TOMOREF operator as a tool to improve weather forecasts

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Interested?

Sure, I want to know everything!

YES, but I do not have time…

Maybe later…

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WHY TO IMPROVE WEATHER FORECASTS?

Over 97 per cent of the water in our world resides in the oceans, and only 0.001 per cent resides in the atmosphere. Indeed, only about 0.005 per cent of the total world water supply is in motion at any one time. However, this very small amount of water is associated with all weather and river flow, and has a profound impact upon the activities of mankind. The measurement of precipitation (rain, snow, hail, etc.) is of primary importance for hydrological calculations.

-- WMO–No. 887

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WHY TO IMPROVE WEATHER FORECASTS?

“

There is a direct influence of global warming on precipitation. Increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought. However, **the water holding capacity of air increases by about 7% per 1°C warming, which leads to increased water vapor in the atmosphere**. Hence, storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones, supplied with increased moisture, produce more intense precipitation events. Such events are observed to be widely occurring, even where total precipitation is decreasing: ‘it never rains but it pours!’. This increases the risk of flooding.

-- Kevin E. Trenberth

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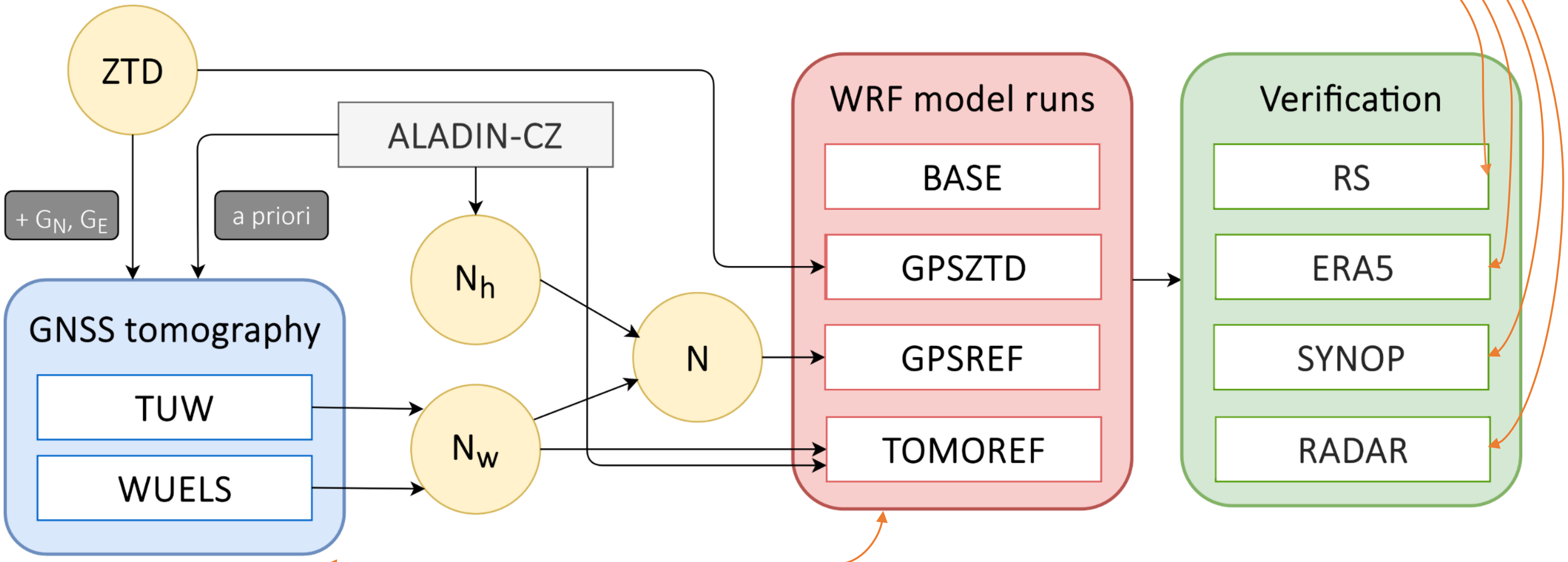
EXPERIMENT DESIGN

Check up on results!



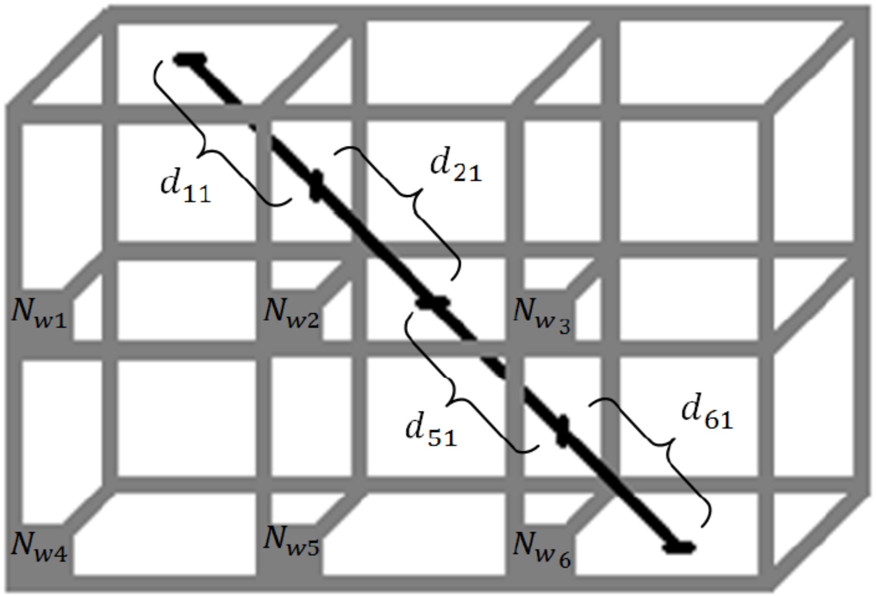
Klick to see the idea of GNSS tomography and the model domains!

Different operators? How does it work?

See Conclusions!

GNSS TOMOGRAPHY

GNSS tomography provides the 3D information about wet refractivity distribution



$$SWD = 10^{-6}\int N_w ds$$

$$SWD = A * N_w$$

known estimated

$$A = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix}$$

TOMOGRAPHIC MODELS

Wet refractivity fields were calculated using two GNSS tomographic solutions:

TUW

- Estimated by ATom (Atmospheric TOMography) GNSS software from the Vienna University of Technology (TUW) (Möller, 2017), where a least squares adjustment is used for the inversion.

WUELS

- Estimated by TOMO2 software developed at the Wroclaw University of Environmental and Life Sciences (WUELS) (Rohm, 2013; Rohm & Bosy, 2009, 2011; Rohm et al., 2014, Trzcina & Rohm, 2019), where a Kalman filter is applied.

In both solutions (TUW, WUELS), additional information about the wet refractivity distribution in the troposphere was introduced as a vector of pseudo-observations derived from the ALADIN-CZ weather model.

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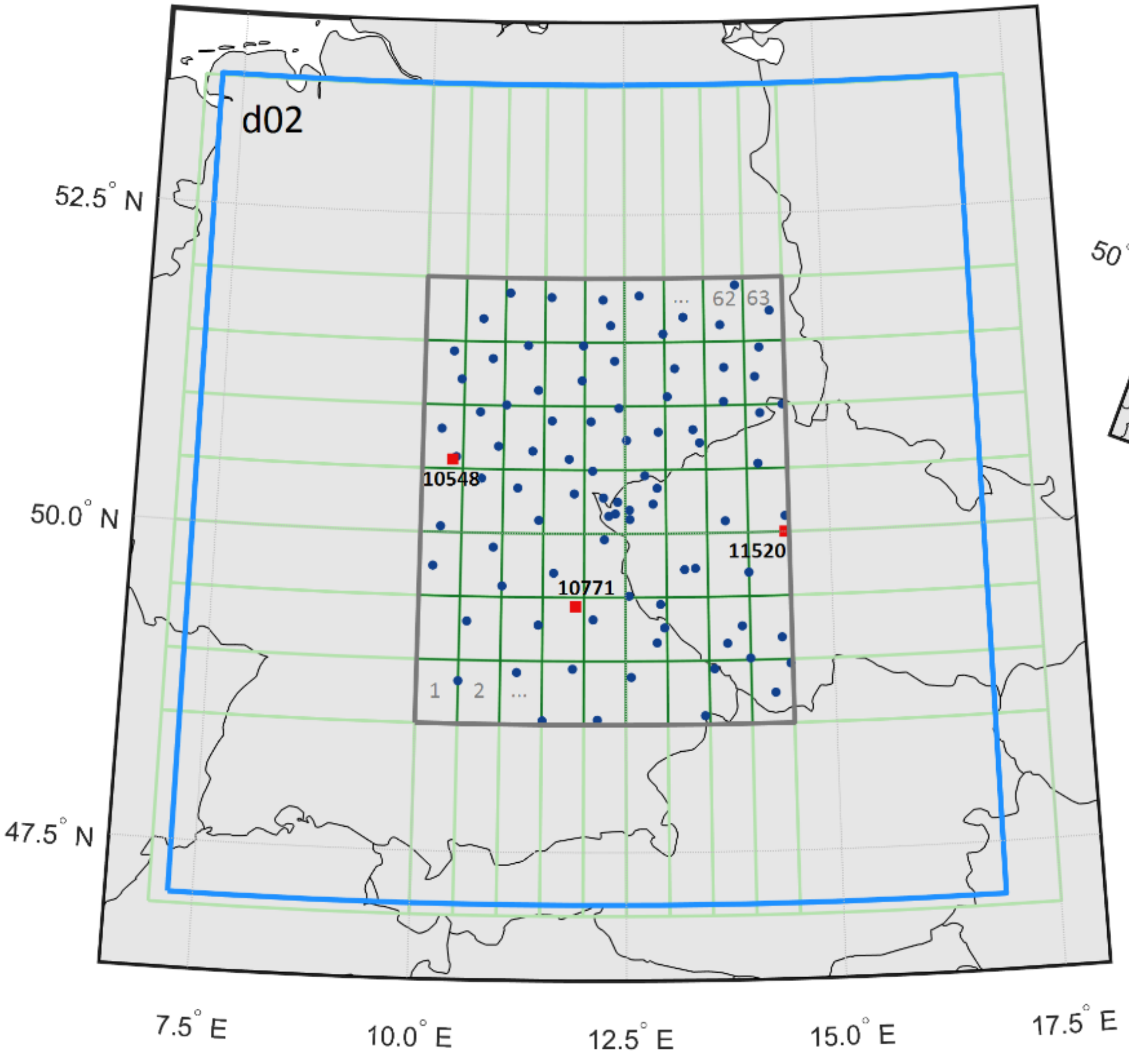
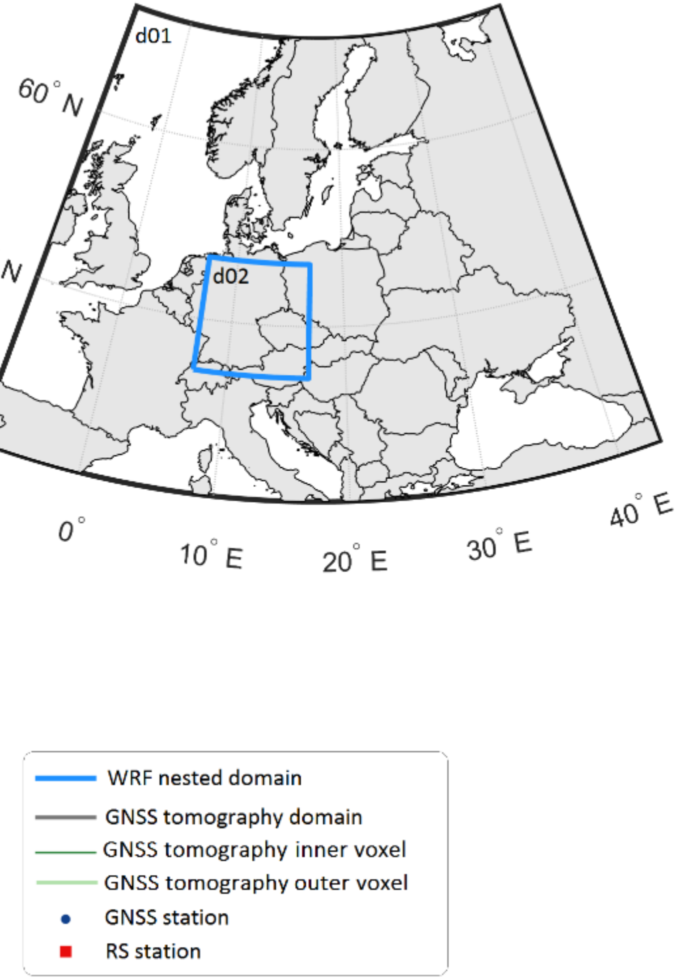
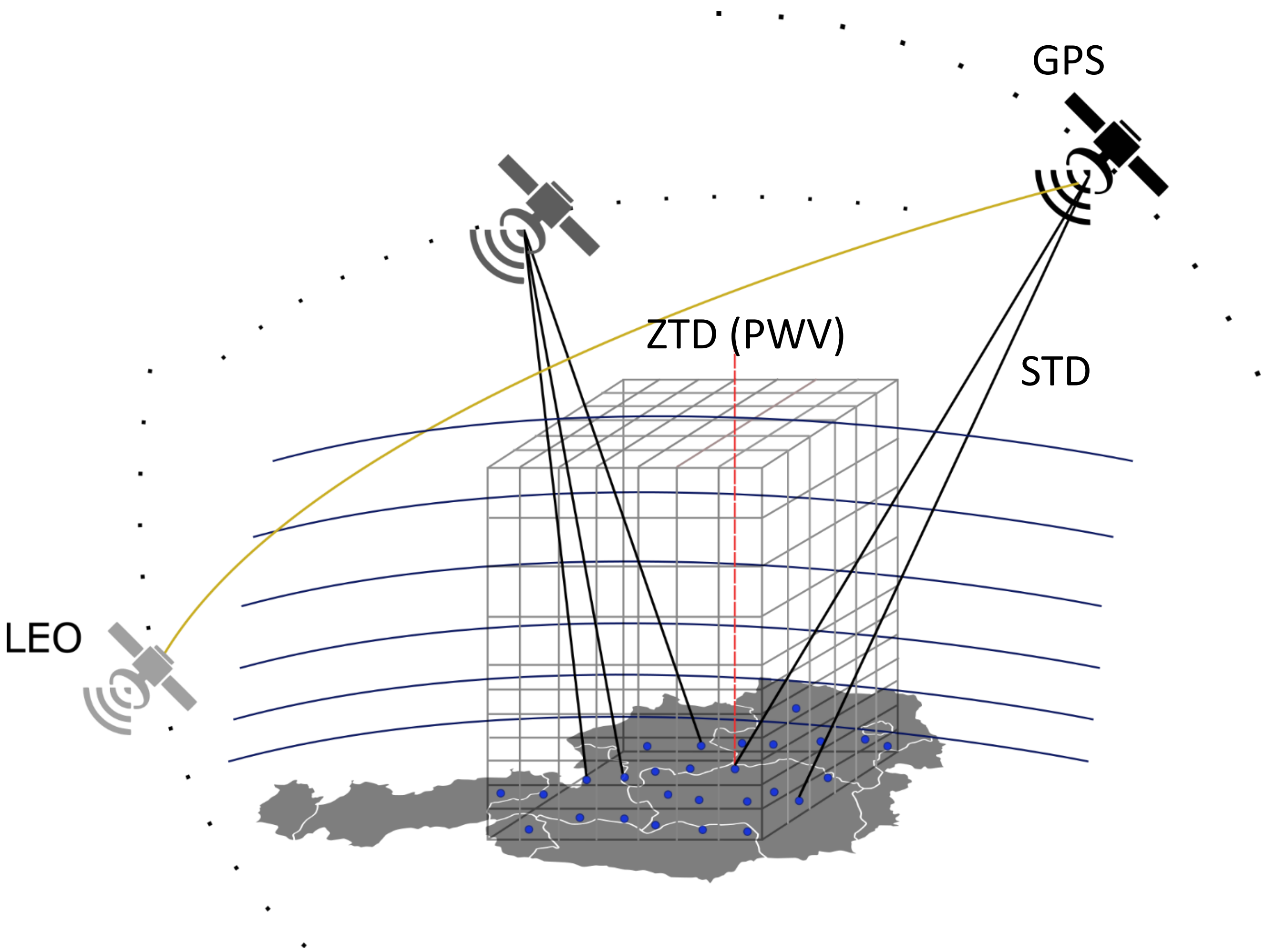
MODEL DOMAIN





GNSS DATA ASSIMILATION: Observation operators



- **ZTD/PWV** operators (integrated observations in the zenith direction) – GPSZTD/GPSPW operators
- **Radio occultation** operator (total refractivity *N*, bending angle) – GPSREF operator
- **STD/SIWV (slant observations in the satellite directions) – not implemented in the WRF DA**
- GNSS tomography wet refractivity fields – new TOMOREF operator (implemented in the WRF DA)

DATA ASSIMILATION SETTINGS

Items	Strategies
Period	29 May to 14 June 2013
Outer domain area	latitude 40.13–66.26°
	longitude −7.79–43.13°
Nested domain area	latitude 47.09–53.52°
	longitude 7.22–16.87°
Nesting feedback mode	one-way
Horizontal resolution	outer domain 36 km × 36 km
	nested domain 12 km × 12 km
Vertical resolution	35 layers (up to 50 hPa)
Background data and boundary conditions	NCEP FNL 1° × 1°
Assimilation method	3D-Var
Assimilation window	1 hr
Model run	00, 06, 12, 18 UTC
Forecast length	6-hr spin-up time + 18-hr forecast
Observation operators	GPSREF (*N*), TOMOREF (N_w), GPSZTD (*ZTD*)

GPSREF OPERATOR

The built-in WRF DA GPSREF operator aims at assimilation of total refractivity fields. The total refractivity was calculated in the following way:

$$N_w + N_h = N$$

N_w is wet refractivity
N_h is hydrostatic refractivity

N_w	N_h	N
tomography outputs	ALADIN-CZ model	assimilated

Hanna, N., Trzcina, E., Möller, G., Rohm, W., and Weber, R. (2019): Assimilation of GNSS tomography products into the Weather Research and Forecasting model using radio occultation data assimilation operator, Atmos. Meas. Tech., https://doi.org/10.5194/amt-12-4829-2019.

TOMOREF OPERATOR

The TOMOREF operator, that aims at assimilation of wet refractivity fields, was build based on the following function:

$$N_w = \mathcal{H}(p, m, T) = \frac{p}{\epsilon} \cdot \left(\frac{k_2'}{T} + \frac{k_3}{T^2} \right) \cdot \frac{m}{1 + \frac{m}{\epsilon}}$$

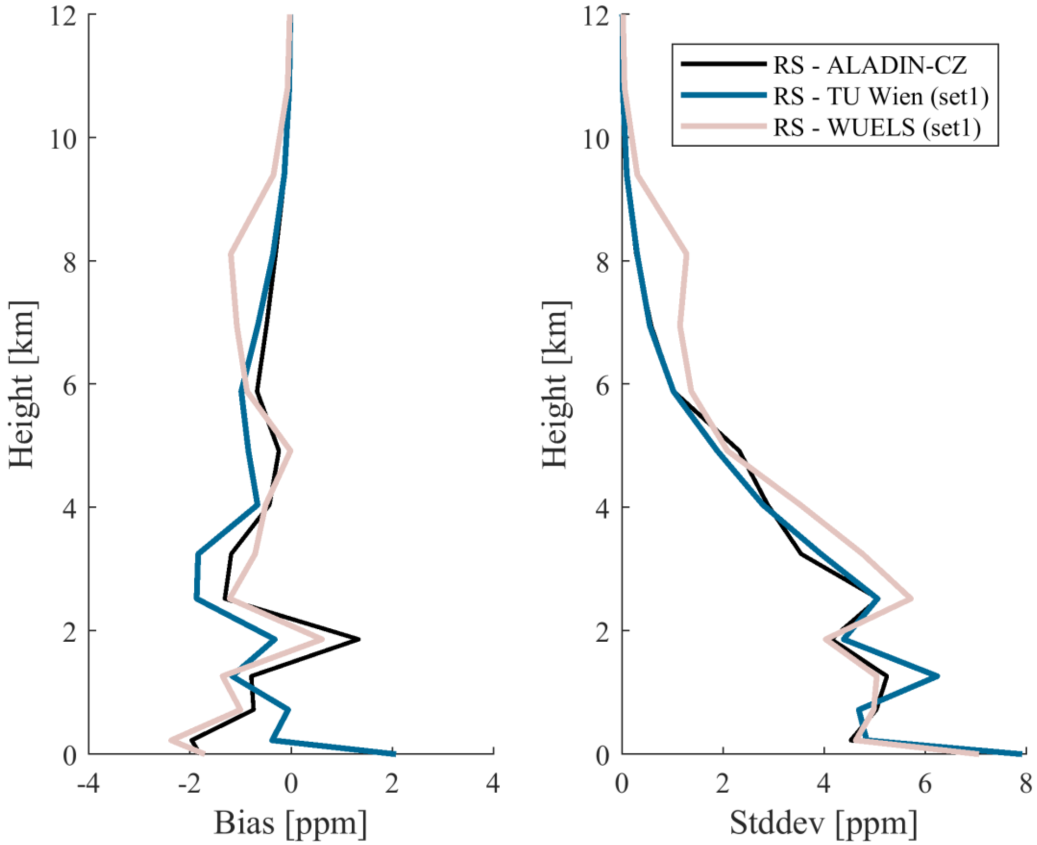
Where p is the atmospheric pressure in Pa, m is the water vapour mixing ratio in $kg \cdot kg^{-1}$, T is the temperature in K. The empirical constants $k_2' = 2.21 \cdot 10^{-1} K \cdot Pa^{-1}$ and $k3 = 3.73 \cdot 10^3 \; K2 \cdot P^{-1}$ are given by Bevis et al. (1994). The ratio between gas constants of dry air and water vapor $\epsilon = 0.622$ is used.

It consists of three parts:

Forward	Tangent Linear	Adjoint
p, m, T	$\delta p, \delta m, \delta T$	δN_w
$\downarrow$	$\downarrow$	$\downarrow$
N_w	δN_w	$\delta p, \delta m, \delta T$

This operator has been implemented in the WRF DA system.

TOMOREF OPERATOR: Observation errors



Observation errors have been set based on the comparison of tomography results with radiosonde profiles (2 weeks period)

Height [km]	Nw error [ppm]
< 1.5	$0.1 \cdot N_w$
1.5 – 5.5	$0.2 \cdot N_w$
5.5 – 8.0	3.0
8.0 – 10.0	2.0
> 10.0	0.2

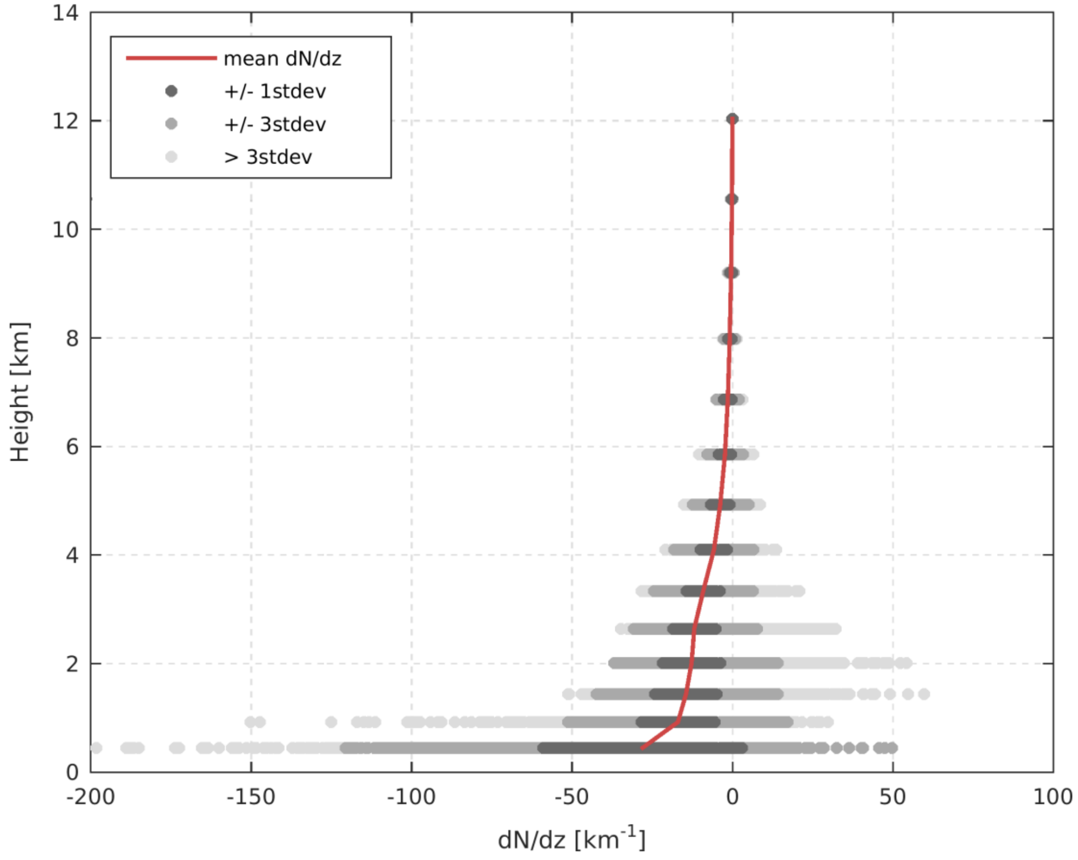
TOMOREF OPERATOR: Quality control

1) Based on the percent error

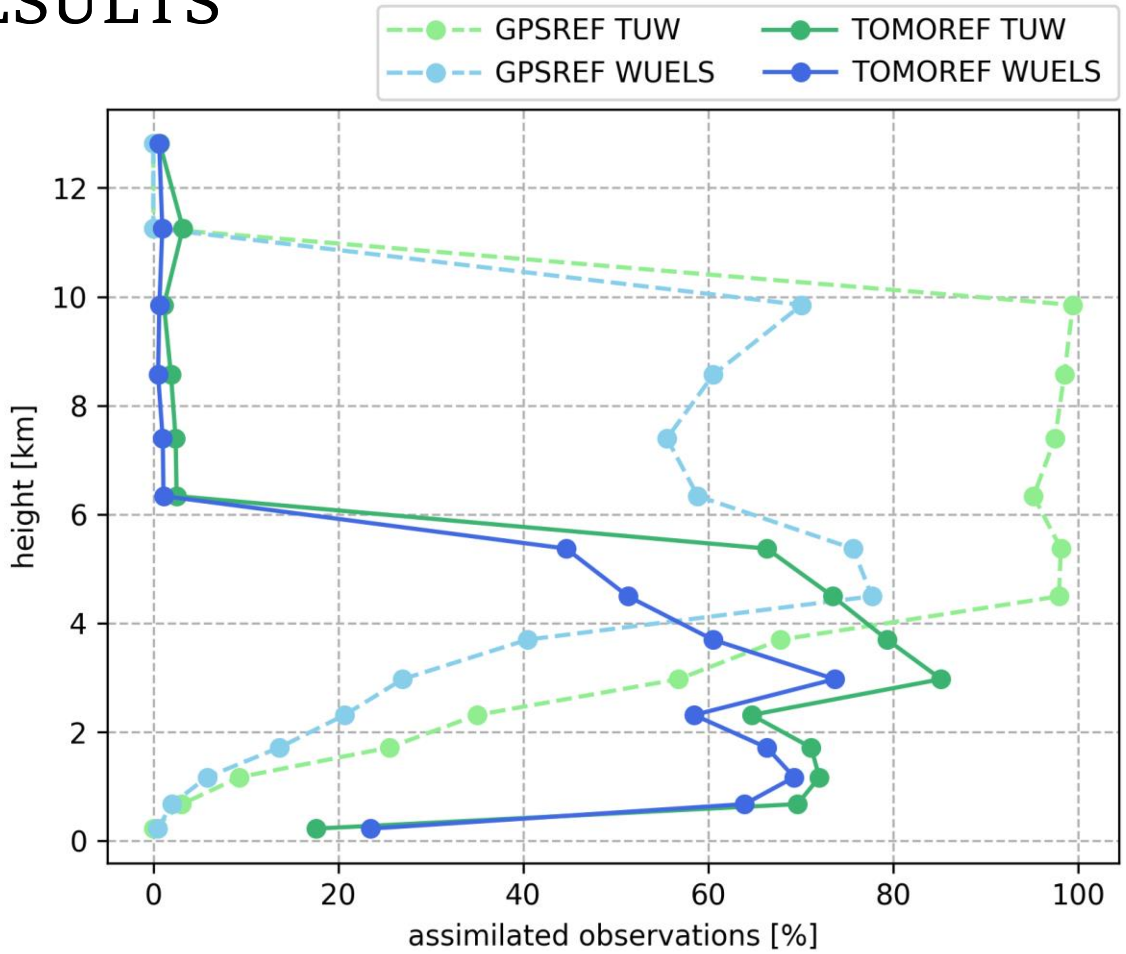
$$\left|\frac{O-B}{(O+B)/2}\right|$$

Height [km]	Max percent error	QC flag
< 2.5	0.15	-31
2.5 – 5.5	0.30	-32
> 5.5	0.15	-33

2) Based on the vertical gradient of N_w (QC flag -34)



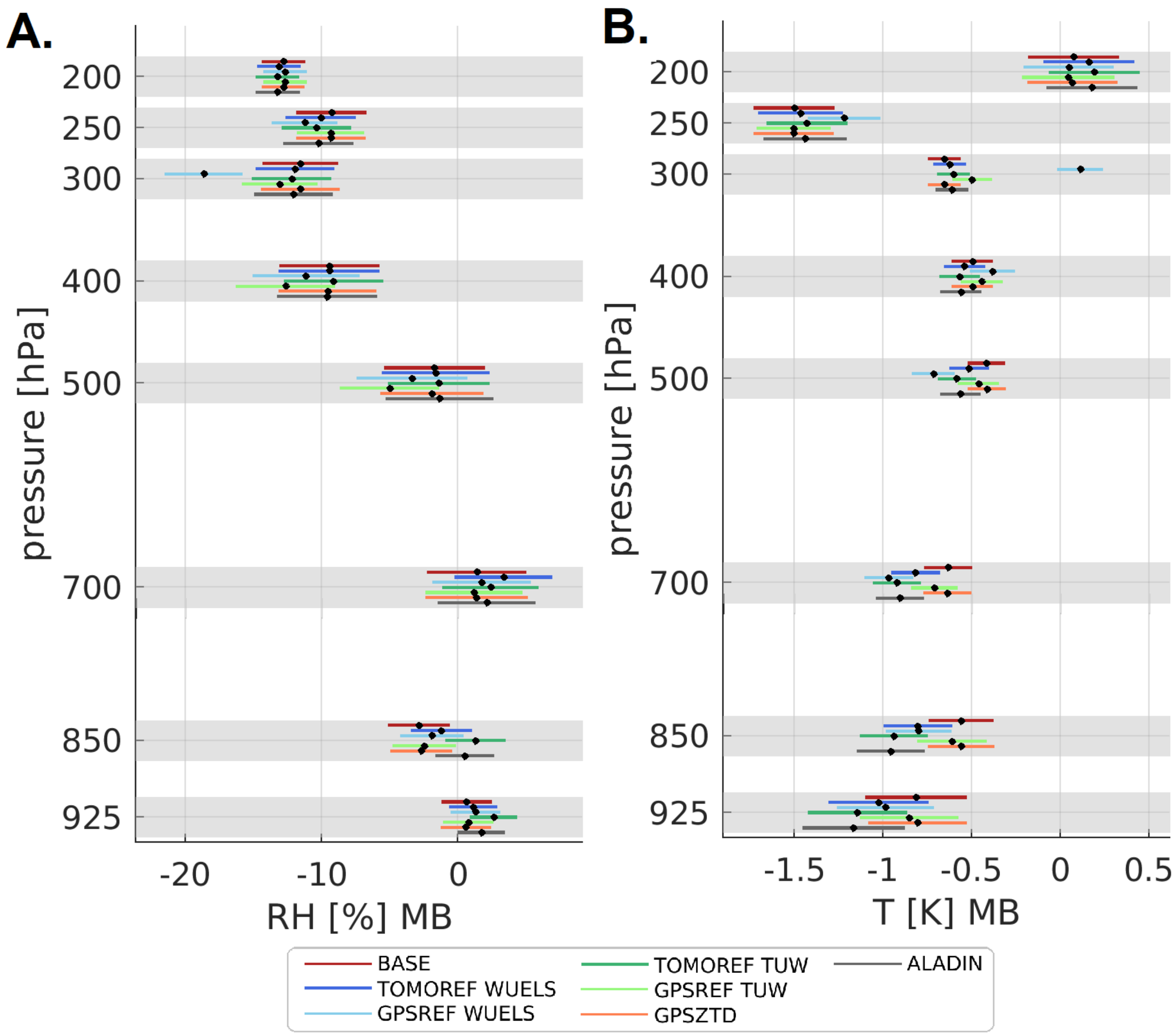
ASSIMILATION RESULTS



GPSREF
0 - 2 km: < 20 % of observations are assimilated
> 6 km: 60-95 % of observations are assimilated

TOMOREF
0 - 2 km: ≈70 % of observations are assimilated
> 6 km: < 5 % of observations are assimilated

VERIFICATION RESULTS: RADIOSONDES

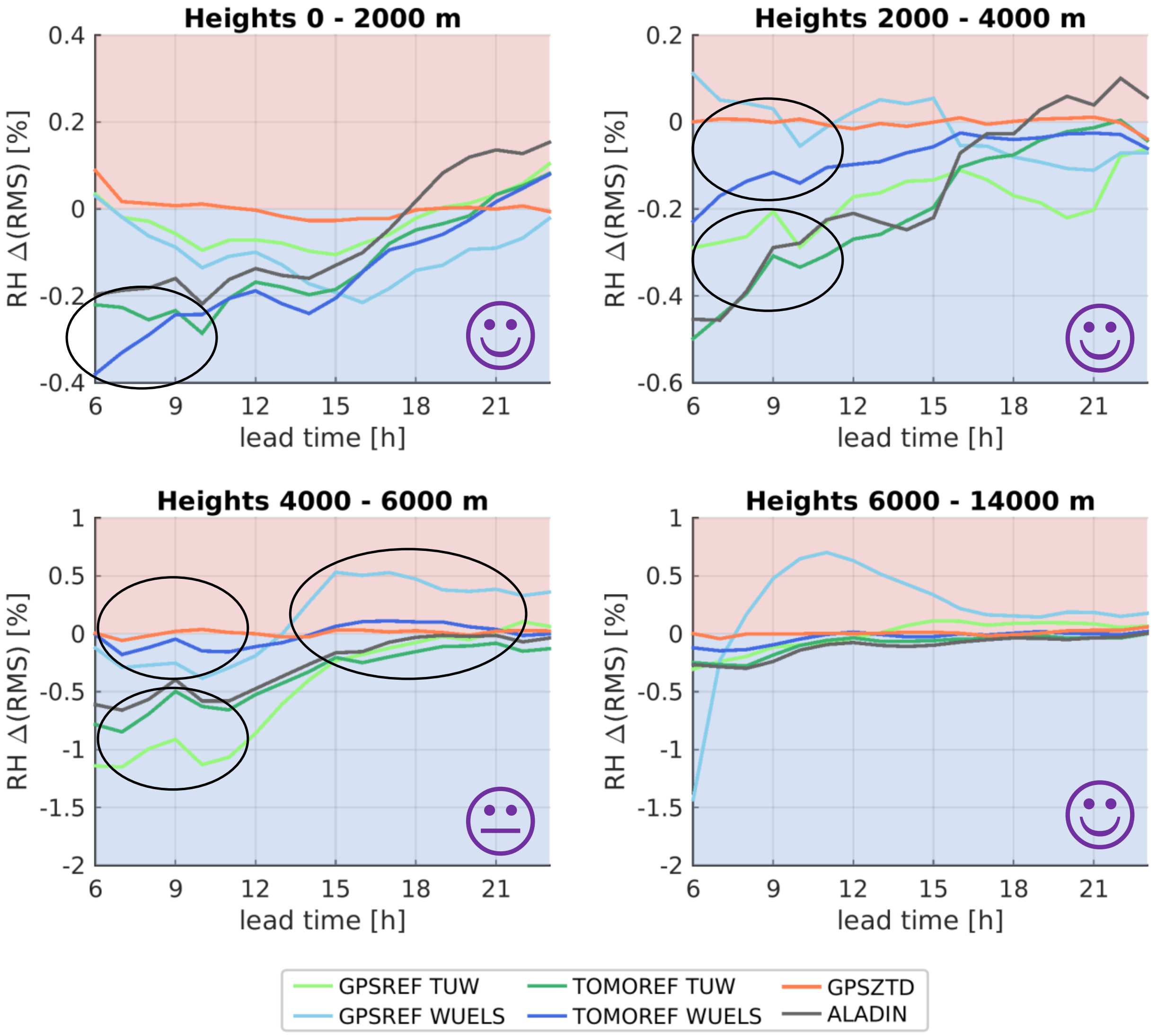


The statistics of mean bias (MB) for both meteorological parameters (RH, T) vary with height.

- **A negative impact on the forecast of RH at the pressure level 300 hPa when GPSREF operator is used** (eliminated by the application of TOMOREF operator);
- In terms of temperature, no improvement in the weather forecast was noticed when TOMOREF operator was used.

The values of MB in the upper part of the troposphere (above 400 hPa) depend on the changing horizontal location of the radiosonde, which does not rise in the perfect vertical direction.

VERIFICATION RESULTS: ERA5



In terms of RH, the assimilation of the GNSS products for both models (TUW, WUELS) using the TOMOREF operator:

- **Gives better results by approximately 0.1-0.5% in the lower part of the troposphere (0-2 km)** than operators GPSREF and GPSZTD (up to 10 h of the forecast);
- **For heights between 2 and 4 km decreases the rms value by approximately 0.1%** when compared to the GPSREF operator;
- In the middle part of the troposphere (4-6 km; up to 7 h of the lead time) gives better result than the BASE run but worse than the GPSREF run;
- In the upper troposphere, **the advantage of the TOMOREF operator over the GPSREF operator is evident through the entire forecast period**.

VERIFICATION RESULTS: SYNOP

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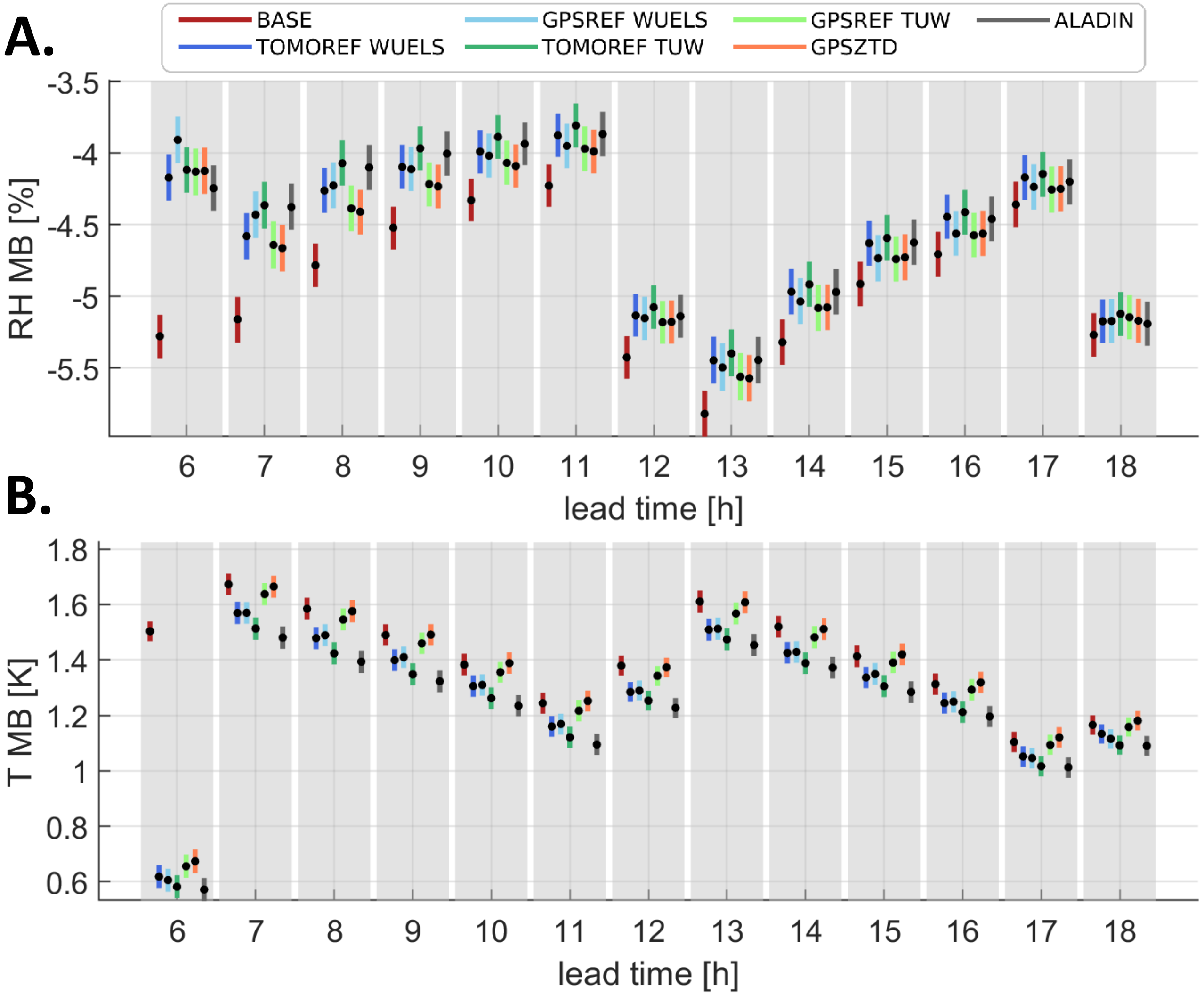

In terms of RH (panel A):

- All runs overestimate the observed RH, with MB in a range of -3.5% to -6.0%;
- In the first hours of the forecast (6-8 hours of the lead time), each case of the assimilation improves the value of MB for RH by approximately 1% compared with the BASE run;
- In the next hours of the forecast (9-14), **significant improvement in RH is evident mainly for the TOMOREF (TUW, WUELS) and ALADIN** assimilation runs.

In the case of T (panel B):

- The maximal improvement of MB (~1 K) is visible for all assimilation runs at the assimilation time.
- During the 7-14 hour of the forecast lead time, the **significant decrease of MB for T (by 0.1-0.2 K) is aparent mainly for the TOMOREF (TUW, WUELS) and ALADIN** assimilation runs.

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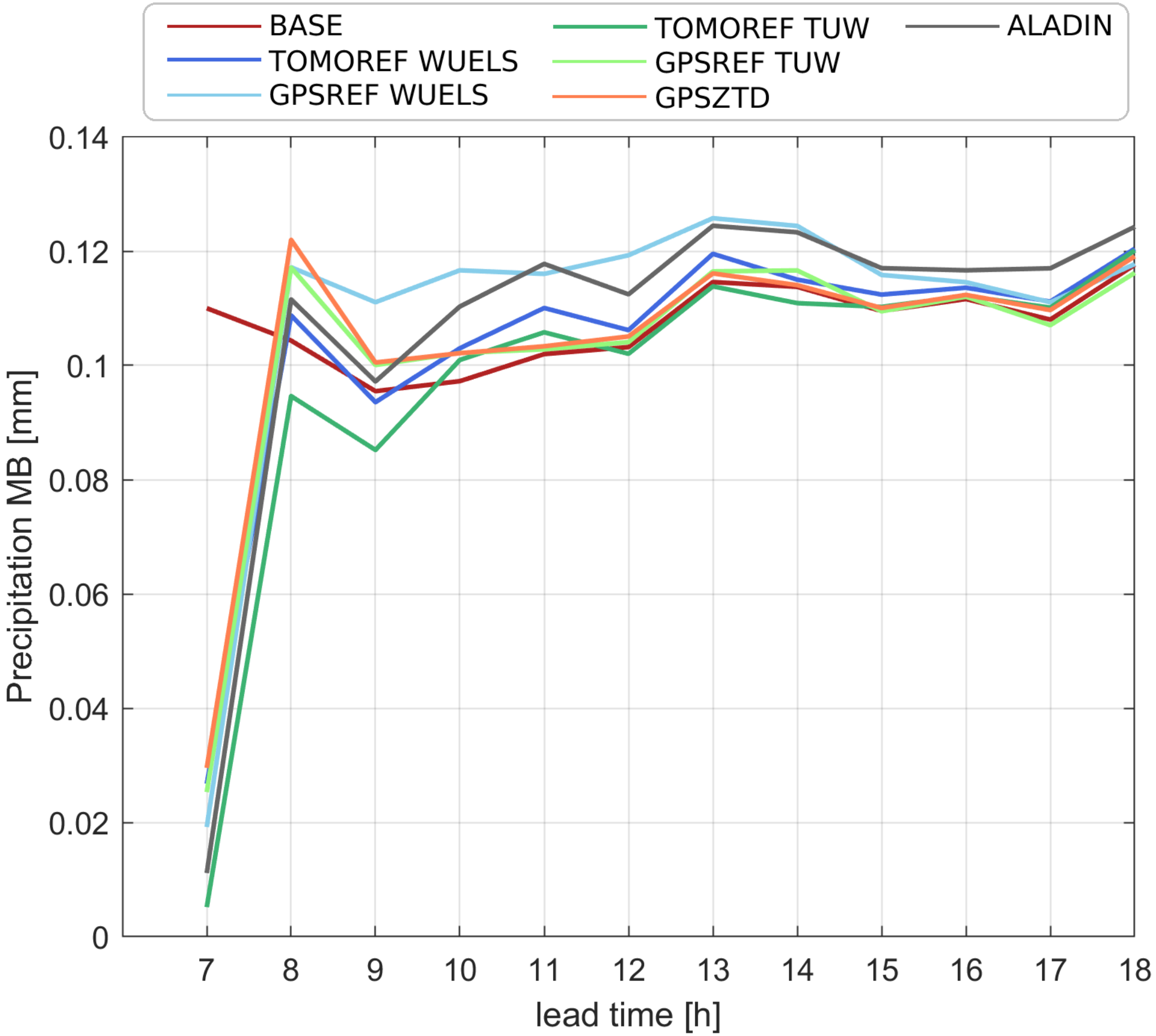
VERIFICATION RESULTS: RADAR



Mean bias (MB) of the precipitation for the WRF simulations in the forecast lead time of 6-18 hr, validated against radar observations.

In terms of precipitation:

- Mean bias reduced by ~0.1 mm within 1 hr after assimilation, when compared to the BASE run
- For both tomographic models (TUW, WUELS) up to 10 hr of the forecast lead time, the MB for the TOMOREF operator is lower (reduced by ~0.02 mm on average) than for the GPSREF operator
- Overall, the assimilation of the ZTD observations does not influence the MB of precipitation forecast noticeably.

MAIN FINDINGS & CONCLUSIONS

- The previous studies on assimilation of the total refractivity field from GNSS tomography into the NWP models are based on the available GPSREF observation operator
- The new TOMOREF operator is dedicated to the assimilation of the GNSS tomography 3D fields of wet refractivity
- The **positive impact of the GNSS tomography data assimilation on the weather forecast of RH** has been noticed (an improvement of rms up to 0.5% when compared to ERA5)
- Mean bias of precipitation is reduced by ~0.1 mm within 1 hr after assimilation
- In the analyzed period, when the high-precipitation events were observed, the positive impact of assimilation of the GNSS data on the precipitation forecasts is of short duration. Within 1 hr after assimilation, the MB values are reduced to nearly 0 when compared to the radar data.
- The assimilation of the GNSS tomography outputs shows **greater influence on the WRF model than the ZTD assimilation**, what proves the potential of using the GNSS tomography data in weather forecasting
- The impact of the GNSS tomography assimilation in different weather conditions and seasons should be investigated
- The performance of the operator in different regions should be examined.

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JUST CHECK UP ON OUR PAPER!

SCAN ME

Trzcina, E., Hanna, N., Kryza, M., & Rohm, W. (2020). TOMOREF Operator for Assimilation of GNSS Tomography Wet Refractivity Fields in WRF DA System. *Journal of Geophysical Research: Atmospheres*, *125*(17), e2020JD032451.