Author response to Referee Comments for: "Validation of first chemistry mode retrieval results from new limb-*imaging* FTS GLORIA with correlative MIPAS-STR observations"

Atmos. Meas. Tech. Discuss., 7, 12691-12717, 2014 (18 December 2014)

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We thank the editor and both referees for their kind cooperation, thorough comments and valuable criticism. Below, we provide our point-by-point answer to the referee comments. Page and line numbers refer to the discussion paper (*amtd-7-12691-2014.pdf*). In the following, we provide the original referee comments (bold letters) followed by our responses. Text added or modified in the revised manuscript is coloured in blue. For easy tracking of the modifications, we furthermore provide the modified manuscript in the attachment.

Response to Referee #2

Atmos. Meas. Tech. Discuss., 7, C4801–C4804, 2015 (03 February 2015)

The manuscript compares retrieval results from the airborne limb-imaging infrared Fourier transform spectrometer (FTS) GLORIA characterised by increased sampling with the airborne limb-scanning infrared FTS MIPAS-STR and in-situ measurements. The results were obtained during the GLORIA's flight aboard the high-altitude research aircraft M55 Geophysica during the ESSenCe campaign (ESa Sounder Campaign 2011) on 16 December 2011. The manuscript analyses data obtained in one of the two measurement modes while data from the other mode is published elsewhere (Kaufmann et al., 2015). Retrieved profiles of temperature, HNO3, O3, H2O, CFC-11 and CFC-12 are compared. Despite of the very good structure of the manuscript (it was really easy to read), please consider several points of criticism before final publication:

We thank the referee for the concise summary and positive statement.

The instrument to be validated with a better resolution (GLORIA) is compared with an instrument with poorer resolution. In principle, the comparison can be done on the resolution of the instrument with the poorest resolution. So the highlighted improvements in the resolution of the GLORIA actually cannot be validated in such a way.

As the referee correctly pointed out, we performed the validation on the lower resolution of MIPAS-STR. Statements on improved resolution of GLORIA are based on retrieval quantifiers (i.e. vertical resolution, derived from averaging kernels). For better clarification, we modified the abstract as follows:

P12693/L11: …directly. We validate the GLORIA results with MIPAS-STR based on the lower vertical resolution of MIPAS-STR and compare the vertical resolutions of the instruments derived from their averaging kernels. The…

It is even unclear if there are any improvements in the resolution of retrieved profiles in the context of information content. One can get such an impression looking on the large scatter of the GLORIA measurements. The results are not discussed with respect to retrieval errors of the involved instruments in necessary detail. Well, there is some mentioning of errors in Conclusions but without showing any number and discussing it previously. Averaging kernels and hence resolution values as in Fig. 3 depend, among other, on regularization constraints, so for a poor quality, oscillating profile, perfect averaging kernels and resolution are possible if weak regularization constraints are used. In other words the resolution plots are useless when plotted alone without additional information.

While our initial intention was to compare the retrieval results of both instruments (obtained from similar but not identical retrieval setups) “as is” and as compact as possible, we agree that additional information allows for a better interpretation of the discussed vertical resolutions. Thereby, a too weak regularization would be reflected by a high spectral noise error.

While a complete characterisation and error budget of the GLORIA observations at the state of the ESSenCe campaign is not available, we performed a limited error budget considering random (noise error) and variable (radiometric calibration and line-of-sight) error sources. We think that the error budget discussed below provides a realistic impression of the vertical resolution quality. We added the following discussion and figure (subsequent figure numbers were updated accordingly):

P12705/L2: …2.5 km). In Fig. 4, the corresponding mean profiles derived from GLORIA and MIPAS-STR are shown together with their standard deviations. Also shown are selected individual profiles of both instruments, measured at ~14:45 UTC. Errors bars of the individual profiles include the following random/variable error components: (i) spectral noise error (from noise covariance matrix), (ii) radiometric gain error (effect on retrieval result from 2% gain modification) and (iii) line-of-sight error (effect on retrieval result from line-of-sight modification of 0.7 arcmin). The error components were treated as 1σ-uncertainties and combined by the root of the square sum. Radiometric gain and line-of-sight errors are estimates based on the state of the GLORIA characterisation at the state of the ESSenCe. For MIPAS-STR, the same error budget was performed, with the only exception that for estimation of the line-of-sight error all elevation angles of the limb sequence were modified more conservatively by 1 arcmin. Spectral line data and cross-section errors were not considered, since the same spectral database and similar spectral microwindows were used for the MIPAS-STR and GLORIA retrievals. Thus, these errors are expected to cancel out in the comparisons between GLORIA and MIPAS-STR.

The mean profiles from GLORIA and MIPAS-STR agree mostly within their standard deviations. Their differences reflect the characteristics of the residual profiles between the smoothed GLORIA mean profiles and the MIPAS-STR mean profiles discussed in the context of in Fig. 3. For HNO_3, the differences between the GLORIA and MIPAS-STR mean profiles exceed the sum of the standard deviations between 13.5 and 16 km and hint on systematic errors.

While the mean and individual GLORIA and MIPAS-STR profiles shown in Fig. 4 have similar overall shape and comparable absolute values, the individual GLORIA profiles show a higher variability. The vertical sections where the differences of the individual profiles exceed the sum of the GLORIA and MIPAS-STR error bars have extensions of 0.5 km to a few km. The vertical structures in the GLORIA profiles exceed the amplitudes of the GLORIA error bars (and thereby the noise error) and hint on variability of the atmospheric scenery. Contributions from non-identified error sources however cannot be excluded. Horizontal variability of the atmospheric scenery along flight track also might play a role here, since the GLORIA hyperspectral image resulting in the shown vertical profile was recorded on a significantly shorter section of the flight track compared to the corresponding MIPAS-STR limb scan.

For HNO_3, the mean profiles from GLORIA and MIPAS-STR are in close agreement below 13.75 km, while a significant systematic bias is observed above. Both the GLORIA mean profile and to a higher extend the individual profile show a local maximum around 13.25 km. The maximum in the individual GLORIA profile exceeds the MIPAS-STR mean and individual profile as well as the GLORIA mean profile. Since the amplitude of the maximum significantly exceeds the GLORIA error bars, this structure can be interpreted as a structure in the vertical distribution of HNO_3. Overall, the vertical extensions of the structures in the individual GLORIA profiles shown in Fig. 3 and 4 are mostly plausible in context of their vertical resolution and error bars and hint on variability in the atmospheric scenery.

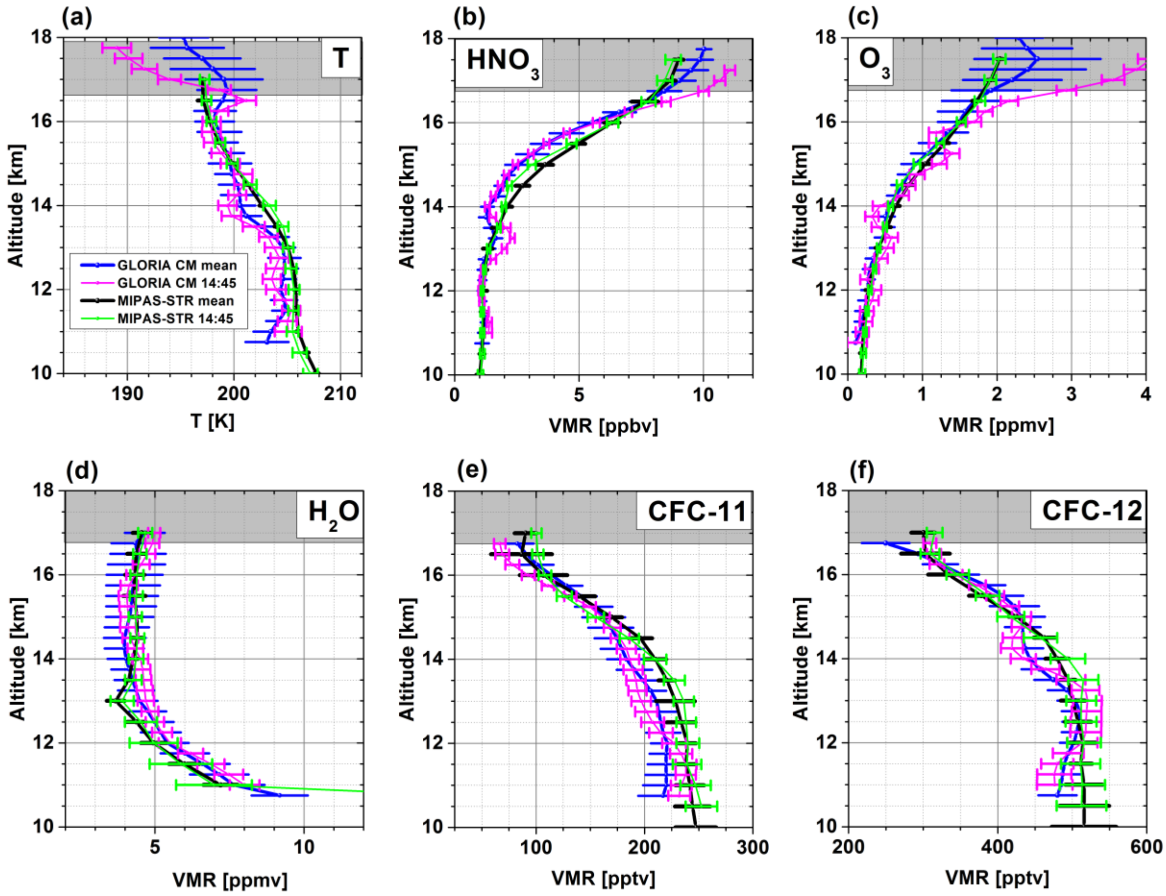

Figure 4: Mean and standard deviation of the GLORIA profles (blue) and MIPAS-STR profiles (black) shown in Fig. 3. Individual non-averaged profiles at ~14:45 UTC together with random/variable uncertainties for GLORIA (magenta) and MIPAS-STR (green).

During the flight much more measurements in the chemistry mode were performed (according to Fig. 1, in Kaufmann et al., 2015). Why only measurements between 14:30 and 14:50 UTC are selected for the comparison? An analysis of more time intervals could help to explain better the discrepancies between the instruments and the role of spatial variability of atmosphere, couldn't it?

As the referee correctly pointed out, more chemistry mode observations were performed during the discussed flight. However, only the chemistry mode observations in the discussed time interval were selected for complete level 1 and 2 processing after quality filtering (i.e. considering pointing stability, thermal stability, interferometer velocity stability etc.). In principle, it would be possible to also process limited data from other flight sections. However, the additional benefit of limited additional data of lower quality does not balance the considerable effort of processing and characterisation of these data in our eyes.

According to the objectives in the foregoing publications (e.g. Riese et al., 2014), 3D distributions by a tomographic retrieval with the new instrument are to be retrieved and analysed. Another paper (Kaufmann et al., 2015) by the same authorship as the current manuscript already implements a tomographic algorithm successfully for the dynamics mode. Is it not possible for the chemistry mode as well? I am therefore wondering why the comparison here is performed for 1D retrieval only; this 1D study possibly is with small use in the future because the other (tomographic) retrieval is the standard.

GLORIA has been operated so far in two different modes, (i) the chemistry mode (high spectral resolution/medium horizontal cross-track sampling) and (ii) the dynamics mode (medium spectral and resolution and extremely high cross-track sampling). Tomographic observations rely on rather high numbers of observations in combination with dedicated scanning patterns (azimuthal scanning) and flight patterns (e.g. hexagons). The fast and extremely dense GLORIA dynamics mode observations were tailored especially for tomographic observations and include azimuth scanning. The slower chemistry mode observations focus on observations of a more extended set of trace gases including minor species. Chemistry mode observations were not designated for tomographic mode so far and were performed in fixed pointing at 90° yaw direction. Therefore, a tomographic retrieval would not make sense here, and classical 1d-retrievals were performed.

Tomographic observations in chemistry mode are possible in principle. However, the effects and limitations of the lower sampling density on the achievable spatial resolution (and potential consequences for flight patterns) were not analysed so far. An assessment of the capabilities of tomographic chemistry mode observations (or a “hybrid-mode”) might be subject of ongoing work.

We furthermore mention that, despite their obvious advantages, tomographic retrievals require rather high computing capacities. Furthermore, the calculation of retrieval diagnostics such as averaging kernels, spatial resolution and error budgets are computationally extremely demanding. Therefore, we expect that classical 1d-retrievals will also play an important role in the future.

We added the following clarification and updated the reference by Kaufmann et al. (2014→2015):

P12694/L23ff: … sampling. The extremely dense dynamics mode observations include azimuth scanning and can be combined with dedicated flight patterns (e.g. hexagons) to enable tomographic retrievals. First results of GLORIA dynamics mode observations, including also tomographic retrievals, are reported by Kaufmann et al. (2015). The GLORIA chemistry mode observations reported here involved fixed pointing and aim on demonstrating the capabilities of classical 1d-retrievals of an extended set of trace gases enabled by the higher spectral resolution. …

I think the depictions selected in the Comparison section seem to be too positive. What is criterion to write that e.g. 10% is a "good" agreement for ozone (P. 12703, L18) and the bias for ozone is "weak" (I could say instead it is not)? Perhaps some acceptable ranges of agreement in IR FTS for different target parameters could be provided/cited or the use of such depictions reduced.

Reminding that this was the very first deployment of a complex new instrument involving a new detector and detection technique, we think that the agreement between the shown observations is indeed good and that our statements are applicable. Similar statements in context of airborne microwave and space-borne IR observations are made for comparable agreement e.g. in Castelli et al. (2013); Cortesi et al. (2007); Wang et al. (2007); Wolff et al. (2008) and other publications. We think that the agreement of the shown results is compatible with other results and statements in the literature and tend to leave our statements as they are.

Title and elsewhere in the manuscript: “new” – the measurements and the instrument are not new: the measurements are 3 years old (almost 3 years at the time of submission) and the instrument has already considerable publication history.

We would like to remind that the development and deployment of GLORIA as well and the level 1 and 2 processing of the huge amounts of data were performed by the same research groups with limited capacities. In context of the overall time period of the development and deployment of a complex instrument and the time required for data processing and analysis we think that the depiction “new” is still applicable (see also Kaufmann et al., 2015). Furthermore, the aim of the AMT GLORIA special issue as a whole is to present the “new” GLORIA instrument in many aspects.

P. 12697, L. 5: Quasi Newton method is a general term, i.e. what simplifications you introduce regarding 'quasi'?

This statement was formulated vague. We reworded as follows and added the reference von Clarmann et al. (2003) for more information:

P12697/L5: … determined by Newtonian iteration (von Clarmann et al., 2003, and references therein).

P. 12703, L18: The mentioned local maximum is not really seen in the Figure and the increase for few profiles could be explained also by retrieval errors. Again, retrieval errors for each of the instruments/in-situ observations are very necessary to be provided and discussed.

See above. Regarding the in situ instruments we added:

P12701/L10: … 2010). The accuracy of the FISH H_2O observations is 0.2 ppm and for the HAGAR CFC-11 and CFC-12 observations 0.6 % and 0.3 %, respectively (von Hobe et al, 2013, and references therein). The estimated error of the Geophysica temperature sensor is 2 K between 10 and 20 km altitude. …

P. 12703, L22: Writing that GLORIA profiles scatter around MIPAS-STR profiles is not correct: at 12.5, 14, 14.7 km I see only one GLORIA profile above MIPAS (and this one as an outlier) but far more profiles below.

We rephrased more accurately as follows:

P12703/L22: ... show on average slightly lower values than MIPAS-STR…

References: perhaps you might add the available web links for proceeding papers: Hoepfner et al., 2001: http://www.imkasf. kit.edu/downloads/ffb/IRS2000_proceedings_hoepfner_1.pdf; Kaufmann et al., 2013: https://earth.esa.int/documents/10174/134665/ESSenCe_Final_Report

Done.

Fig. 3. The many profiles overly so dense that it is hard to guess their distribution pattern. Please include mean of all profiles for both FT instruments and indicate their scatter range (standard deviation).

We followed the recommendation of the referee and included mean and standard deviation (separate new Figure 4, for better clarity; see above).

Response to Referee #1

Atmos. Meas. Tech. Discuss., 7, C4946–C4948, 2015 (21 February 2015)

The paper reports the results of the comparison between retrieval products obtained by the limb-imaging FTIR spectrometer GLORIA and the MIPAS-STR limb scanning infrared FTS simultaneously flown on board the stratospheric research aircraft M-55 Geophysica during the ESSenCe flight in the Arctic polar vortex on 16 December 2011. The focus of the article is on the first deployment of the new limb-imager GLORIA, here operated in the chemistry mode, and on the opportunity offered by the comparison with the MIPAS-STR conventional limb sounder to evaluate on the field the innovative capabilities and performances of GLORIA. As properly pointed out by the authors in the introduction, the work makes a substantial contribution in the context of an on-going process of development and consolidation of an instrument belonging to a novel generation of atmospheric FTS. A valuable piece of information added by the results of the comparison is the demonstration of the improvements made by GLORIA in terms of horizontal cross-track sampling and vertical resolution.

The quality of GLORIA Level 2 data is evaluated for a number of atmospheric targets simultaneously observed by MIPAS-STR, including temperature, HNO3, O3, H2O, CFC-11 and CFC-12. Validation of a subset of these products is also available from comparison against correlative measurements acquired by the in situ payload aboard the Geophysica aircraft: H2O by the commercial Rosemount sensor, total water by FISH, CFC-11 and CFC-12 by HAGAR.

The paper is well-written and organized and the main outcome of the first validation exercise on GLORIA data are presented in a compact manner with adequate technical details if regarded, as previously specified, in the context of an on-going work, which is already planning for further improvements and testing.

I do not have any major remarks and I recommend the publication on the journal in consideration of the impact that the research work presented by Woiwode et al. might have in the current scenario of atmospheric remote sensing in Europe. Development, deployment and validation of new limb measurement capabilities of atmospheric temperature and composition is, indeed, especially relevant for the lack of operating or planned spaceborne observation after the end of the ENVISAT mission.

We thank the referee for this very positive and encouraging statement.

Technical corrections/minor changes I suggest to the current version of the paper before publication are listed herebelow:

- page 2, line 8: change “in-situ” to “in situ”;

- page 3, line 8, change “aims: The” to “aims: the”

- page 4, line 27, use a consistent spelling with page 6, line 25 (“nonlinearity” vs “nonlinearity”)

- page 5, lines 16, 20 and 21: change “a-priori” to “a priori”;

- page 5, line 31: “avoid” might be replaced by “minimize”, “limit”, “reduce”;

- page 8, line 28: change “AltitudeGas” to “Altitude Gas”;

- page 8, line 30: change “due the fact that the both the” to “due to the fact that both the”;

- page 9, line 16: change “due a higher” to “due to a higher”;

- page 12, line 5: why “unique”? Isn’t it better “first” (in particular, if we consider that at the end of the Conclusions section the authors highlight the fact that “a further simultaneous airborne deployment of the two instruments would thus be extremely helpful to check . . .”)?

- page 16, line 24: change “in- situ” to “in situ”.

We included all corrections and minor changes as suggested by the referee.

Further clarifications:

P12697/L16: …2007). CO_2-profiles were updated for the Arctic winter 2011/12 involving simultaneous CO_2 in situ observations by HAGAR (Riediger et al., 2000; Werner et al., 2010) aboard the Gephysica and considering the Mauna Loa record (see: http://www.esrl.noaa.gov/gmd/ccgg/trends/). …

P12706/L15: … performance, characterisation and calibration of the GLORIA observations from subsequent campaigns …

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