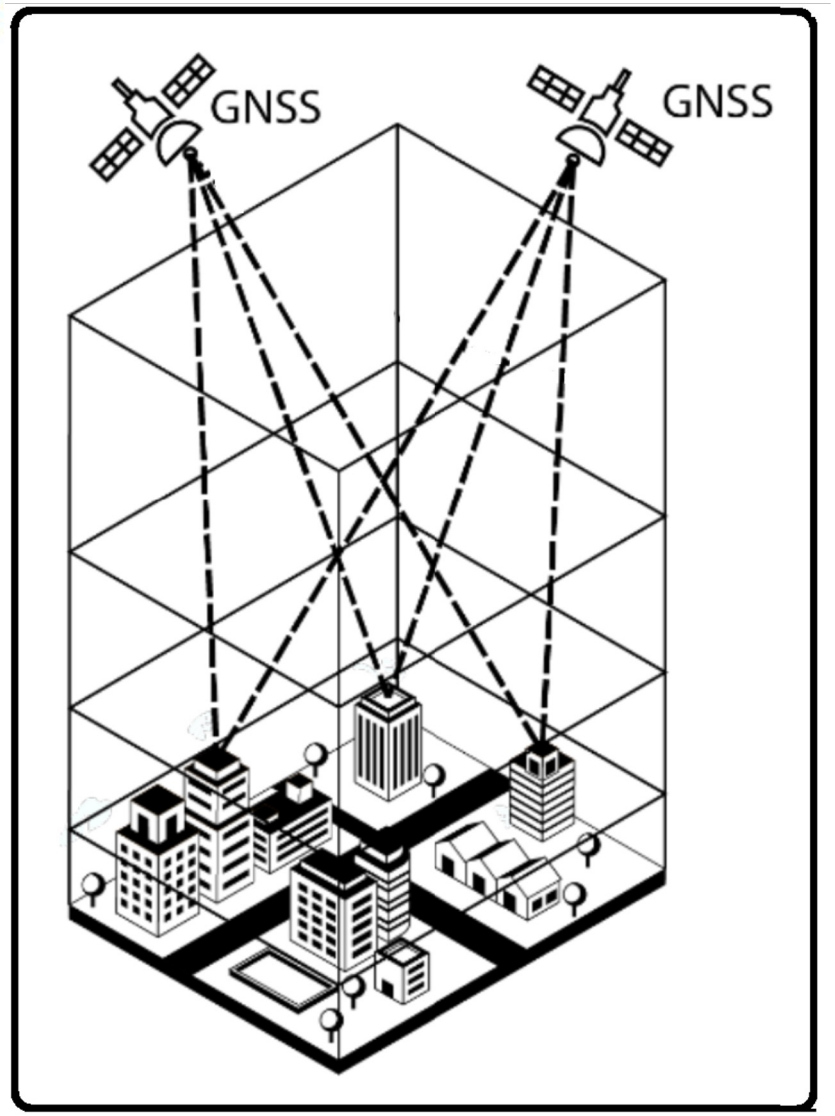
GNSS tomography

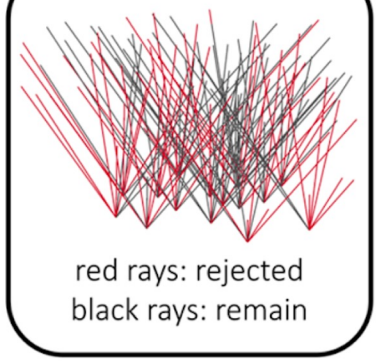


- low computational efficiency
- need for a priori field to stabilize the results
- need for proper parameterization and geometry
- numerical stability of inversion methods

$$\overline{SWD} = A \cdot \overline{N_w}, \qquad A = \begin{pmatrix} \alpha & \alpha & 0 & \cdots & 0 \\ 0 & \alpha & \alpha & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \alpha & 0 & \alpha & \alpha \\ 0 & 0 & 0 & 0 & \alpha \end{pmatrix}$$

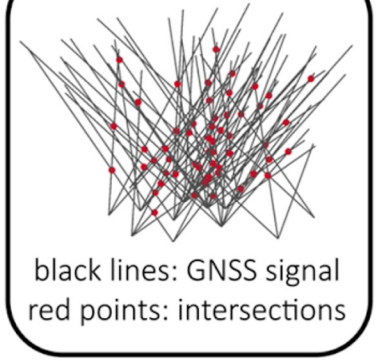
GNSS tomography

Dynamic nodes parameterization



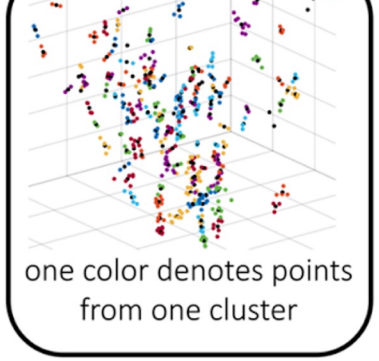
red rays: rejected
black rays: remain

the most valuable observations



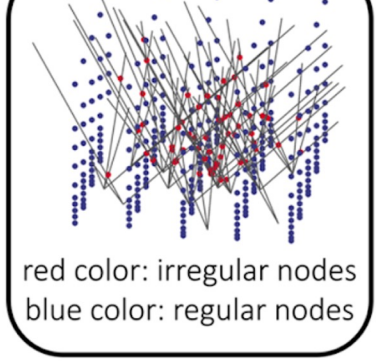
black lines: GNSS signal
red points: intersections

spots with the most GNSS information



one color denotes points from one cluster

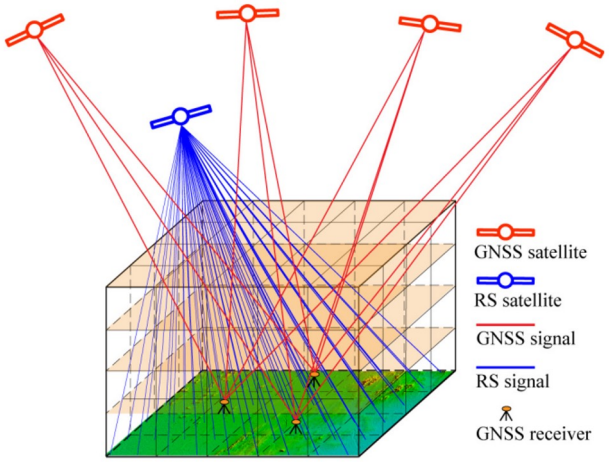
to avoid small inter-distances between nodes



red color: irregular nodes
blue color: regular nodes

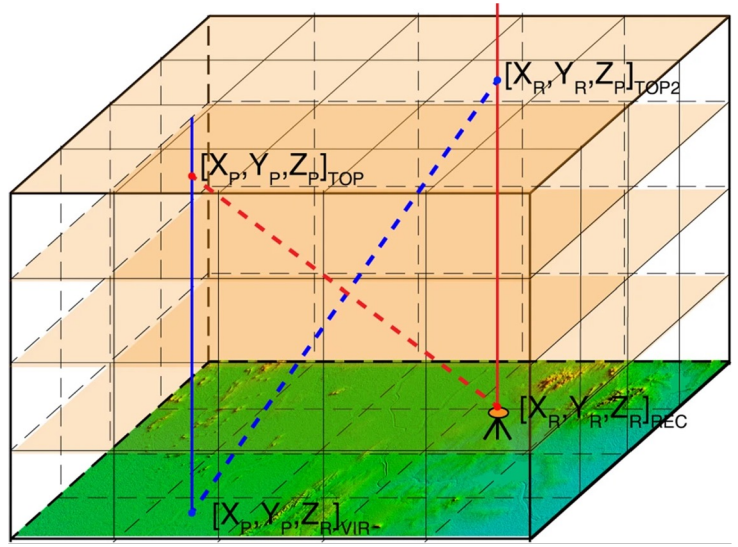
for proper modelling of the SWD

Trzcina, E., Rohm, W., & Smolak, K. (2023). Parameterisation of the GNSS troposphere tomography domain with optimisation of the nodes' distribution. *Journal of Geodesy*, *97*(1), 2.



Adding meteorological observations

Zhang, W., Zhang, S., Ding, N., Holden, L., Wang, X., & Zheng, N. (2021). GNSS-RS tomography: Retrieval of tropospheric water vapor fields using GNSS and RS observations. IEEE Transactions on Geoscience and Remote Sensing, 60, 1-13.



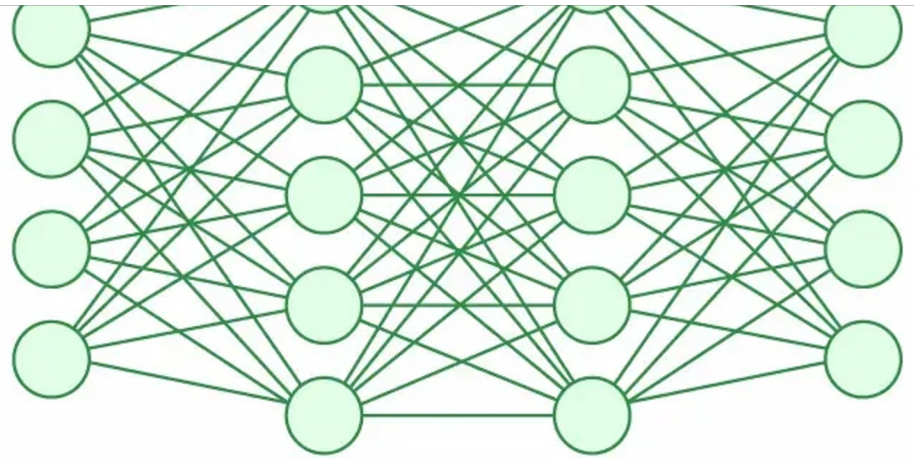
Adding virtual observations

Zhang, W., Zhang, S., Chang, G., Ding, N., & Wang, X. (2021). A new hybrid observation GNSS tomography method combining the real and virtual inverted signals. *Journal of Geodesy*, *95*, 1-18.

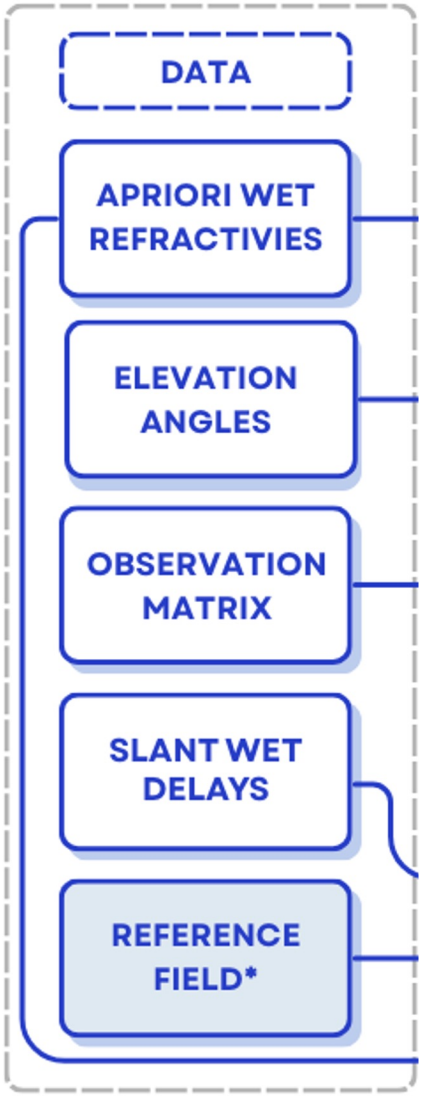
GNSS tomography → Tomography - based NN

$$\overline{SWD} = A \cdot \overline{N_w},$$

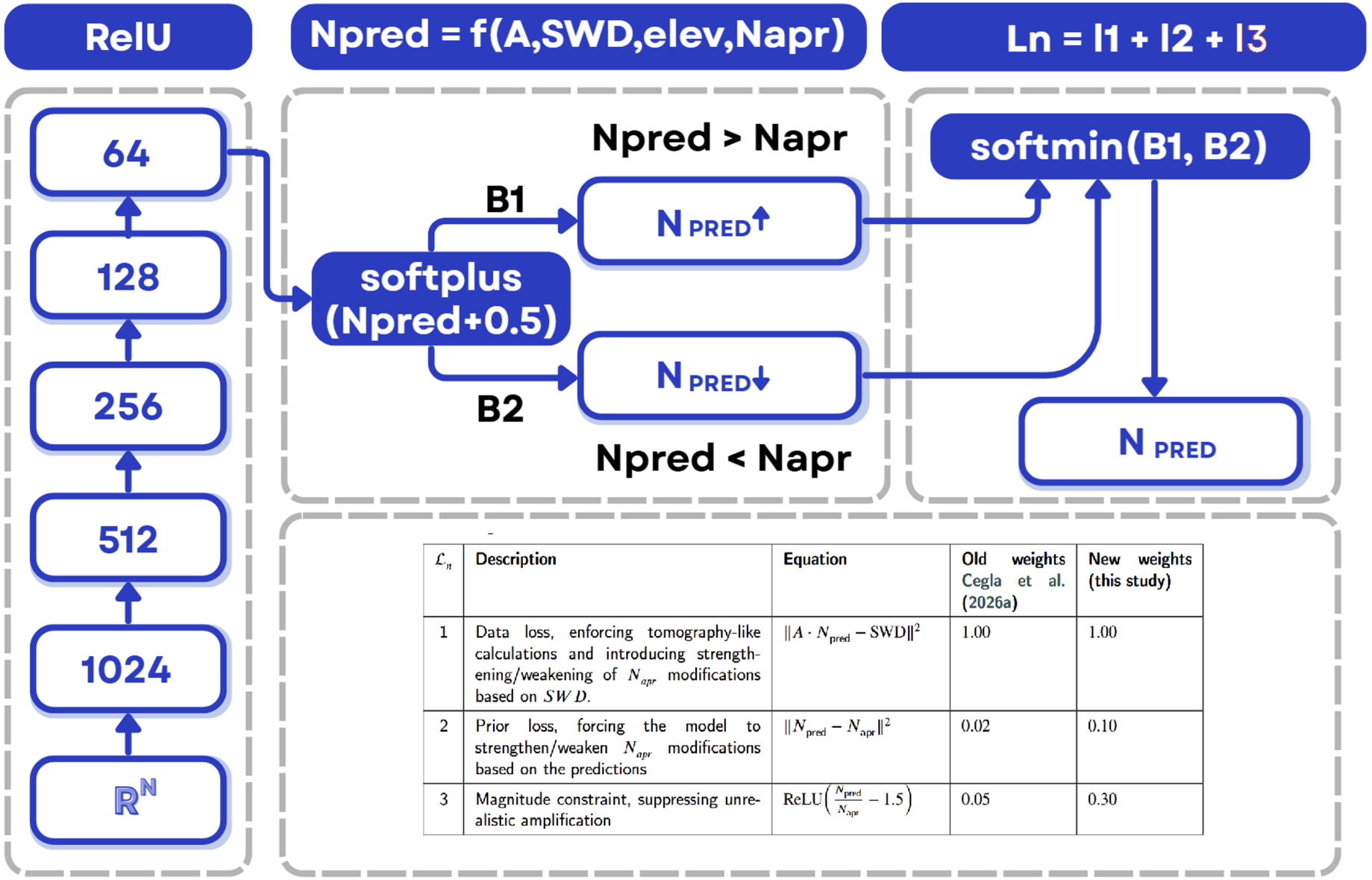
$$\overline{N_w} = (A^T \cdot P \cdot A)^{-1} A^T \cdot P \cdot \overline{SWD},$$



TomoNet - first NN-based tomography algorithm

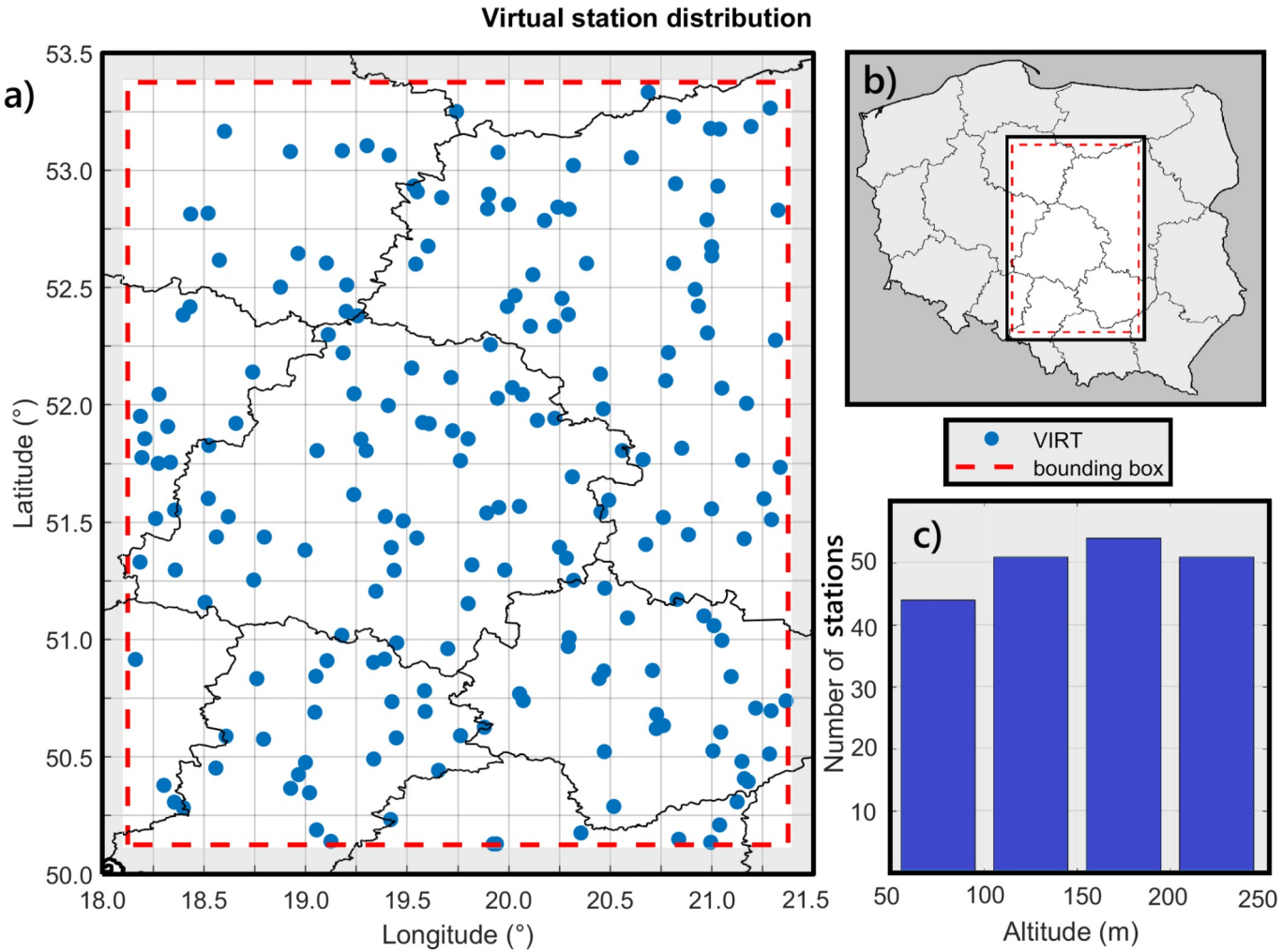


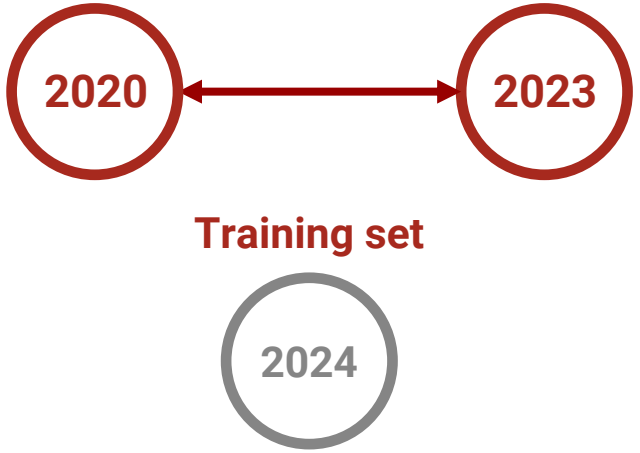
Tomography MLP



$\mathcal{L}_n$	Description	Equation	Old weights Cegla et al. (2026a)	New weights (this study)
1	Data loss, enforcing tomography-like calculations and introducing strengthening/weakening of N_{apr} modifications based on SWD.	$\|A \cdot N_{\text{pred}} - \text{SWD}\|^2$	1.00	1.00
2	Prior loss, forcing the model to strengthen/weaken N_{apr} modifications based on the predictions	$\|N_{\text{pred}} - N_{\text{apr}}\|^2$	0.02	0.10
3	Magnitude constraint, suppressing unrealistic amplification	$\text{ReLU}\left(\frac{N_{\text{pred}}}{N_{\text{apr}}} - 1.5\right)$	0.05	0.30

Methodology - simulated data

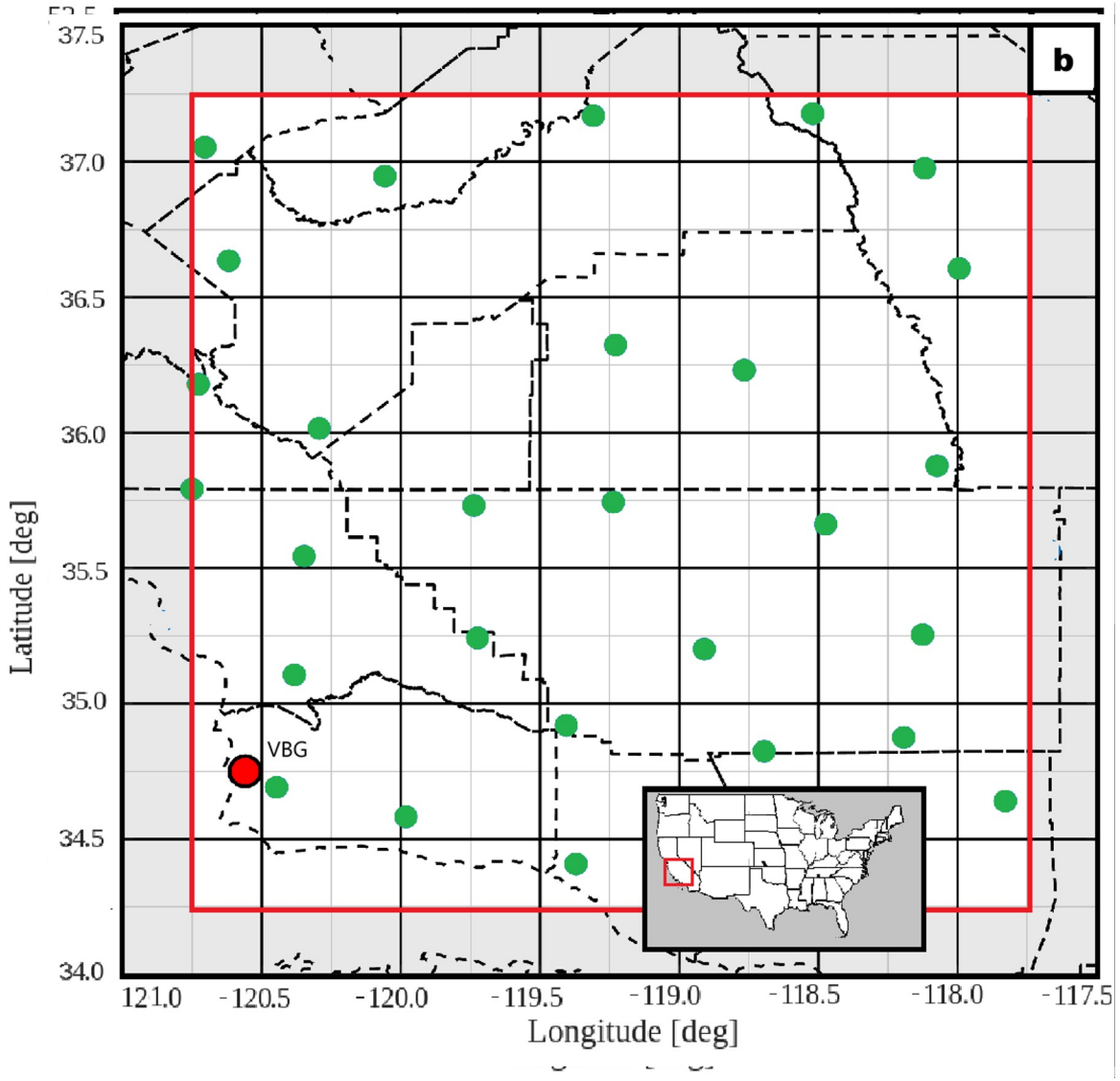


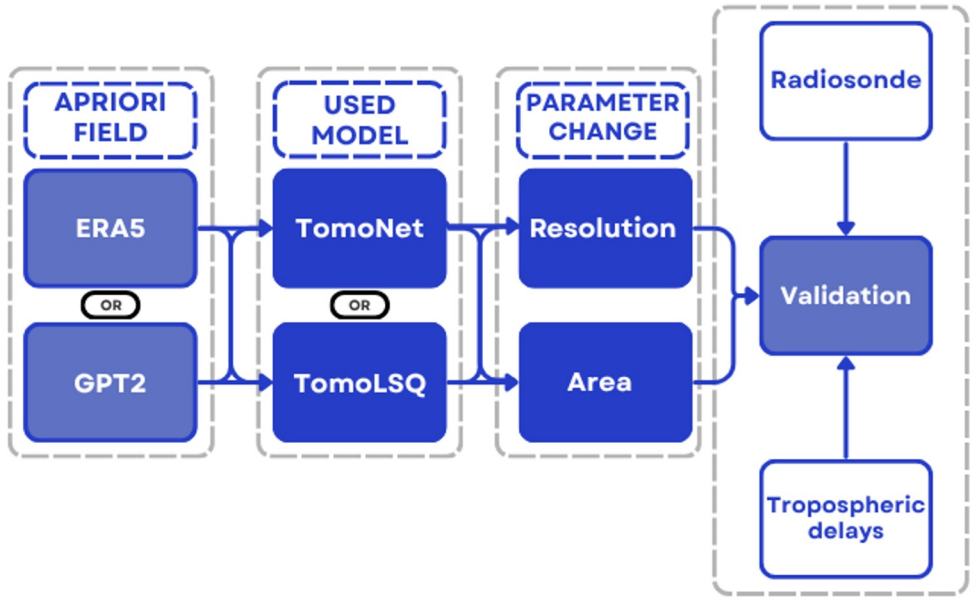


ATom GNSS
Release 1.0

Möller, G. (2017). *Reconstruction of 3D wet refractivity fields in the lower atmosphere along bended GNSS signal paths: Vol. Heft Nr. 101,2017*. TU Wien. https://resolver.obvsg.at/urn:nbn:at:at-ubtuw:3-3303

Methodology - real data





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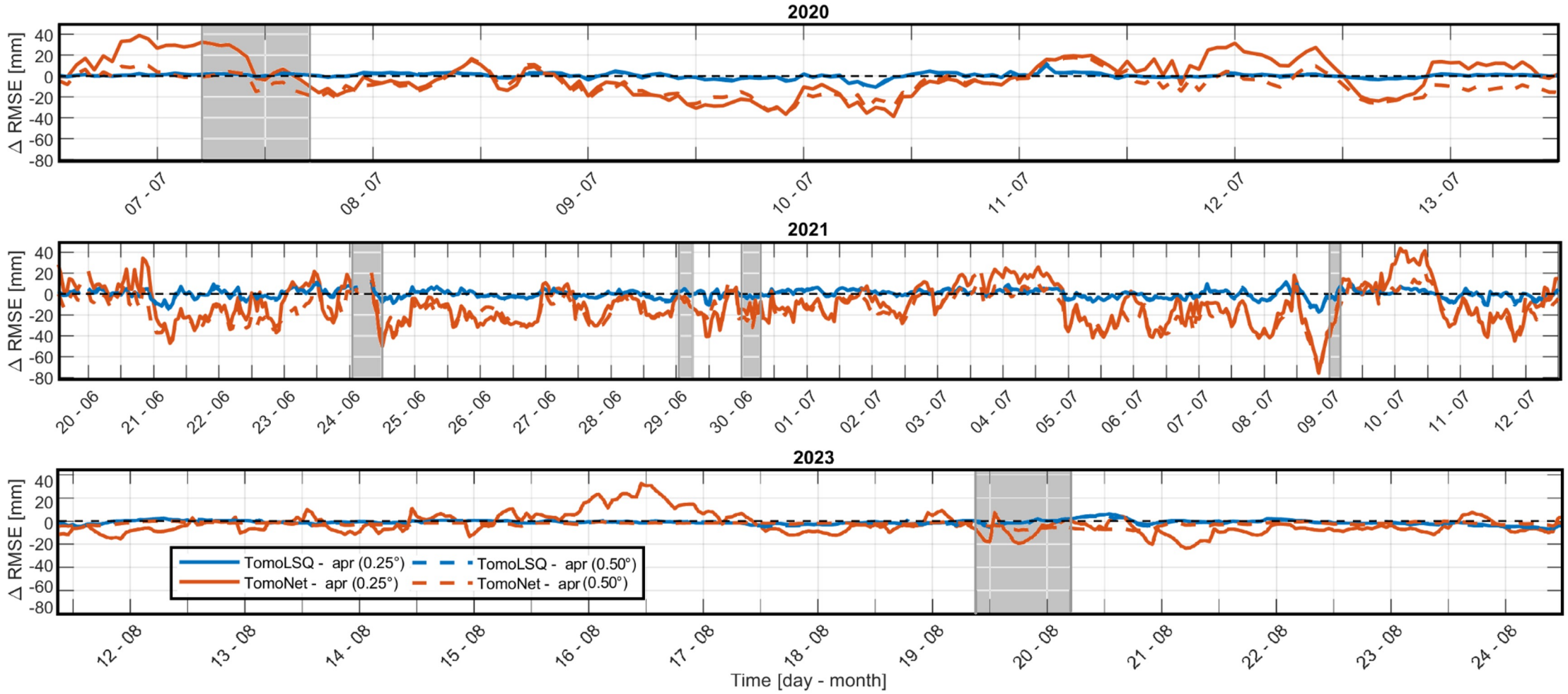
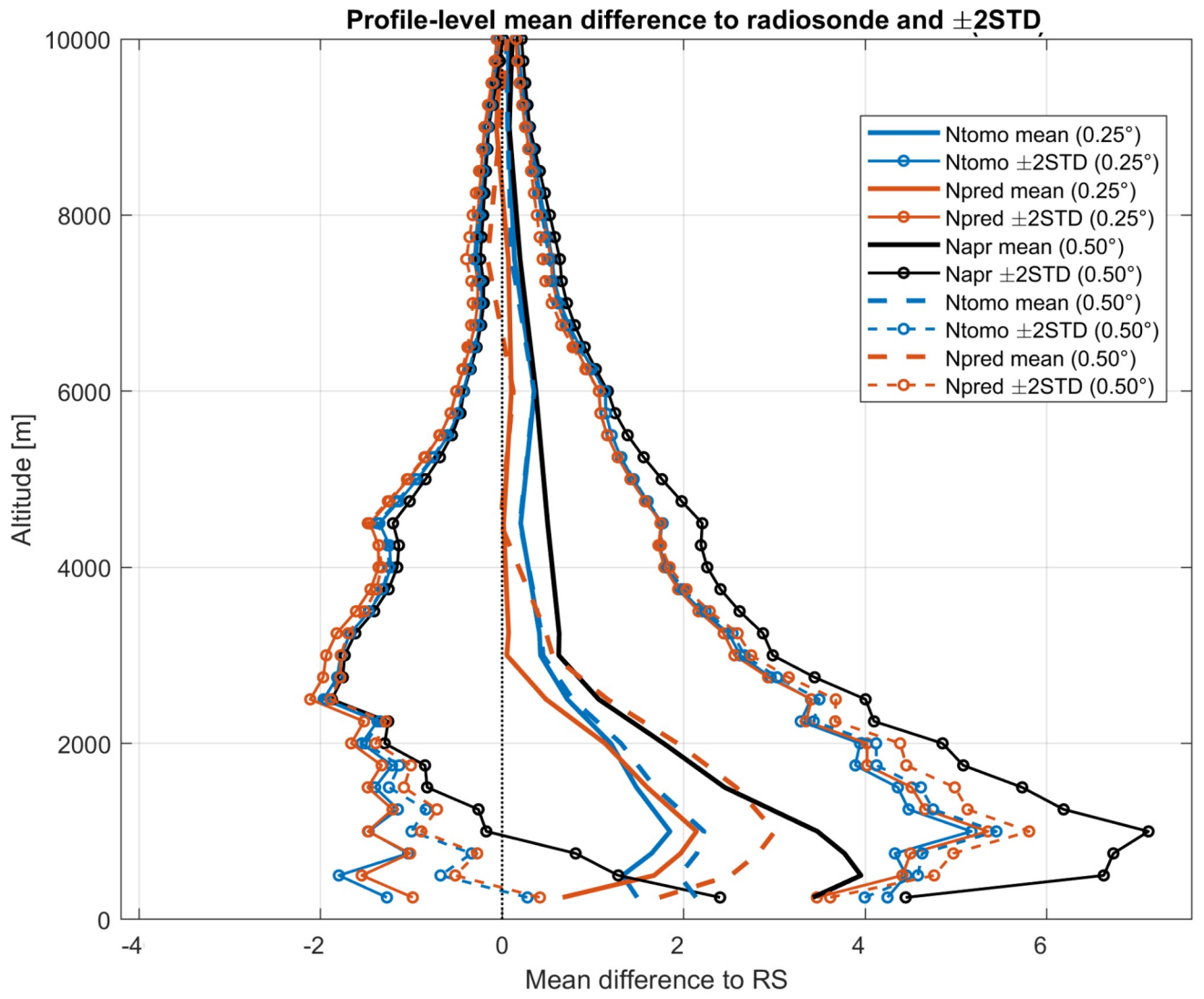
Processing quality

RMSE reduced up to 40% with average value of 20% better than LSQ-based approach

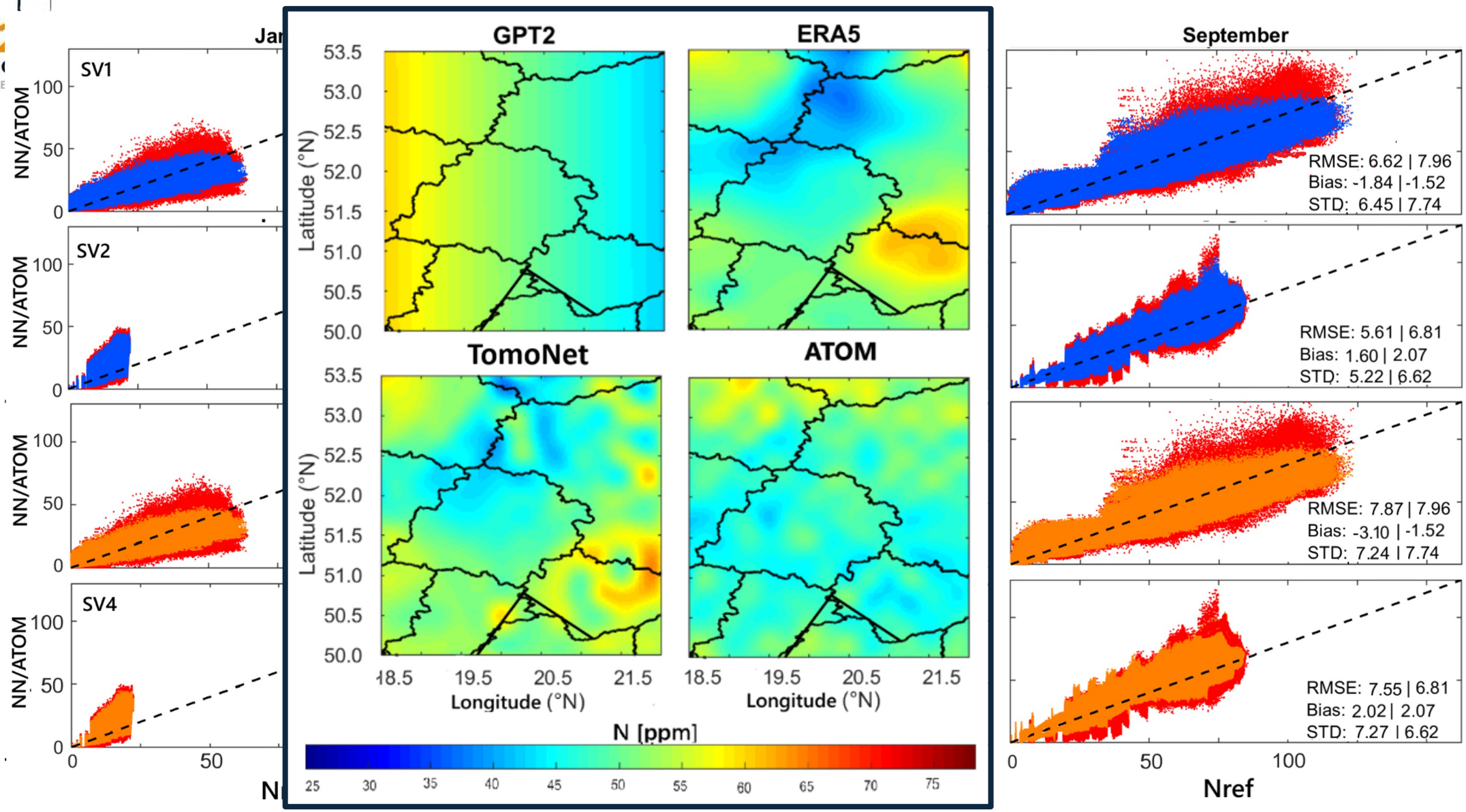


Processing quality

RMSE reduced up to 25% with average value of 14% better than LSQ-based approach



Processing quality



Conclusions

TomoNet model successfully outperforms classical tomography approach in all configurations.

- Increases stability,
- Reduces RMSE by up to 40% compared to LSQ-based method,
- The processing time was reduces from hours to seconds.

Several issues are to be solved:

- The best performance is achieved when the model topography of the model is similar to the one over area of Poland
- Neural networks tends to overestimate the true values of refractivity, and to choose ‘best average’ values rather than spatial variability with insufficient number of observations

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