Analyzing structural uncertainty in rOPS and ROPP processing: the chain from bending angle to dry-air atmospheric profiles

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In a joint project of WEGC and the ROM SAF we investigated structural uncertainties within the Level 2a (L2a) processing chain of the radio occultation (RO) retrieval algorithms of two different processing systems, namely the GNSS Processing and Archive Center (GPAC) implementation of the Radio Occultation Processing Package (ROPP) at DMI used for the generation of the first ROM SAF Climate Data Record and the Reference Occultation Processing System (rOPS) used for R&D processing by WEGC, with focus on validation and climate studies. We understand L2a structural uncertainty in this context as the part of the uncertainty emerging in retrieved profiles that derives from different plausible algorithmic choices and numerical implementations in the L2a retrieval steps of rOPS and GPAC/ROPP when we supply both processing systems with identical input data.

1 Schematic Flow

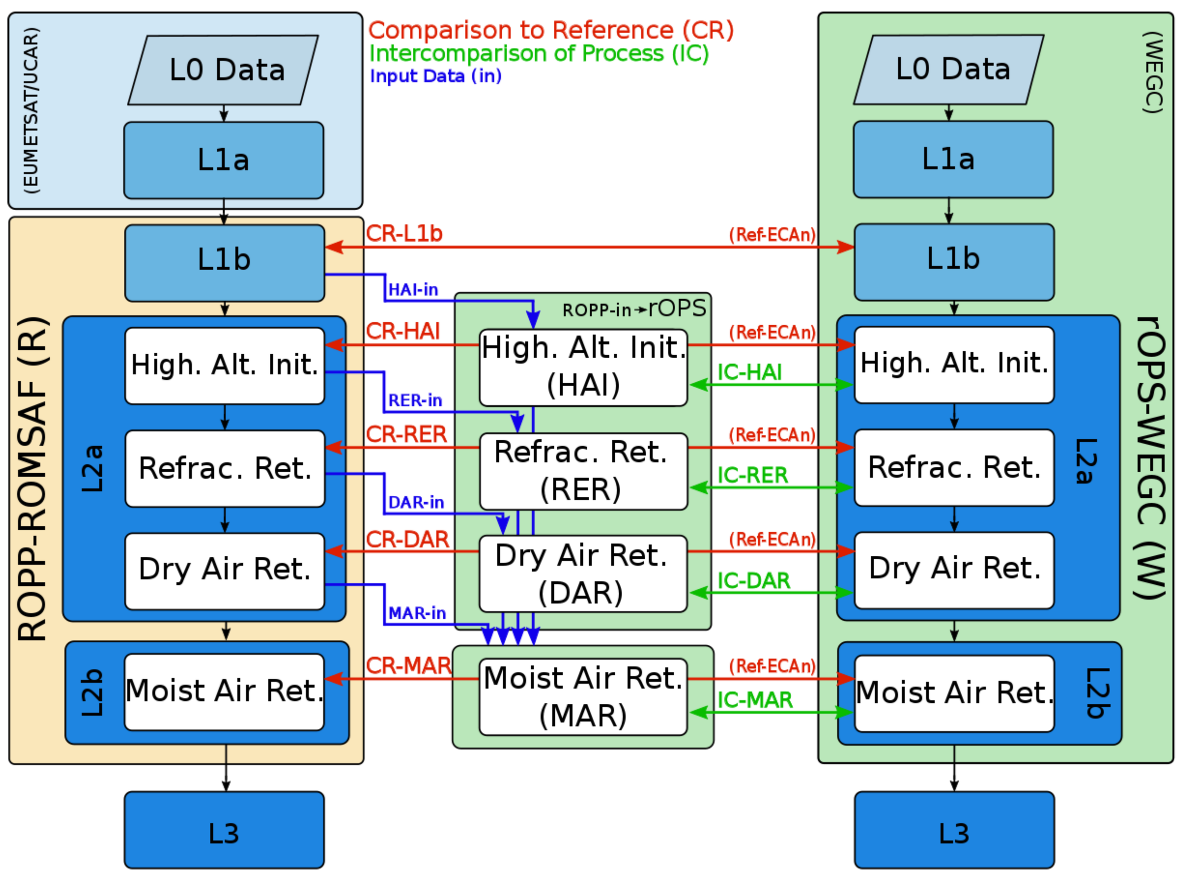

Figure 1: Scheme of the ROPP and rOPS processing system and the input data sub-process flow and comparison steps between the two systems.

In Figure 1 the input data flow from ROPP to rOPS sub-processes to investigate the structural uncertainty is shown. The focus lies in the L2a processing on the High Altitude Initialization (HAI-in), the Refractivity Retrieval (RER-in) and the Dry Air Retrieval (DAR.in) from ROPP data into the rOPS processing system. This enables selective analysis on structural uncertainty of different sub-processes for the bending angle initalization algorithm (optimized bending angle), the different Abel-Integral (refractivity) and the Pressure-Integral (dry pressure) implementations of ROPP and rOPS.

2 Results

DAR-in

DAR-in rOPS Setup: 1) Refractivity profile interpolated to a 100 m altitude grid. 2) Retrieved (retr.) dry density filled up to 120 km with a log-linear shifted at top of measurement background profile (bgr.). 3) rOPS Pressure-Integral in residual mode (diff. profile of retr. minus bgr.), integration step 10 m.

Figure 2 shows, that only the initialization at 120 km causes differences and reaches a 1% diff. at 60 km and becomes unbiased at 40 km.

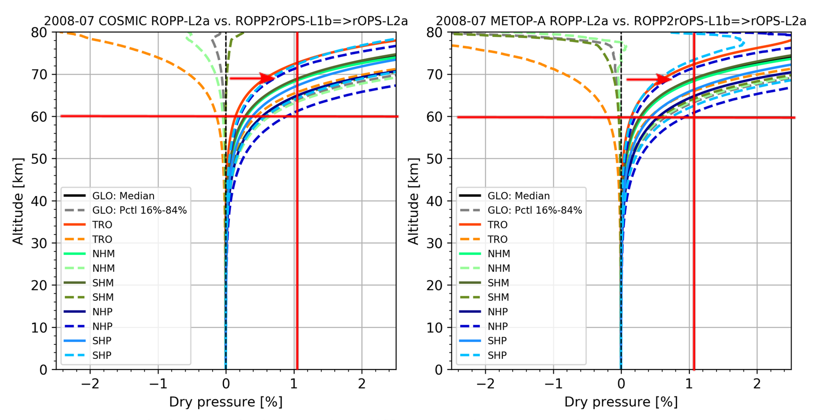

Figure 2: The left panel shows the difference between dry pressure ROPP and dry pressure DAR-in rOPS for COSMIC 2008-07 globally and the five latitudinal bands, the right panel the same for METOP-A.

RER-in

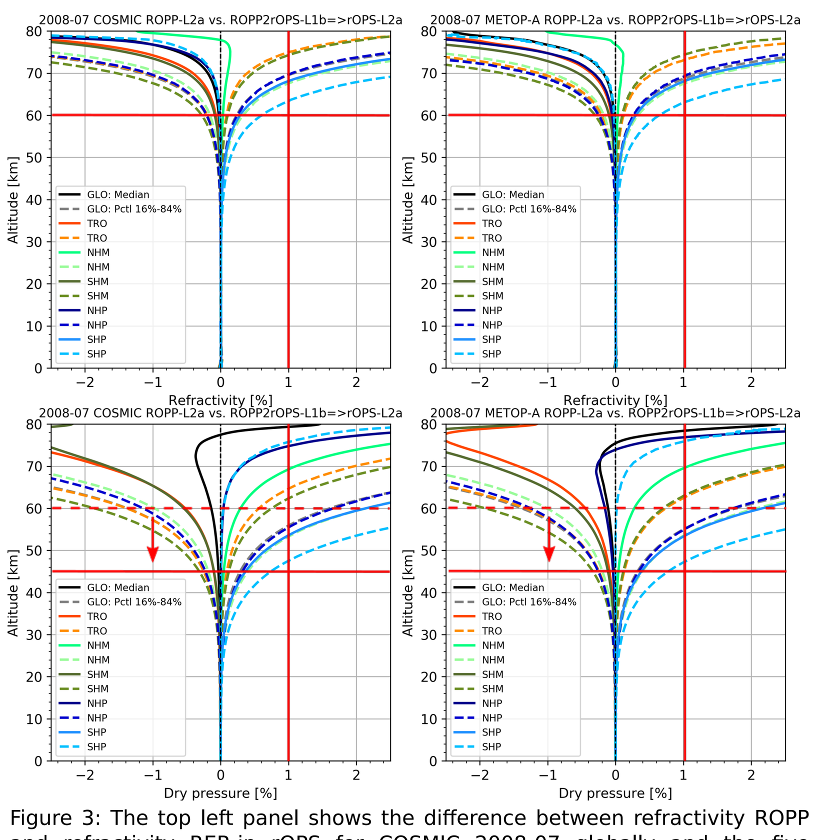

Figure 3: The top left panel shows the difference between refractivity ROPP and refractivity RER-in rOPS for COSMIC 2008-07 globally and the five latitudinal bands, the top right panel the same for METOP-A with IFS-od fc initialization at top of measurement. The bottom panel shows the dry pressure results for COSMIC (left) and METOP-A (right).

RER-in rOPS Setup: 1) Interpolation of the optimized bending angle (BA) profile to a co-located forward modeled (IFS-od fc) impact altitude grid, based on a 100 m altitude grid. 2) Optimized (BA) profile filled up at top of measurement with a bgr. co-located IFS-od fc (ECMWF forecast) BA profile without a shift at top of profile. 3) rOPS Abel-Integral in residual mode with 20 m integration step. 4) rOPS Pressure-Integral same as in DAR-in.

Figure 3 shows the initialization of the Abel-Integral at 120 km with RER-in rOPS setup causing a refractivity diff. and reaches a 1% diff. at 60 km. The Pressure-Integral lowers the 1% diff. level down to 45 km for the dry pressure and becomes unbiased below 40 km.

RER-in BAROCLIM-init

RER-in BAROCLIM-init rOPS Setup: Setup is the same as for RER-in rOPS although step 2, filling up of the BA up to 120 km is done with the BAROCLIM BA from ROPP.

Figure 4 top left shows the initialization of the Abel-Integral at 120 km with BAROCLIM causes 0,1 % diff. for COSMIC and becomes unbiased below 70 km. Remaining effect due to Abel-Integral residual mode. The Pressure-Integral (bottom left) lowers the 1% level to 60 km close to DAR-in case. The METOP-A refractivity (Fig. 4 top right) shows a 1 % diff. at 70 km because the BAROCLIM BA profile is provided up approx. 90 km and thus filled up to 120 km with collocated MSIS-90 profile. The Pressure-Integral 1 % level is at 55 km.

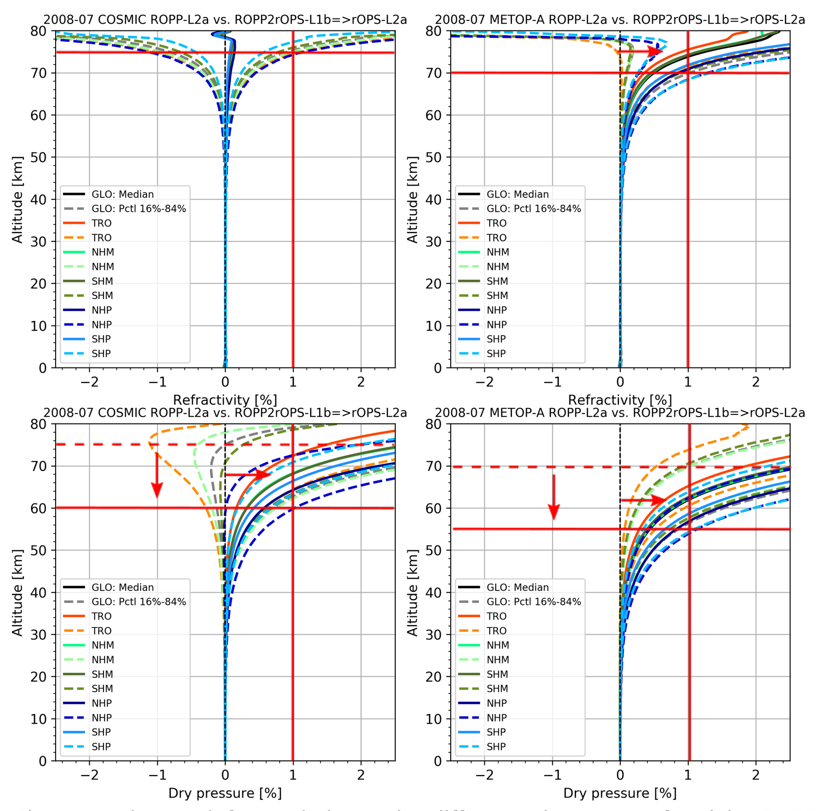

Figure 4: The top left panel shows the difference between refractivity ROPP and refractivity RER-in BAROCLIM-init rOPS for COSMIC 2008-07 globally and the five latitudinal bands, the top right panel the same for METOP-A with a BAROCLIM initialization at top of measurement. The bottom panel shows the dry pressure results for COSMIC (left) and METOP-A (right).

Statistical Optimization

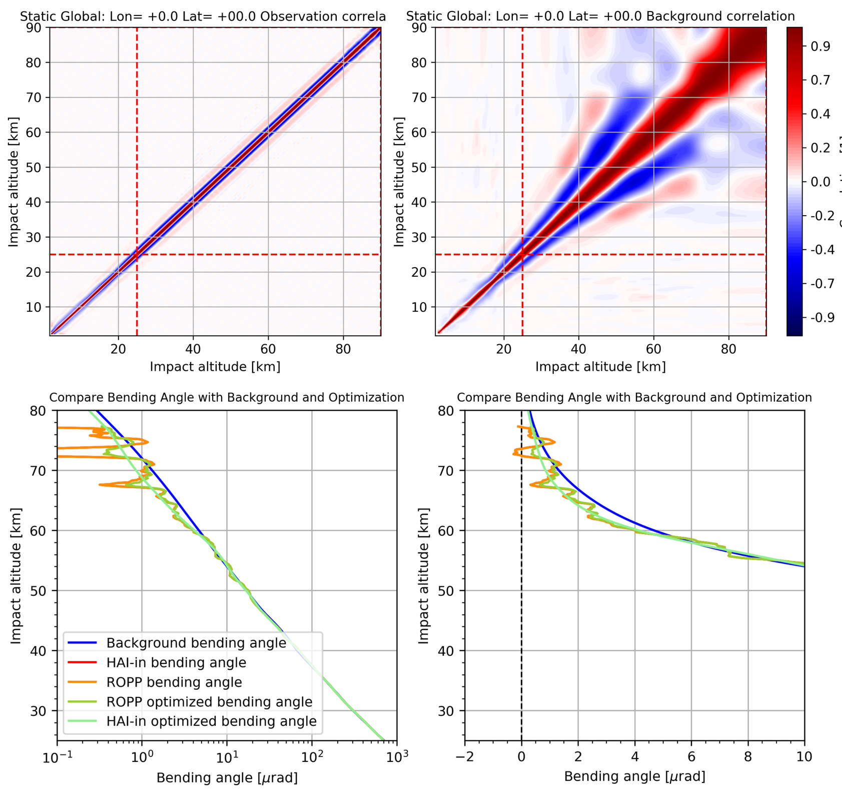

Figure 5: The top panel shows the BA correlation for measurement (left) and background profiles (right). The bottom panel shows an example optimization bending angle result for METOP-A.

In Figure 5 the correlation matrices for the measurement and background BA, used for the dynamical statistical optimization in rOPS are given (see [1] and [2]). An example result is shown in the bottom panel of Fig. 5. The rOPS statistical optimization reduces the noise of the optimized BA significantly compared to the ROPP optimized BA. Optimized and non-optimized BA become almost the same at 65 km for ROPP and at 60 km for rOPS. Since the rOPS BA is smooth and not negative a bgr. BA profile can be log-linear shifted at top of measurement to a reasonable value. The ROPP optimized BA is filled up to 120 km with a BAROCLIM BA without any shift at top of measurement.

HAI-in

HAI-in rOPS Setup: 1) Interpolation of the BA profile to a co-located forward modeled (IFS-od fc) impact altitude grid, based on a 100 m altitude grid. 2) Statistical optimization with a dynamic weighting matrix calculated with estimated observed and bgr. uncertainty. Optimization calculated up to min/max 70/80 km. The dynamic optimiazation uses the bgr. BA as calculated in [1]. 3) Abel-Integral same as in RER-in rOPS setup although with log-linear shift for the 120 km filled up optimized BA profile with the bgr. BA (IFS-od fc) profile at top of measurement. 4) Pressure-Integral same as for RER-in rOPS setup.

Figure 6 (top panel) shows the optimization process results in a stronger noise although the median reaches the 1 % diff. level at about 60 km and is unbiased at 55 km. The initialization of the Abel-Integral at 120 km with RER-in rOPS setup causing a refractivity diff. and reaches a 1% median diff. at 50 km. The Pressure-Integral lowers the 1% median diff. level down to 40 km for the dry pressure and becomes unbaised below 30 km.

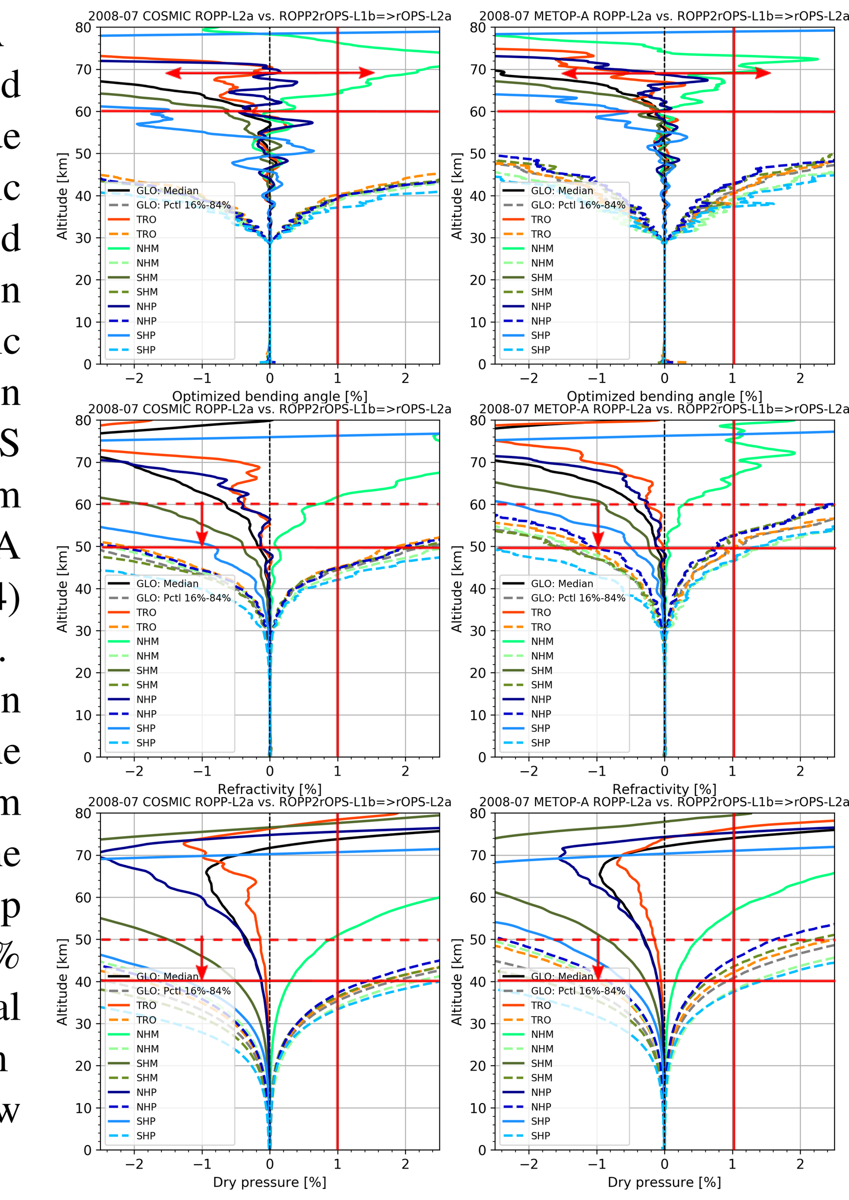

Figure 6: The top left panel shows the difference between optimized BA ROPP and optimized BA HAI-in rOPS for COSMIC 2008-07 globally and the five latitudinal bands, the top right panel the same for METOP-A. The second and third panel shows the same as for Figure 3.

HAI-in BAROCLIM-init

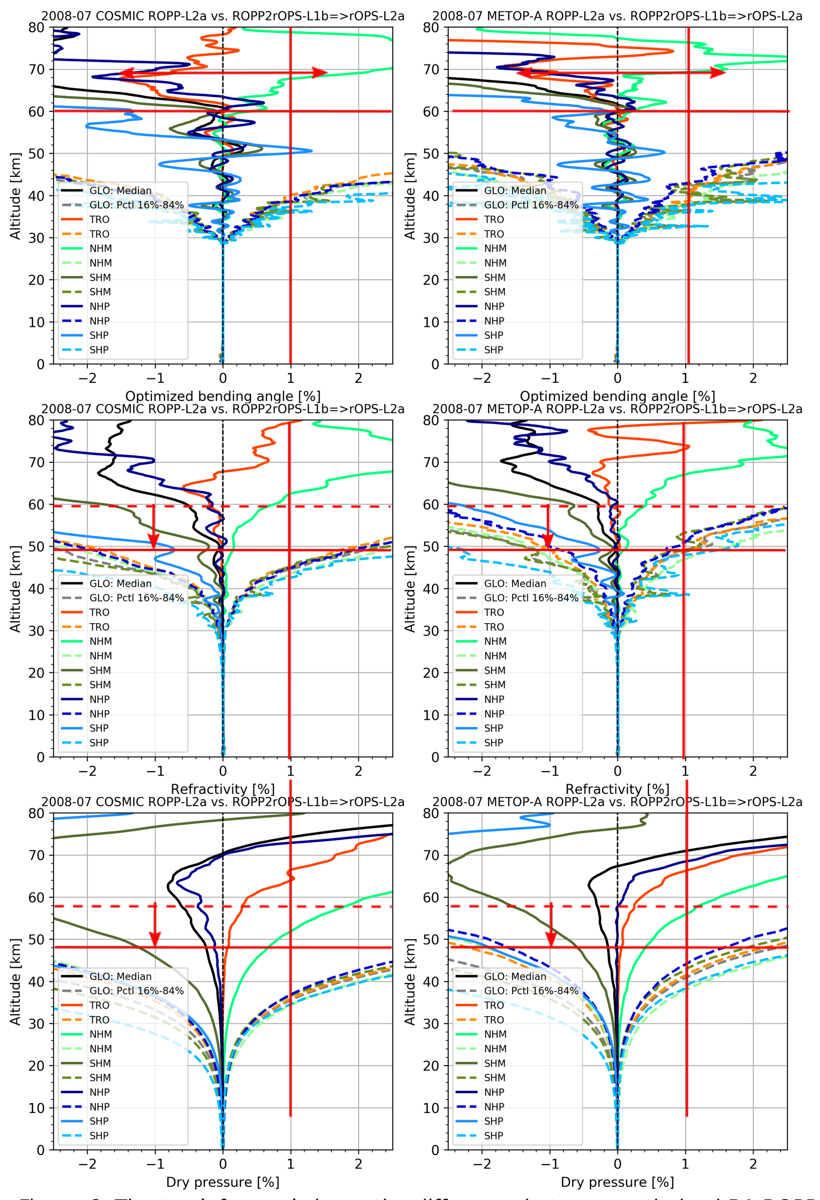

Figure 6: The top left panel shows the difference between optimized BA ROPP and optimized BA HAI-in BAROCLIM-init rOPS for COSMIC 2008-07 globally and the five latitudinal bands, the top right panel the same for METOP-A. The second and third panel shows the same as for Figure 4.

HAI-in BAROCLIM-init rOPS Setup: Setup is the same as for HAI-in rOPS although step 2 and 3 uses a BAROCLIM BA profile as bgr. BA profile for the optimization process and the optimized BA filling up to 120 km.

Figure 6 (top panel) shows the optimzed BA diff. with stronger median oscillation compared to the HAI-in results. The oscillation is a result of the used bgr. correlation in the rOPS BA optimization. The 60 km to 80 km altitude range are closer to the ROPP resulst compared to the HAI-in results, since the same bgr. is used and shows thus the difference on the different processes. The Abel-Integral lowers the median diff. altitude level to about 70 km and the Pressure-Integral lowers the level again to about 50 km. Overall these results are closer to the ROPP results compared to the HAI-in results, due to the used BAROCLIM BA background. Besides the initialization of the profiles, the used background for the optimization affects the retrieval results see the Sudden-Stratospheric-Warming (SSW) event in Figure 7 and 8.

SSW Event

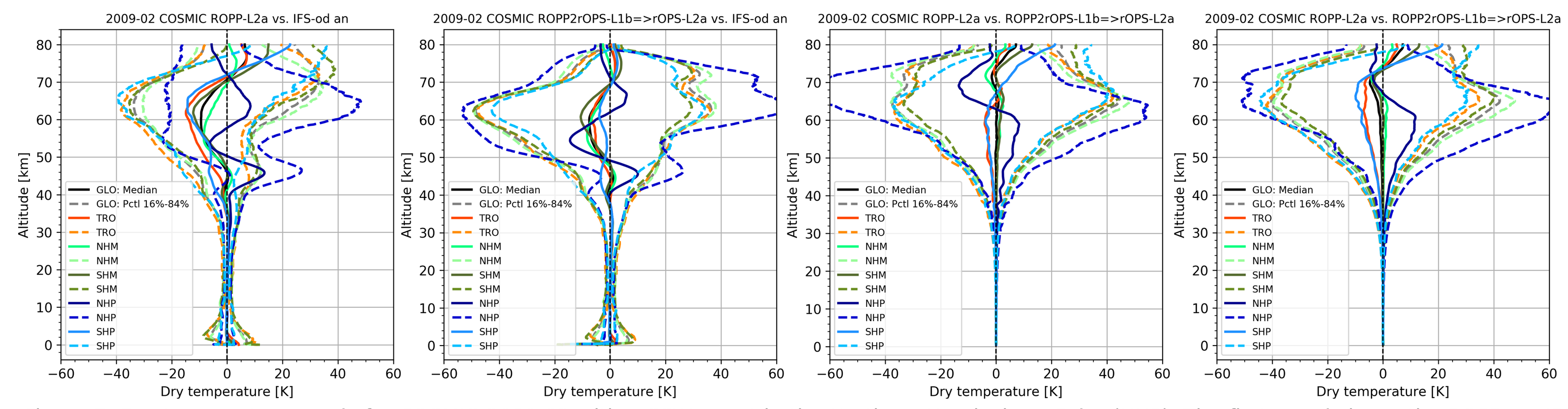

Figure 7: Dry temperature resuls for COSMIC 2009-02 with a SSW event in the Northern Hemisphere Polar (NHP). The first panel shows the ROPP vs. IFS-od an, the second panel the HAI-in vs. IFS-od an, the third ROPP vs. HAI-in and the fourth ROPP vs. HAI-in BAROLIM-init dry temperature differences.

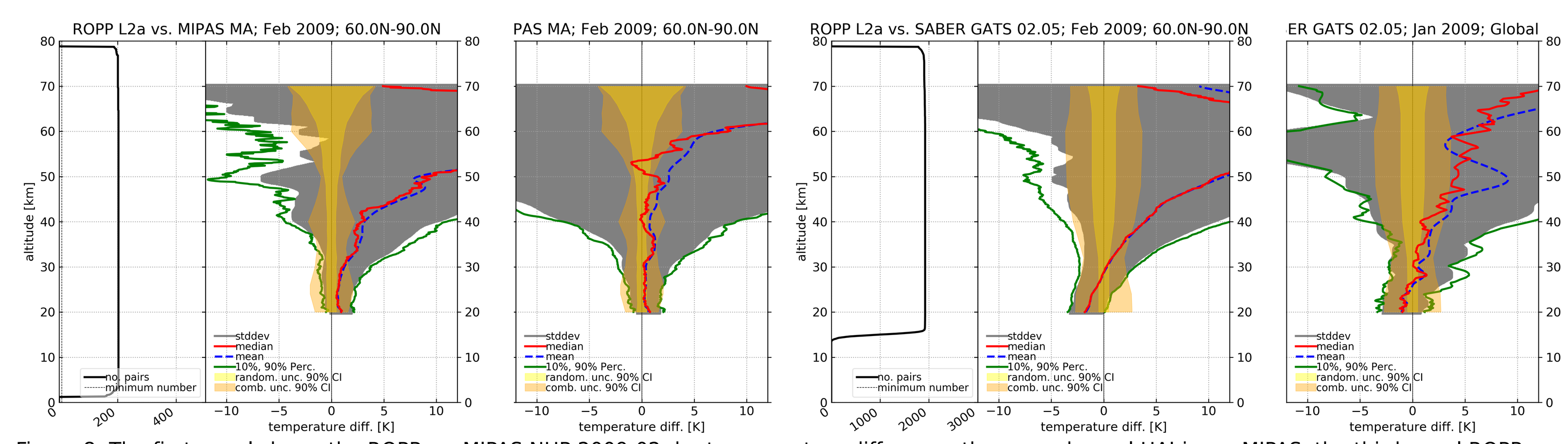

Figure 8: The first panel shows the ROPP vs. MIPAS NHP 2009-02 dry tempearature differnces, the second panel HAI-in vs. MIPAS, the third panel ROPP vs. SABER and the fourth HAI-in vs. SABER.

References and Acknowledgments

[1] Li, Y. et al., Dynamic statistical optimization of GNSS radio occultation bending angles: advanced algorithm and performance analysis, Atmos. Meas. Tech., 8, 3447–3465, doi:10.5194/amt-8-3447-2015, 2015, [2] Li Y. et al., A new dynamic approach for statistical optimization of GNSS radio occultation bending angles for optimal climate monitoring utility, J. Geophys. Res., 118, 13022–13040, doi:10.1002/2013JD020763, 2013. *The work was funded by FFG-ALR (ASAP project ATROMSAF1).*