

IMPACT OF GNSS ZENITH TOTAL DELAY ASSIMILATION FROM NORTHERN GERMANY ON NUMERICAL WEATHER PREDICTION OVER THE METCOOP DOMAIN



Mehdi Eshagh, Martin Ridal and Magnus Lindskog
Division of Meteorology-Forecast and Observations, Department of Research and Development

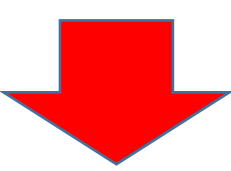
Summary

- **GNSS ZTD** provides key humidity information for NWP
- The **southern MetCoOp domain** remains sparsely observed but along the southwesterly moisture-transport pathway into Fennoscandia.
- Additional ZTDs from **GFZ stations in northern Germany** offer upstream constraints on humidity and temperature advection, particularly relevant during summer.
- Two HARMONIE–AROME/SURFEX experiments (Jun–Aug 2025) were run: baseline vs. assimilation of GFZ ZTDs.
- Assimilating GFZ data **sharpens mid-to-lower-tropospheric moisture structure** (500–925 hPa), improves boundary-layer gradients, and enhances short-range humidity analyses.

Precise point positioning with ionospheric-free combination of carrier phases

$$\Phi_{IF} = \rho + c\Delta\delta + m(e) \Delta^{ZTD} + N_{IF}$$

$$\left(\begin{matrix} \Phi_{IF} \\ N_{IF} \end{matrix} \right) = \frac{f_1^2 \lambda_1}{f_1^2 - f_2^2} \left(\begin{matrix} \Phi_1 \\ N_1 \end{matrix} \right) - \frac{f_2^2 \lambda_2}{f_1^2 - f_2^2} \left(\begin{matrix} \Phi_2 \\ N_2 \end{matrix} \right)$$



- c the speed of light
- ρ distance between the satellite and receiver,
- $\Delta\delta$ clock error,
- N_{IF} ambiguity parameter for the ionospheric-free combination
- $(N_1, N_2), (\lambda_1, \lambda_2) (\Phi_1, \Phi_2)$ the ambiguity parameters, wavelengths and received phases of the first and second signals
- $m(e)$ is the mapping function with elevation angle e

Components of Zenith Total Delay

$$\Delta^{ZTD} = \Delta^{ZHD} + \Delta^{ZWD}$$

hydrostatic (dry) component

$$\Delta^{ZHD} = 2.2768 \times 10^{-5} [\text{m/Pa}] \frac{P_a}{1 - 2.66 \times 10^{-3} \cos(2\theta) - 2.8 \times 10^{-7} [\text{m}^{-1}] h_a}$$

wet component

$$\Delta^{ZWD} = \frac{R}{g(\theta)} \sum_{i=1}^M q_i \left(k' + \frac{k_3}{T_i} \right) (p_{i+1/2} - p_{i-1/2})$$

(Saastamoinen 1972)

(Vedel and Huang 2004)

3D-VAR data assimilation

$$\begin{pmatrix} \delta x^a \\ \delta \beta^a \end{pmatrix} = \begin{pmatrix} \delta x^b \\ \delta \beta^b \end{pmatrix} + \begin{pmatrix} \mathbf{B} \mathbf{H}_x^T \\ \mathbf{B}_\beta \mathbf{H}_\beta^T \end{pmatrix} \left(\mathbf{H}_x \mathbf{B} \mathbf{H}_x^T + \mathbf{H}_\beta \mathbf{B}_\beta \mathbf{H}_\beta^T + \mathbf{R} \right)^{-1} (y - \underline{h}(x, \beta) - \mathbf{H}_x \delta x - \mathbf{H}_\beta \delta \beta)$$



- p_a, θ and h_a pressure, latitude and height at the station
- M and R number of troposphere layers and the gas constant
- $g(\theta)$ gravity, $p_{i+1/2} - p_{i-1/2}$ the pressure difference
- $k' = 2.21 \times 10^{-7} [\text{K/Pa}]$ and $k_3 = 3.7 \times 10^{-3} [\text{K}^2/\text{Pa}]$ (Bevis et al. 1992)

- $\delta x = x - x_b$ and $\delta \beta = \beta - \beta_b$
- x is the control vector,
- β the vector of variational biases,
- x_b and β_b the background control and bias,
- $\mathbf{R}, \mathbf{B}$ and $\mathbf{B}_\beta$ variance-covariance matrices
- $\underline{h}(x, \beta) = h(x) + b(\beta, x)$
- $\mathbf{H}_x = \frac{\partial \underline{h}(x, \beta)}{\partial x}$ and $\mathbf{H}_\beta = \frac{\partial \underline{h}(x, \beta)}{\partial \beta}$

Average RMS of 2-m temperature and specific humidity, 10m wind components over the area

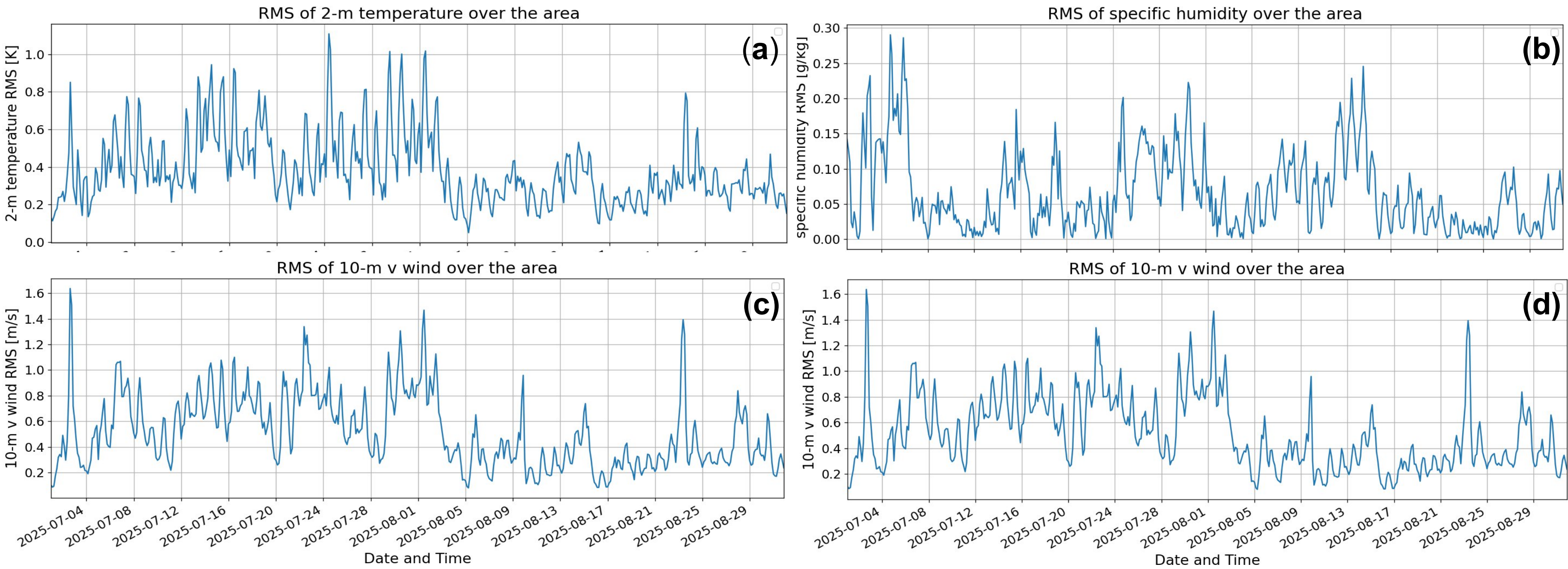


Figure 2. Time series of the root mean square error (RMS) of the differences between CTRL-exp and GFZ-exp for (a) 2-m temperature (K), (b) 2-m specific humidity (g kg^{-1}), (c) 10-m u-wind component (m s^{-1}), and (d) 10-m v-wind component (m s^{-1}). RMS values remain low throughout the period, indicating that assimilation of GFZ ZTDs introduces only minor changes to near-surface meteorological fields, with slightly reduced RMS during moist and windy episodes.

Average RMS vertical profile of Temperature, specific humidity and wind over the area

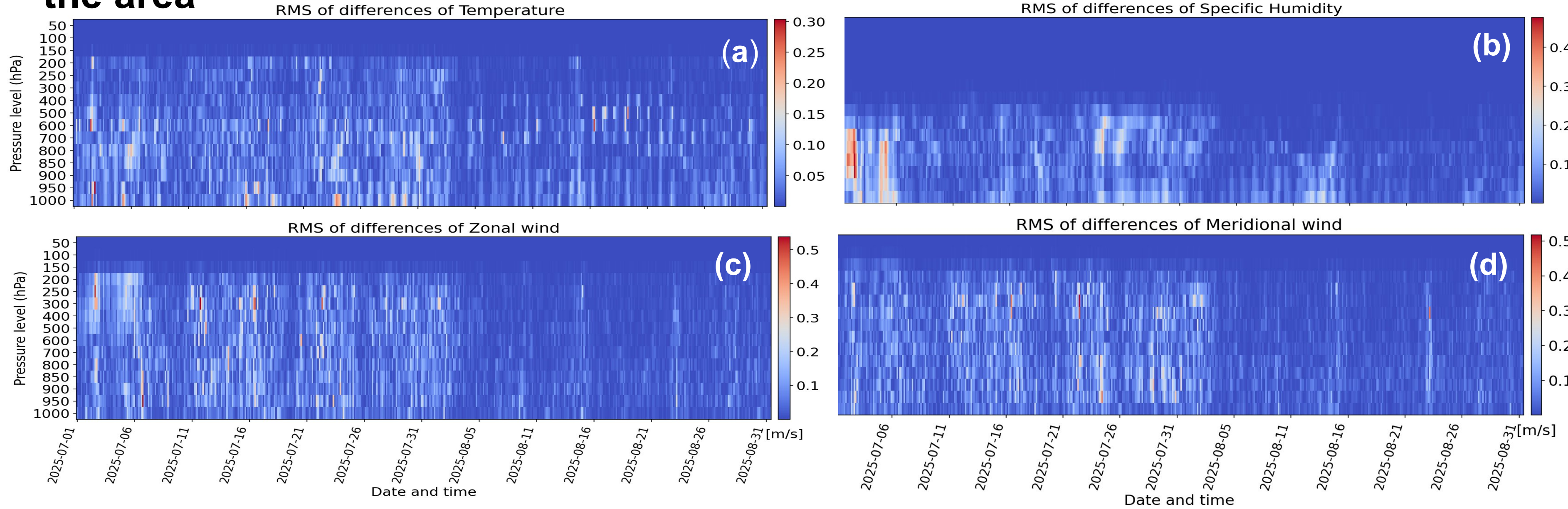


Figure 3. Plots of RMS of differences between (a) temperature, (b) specific humidity, (c) zonal wind (u-wind) and (d) meridional wind (v-wind) of CTRL-exp and GFZ-exp. Blue shading indicates small RMS differences, while warmer colours mark larger discrepancies. The results show that assimilation of GFZ ZTDs produces only minor changes, with slightly higher RMS values near the lower troposphere during moist or windy episodes.

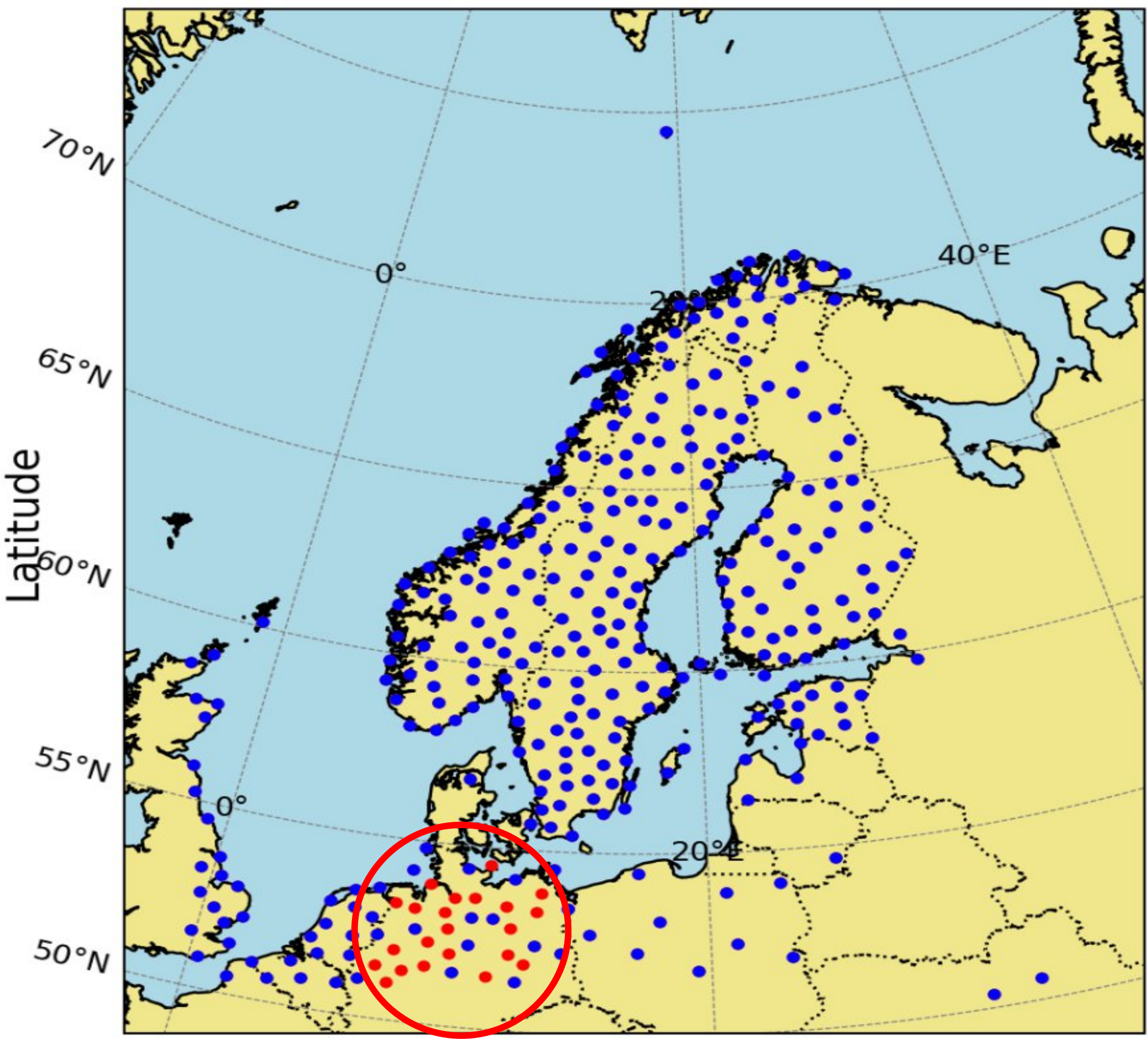


Figure 1. Allowlisted GNSS stations based on 50 km thinning distance for the MetCoOp domain, Red circles are locations of GFZ GNSS stations.

Comparison with Radiosondes profiles

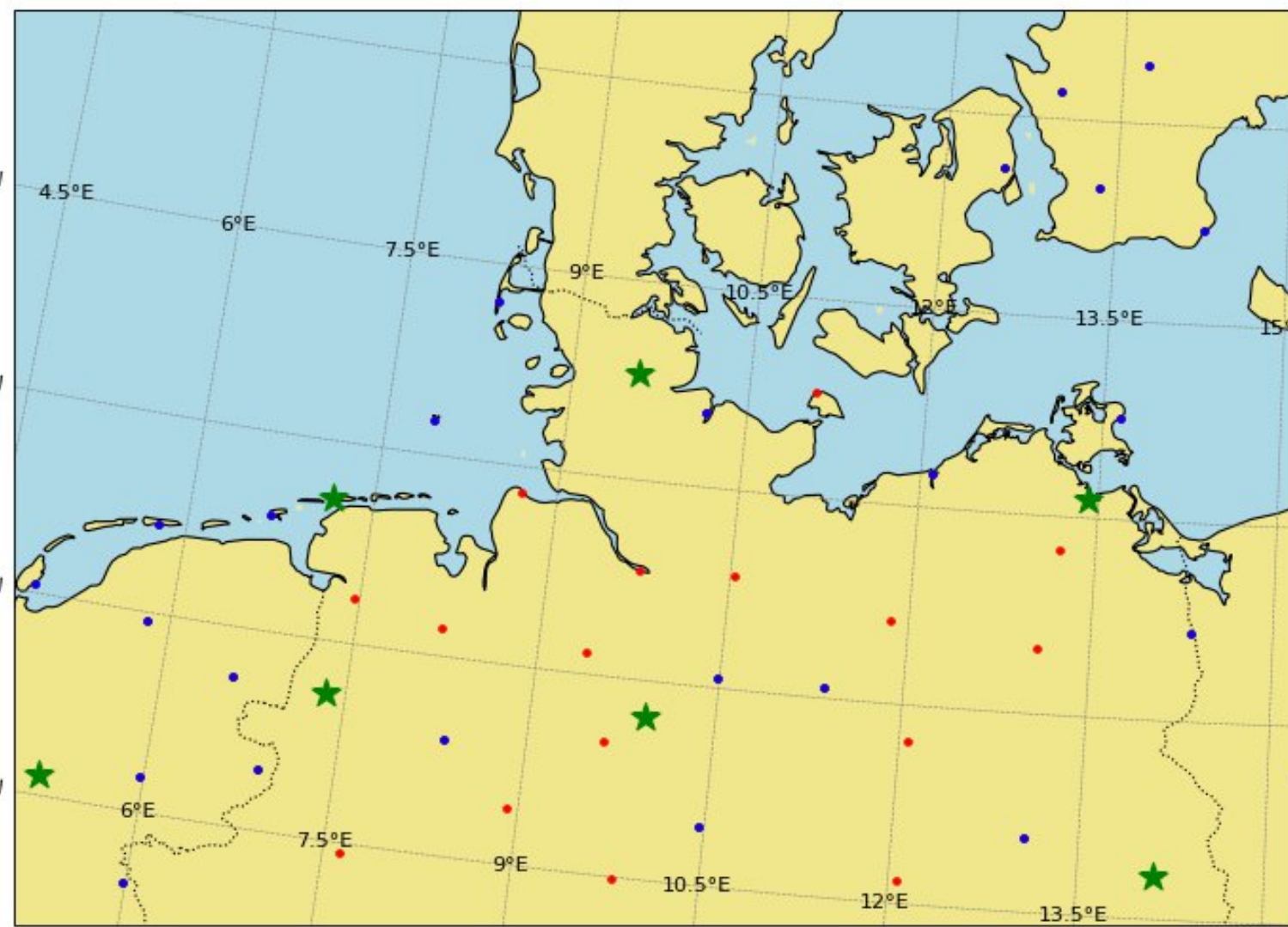


Figure 4. Locations of GNSS stations used for computing ZTDs: blue circles those active in the MetCoOp system, and red circles those from GFZ, and radiosonde stations by green stars.

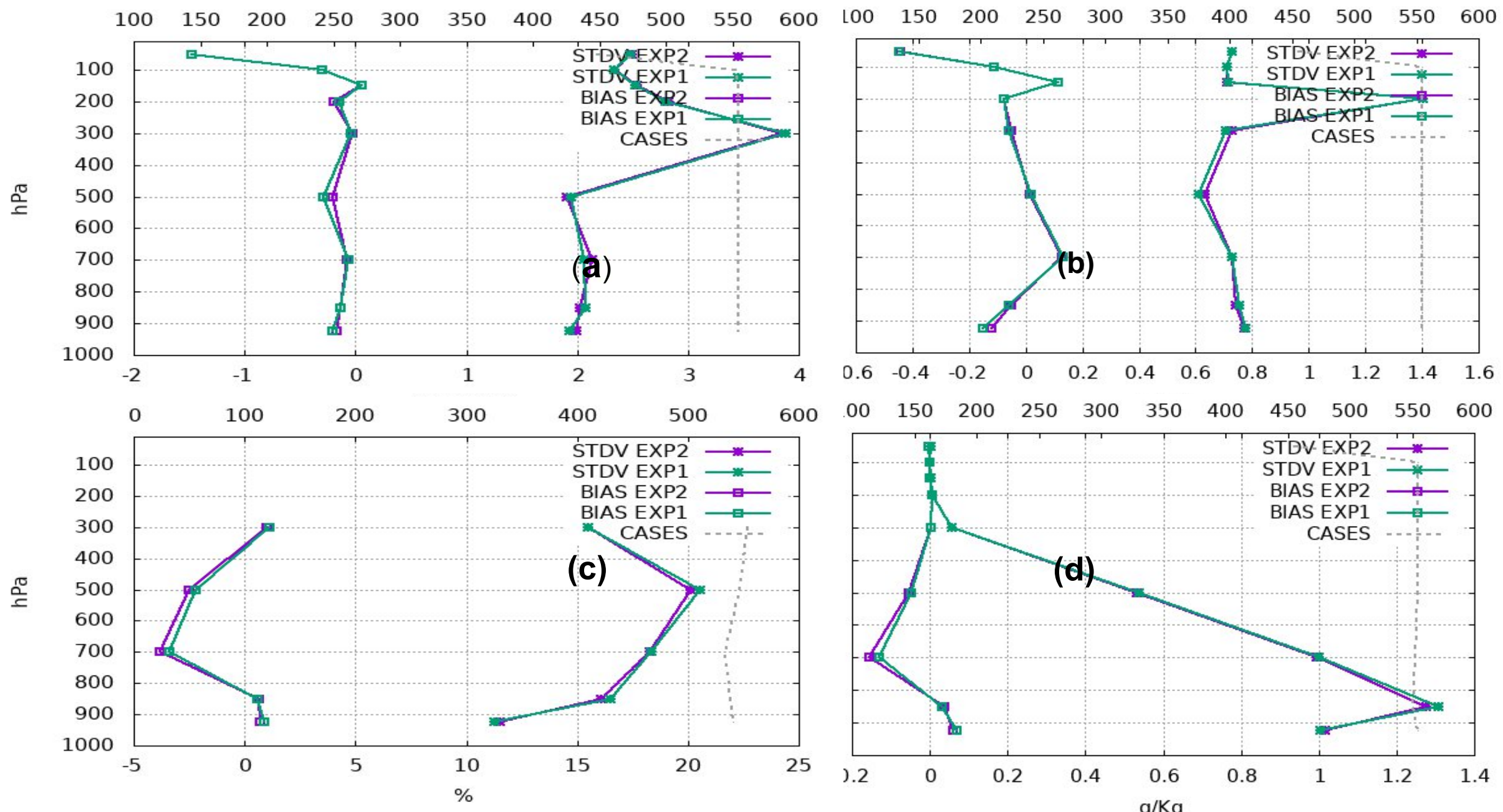


Figure 5. Vertical profile differences of CTRL-exp (EXP 1) and GFZ-exp (EXP2) with radiosonde data (16 July 2025–31 August 2025): (a) temperature [K], (b) wind speed [m/s], (c) relative humidity [%], and (d) specific humidity [g/kg].

References

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Impact on Data Assimilation of Extended Coverage of GNSS Zenith Total Delay Network in Southern Part of the MetCoOp Domain

Mehdi Eshagh; Martin Ridal; Magnus Lindskog

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