Review of manuscript amt-2015-131 "Preliminary validation of refractivity from a new radio occultation sounder GNOS/FY-3C" by M. Liao, P. Zhang, G.L Yang, Y.M Bi, Y. Liu, W.H Bai, X.G. Meng, Q.F. Du, and Y.Q. Sun

The manuscript discusses validation-results from the new multi-GNSS capable radio occultation sounding instrument GNOS, which is mounted on the operational meterological satellite FY-3C. The authors compare refractivity and bending angle profiles derived from GNOS data with data from MetOp/GRAS, COSMIC, and the ECMWF reanalysis ERA-Interim.

The results demonstrate that GNOS data are highly consistent with the other data sources and confirm the essentially bias-free and mission-independent nature of RO observations.

General comments

The quality of the paper has substantially improved compared to the initial submission. All essential suggestions of the access review have been addressed, including the request to compare raw bending angle profiles (rBA) of GNOS-GPS to the reference data sets (additionally to the refractivity profiles).

Unfortunately the choice of the reference data source (MetOp/GRAS only) and presentation style (e.g. different units) renders it impossible to draw substantial conclusions from the comparison, and the main potential benefit of the additional work has thus not been fully exploited:

1. It remains unclear whether the differences observed in the refractivity noise from 30 to 50km altitude (visible in Figure 6., right panel) are already present in the rBAs (if so, it would indicate that differences arise from the receiver or the bending angle retrieval), or not (which would indicate that differences might arise from the use of different statistical optimizations or refractivity retrievals).

The manuscript indicates (at p9023/L3-11) that the authors have drawn a respective conclusion (namely that differences in refractivity noise are already equivalently present in the rBA, i.e. before the stat.opt.), but it remains difficult to reproduce for readers. Therefore I strongly recommend the following changes:

1.1. Compare GNOS rBAs not just to MetOp/GRAS, but also to COSMIC.

Reasons:

- COSMIC has more occultations than MetOp/GRAS,

- a second reference data set can increase significance of an attribution concerning the origin of the differences.

I do not think the differences in orbit between COSMIC and GNOS, listed as arguments for a validation with MetOp/GRAS, will cause large deviations.

1.2. Ensure the method of comparison for the raw bending angle profiles is as analogous as possible to the one used for the refractivity profiles (use the same unit (i.e. %) for both, use the same timeranges for both, the same reference e.g. ECMWF for both, etc.).

2. Even if it is concluded that differences in noise are already present in the rBA, it is still unclear whether they are caused by the preceding retrieval steps (e.g. the bending angle retrieval), or rather by the lower SNR of the receiver.
You seem to realize this shortcoming yourself:
- at p9021/L2 you state "we think this discrepancy [stems] from the data-processing algorithm rather than [...] the instrument observation noise" while
- at p9023/L8 you state "this probably results in fewer occultations and lower SNR for GNOS [...]. This could aid in interpreting the discrepancy [...]"

In order to separate the two effects I suggest to estimate the GNOS-GPS bending angle noise at 60-80km (where the neutral atmosphere signal is very small). This can be done either by using an external reference (e.g. MSIS, or the NCAR Climate Model used by Schreiner et al. (2011)), or alternatively, if no such external source is available, by calculating the standard deviation of each rBA profile between 60 and 80 km, and then calculating the average std.dev of all profiles. The result could be compared to e.g. Fig 13. & Fig 14. in Schreiner et al. (2011).

Specific comments

- p9011/L6: Hajj et al. 2004 do not show that RO data is widely used in NWP, and even Kuo et al. 2000 only analyse/demonstrate the **potential** of RO assimilation. I would recommend to replace Hajj et al. 2004 by e.g. Healy and Thepaut 2006, Aparicio and Deblonde 2008, Cucurull and Derber 2008, and Rennie 2010).

- p9011/L7: I suggest to add the quote of the review paper Steiner et al. 2011 to Anthes 2011 (as it used to be in the initially submitted manuscript).

- p9011/L16: This is not accurate anymore, ECMWF and NCEP assimilate **bending angles** (e.g. Poli et al. 2010).

- p9011/L21: I suggest to add quotes to “assess the performance of the current radiosonde” (e.g. He et al. 2009, Ladstädter et al. 2015)

- p9013/L13: I suggest to add a quote to “Bernese software v5.0” (e.g. Dach et al. 2007)

- p9014/L9: Multipath effects are a phenomenon of the troposphere, why is wave optics applied **up to 25km**?

- p9015/L14: Profiles are rejected, if larger than 0.06 rad. Is this applied at a certain altitude range, or to the entire profile? If applied to the entire profile, rejections will probably happen mostly below the boundary layer, and could randomly reject (also high quality) profiles. The measure might also introduce a bias, by constantly rejecting profiles with larger bending angles/refractivities at low altitudes. Has this been tested?

- p9016/L5: "BDS B1 has not implemented open-loop tracking". Does the implementation of open-loop tracking really require changing the **transmitted** signal (and not just changes to receiver and processing)? Or is it merely a language issue: "Open-loop tracking has not been implemented for BDS B1 signals yet."

- p9015/L25: "This penetration is comparable to the GPS occultation." The whole paragraph is about GPS occultations. Do you mean comparable to GRAS/COSMIC?

- p9017/L1: are the products open for the public, the entire scientific community, or just parts of it?

- p9017/L13: Instead of using "cosmic2013" I suggest to search for and provide the ID of the reprocessing, do the same for MetOp/GRAS, and then call the datasets just "COSMIC" and "GRAS".

- p9017/L16: I doubt that COSMIC and GRAS use/are the **identical** type of sounders as GNOS.

- p9017/L24: Different time-ranges still appear confusingly often (p9017/L24: October 1st to November 30th 2013, Figure 10.: November 1st to December 31st, Figure 7.: "October to December 2013"). Unless seasonal effects or a particular sample size are important, I suggest to always stick to **the same** time-range. Exceptions should be clearly **indicated** (potentially they should be even **justified**).

- p9017/L20: The horizontal resolution of RO is often estimated to be ~300km, the spatial resolution of T255 is therefore very high...

- p9018/L23: Compared to the initial submission, various references to different daily numbers of profiles have been largely either clarified or removed, but there is still an unexplained discrepancy between Figure 1 (~ **400-450** daily refractivity profiles), and p9018/L23 (17509/60 ~ **300** daily profiles).

I suggest to add a table after the introduction of the time-range (p9017/L24), where all the numbers of profiles and profile-pairs used for calculations or plots are listed.

- p9018/L24: Add a sentence clarifying that the same procedure as for refractivity is used for the rBAs. E.g. "Raw bending angle differences, their bias, and standard deviation are calculated analogously" (only if ECMWF is used as reference also for the rBA comparison, else describe the procedure used)

- p9019/L9: The bias from 5-30km is -0.09% and therefore larger than the bias above 45km (-0.05%). This is counterinduitive… Maybe also explain once, how these biases are calculated (I assume through vertical averaging).

- p9019/L15: The reduced number of profiles might be a major source of the **bias** at high altitudes (the 1hPa level of **high-pressure** profiles is at higher altitudes then the one of low-pressure profiles). Potential remedy: consider cutting the plots off at 45km.

- p9019/L19: I suggest to also add the more recent Pirscher et al. 2011

- p9020/L1: “This shows better performance than GNOS GPS. We attribute this to the B2.” Very interesting result...

- p9020/L7: “the “good” performance of BDS below 5 km may be an illusory phenomenon. The sample size [**shown**] on the right panel of Fig. 5 [**decreases**] rapidly below 5 km.” Besides the language points, I have two remarks: 1. the sample size starts to decrease at 10 or 8km, rather than 5km. 2. the sample size at 5km is still ~1000 profiles, definitely sufficient to calculate mean and std.dev. The Beidu performance appears to be very good…

- p9020/L25: see comment at p9011/L6

- p9021/L1-3: see **general comments**.

- p9022/L15: “range of +/- 0.05”. Why do you use fractions, not %?

- p9022/L18: “representativity error due to time and space gaps”. See **general comments**. Your own test of time intervals (p9023/L2) showed that outliers are not sensitive to these (time) gaps.

- p9022/L24: at which altitude do you apply the 10murad quality check?

- p9023/L1-11: see **general comments**.

- p9023/L20: in Figure 9, consider merging rising and setting occultations (using different colors/linestyle) to one plot for GPS and one plot for BDS

- p9023/L21: delete **lower** (you show 0-12km)

- p9024/L17-22: It would improve the structure of the paper to include a slightly more detailed description of the Beidou-Satellites active in RO soundings in one of the first sections (e.g. in “2.2 The status of the GNOS products”).

Consider replacing Figure 10 by a figure similar to Figure 3 (but for BDS instead of GPS), including penetration depth in color. These two Figures could then be named 3a (GPS) and 3b (BDS), using the same time-frame (e.g. October 1st – November 30th 2013) for both figures. You could then eventually even delete Figures 2a and 2b.

<u>Technical corrections</u>

(For all language based recommendations please note that I am **not** a native speaker.)

- <u>Acronyms</u>: Ensure consistent acronym use: Introduce acronyms/abbreviations at the first occurrence of the full name/phrase to be abbreviated, then just use the acronym.

- <u>Captions</u>: Ensure captions of figures and tables are self-explanatory (e.g. unless the used time-range is the same in **all** the figures, it should be provided in each of the captions). The captions of e.g. Table 1. and 2. should include sample size, time range, units, the averaged altitude range, etc.

- <u>Datasets</u>: The reference data source, the ECMWF reanalysis ERA-Interim, is referred to differently throughout the text ("reanalysis", "analyses", "analysis", with or without "ECMWF"), I would recommend to use "ECMWF reanalysis" or even just "ECMWF" consistently. As common name for all candidate-datasets (MetOp/GRAS, COSMIC and GNOS) you could e.g. use the term "RO profiles" or "RO data", I do not think "ROs" is adequate. e.g. representatively for other parts of the manuscript: p9018/L15: "there are four pairs of ECMWF profiles and RO profiles"

- <u>Language: Articles</u>

Again and again throughout the manuscript articles are used or not used at the wrong places, and singular/plural are often interchanged. I recommend putting a special focus on articles and use of plural when proof-reading. e.g. p9010/L2-3: I would write: "[…] carrying out atmospheric sounding**s** since 23 September 2013. GNOS takes daily measurement**s** up to [...]".

- <u>Language: TYPOs, minor Errors etc.</u>

- Title: Preliminary validation of refractivity from **the** new radio occultation sounder GNOS/FY-3C

- p9011/L2: "[…] **self**-calibration, long-term **stability** and global coverage [...]"

- p9011/L6: "**numerical** weather prediction"

- p9014/L5: "developed at **ROM** SAF"

- p9014/L14-15: consider rephrasing… the ionosphere is (quite) independent of GPS signals, just the refraction of different GPS signals is different in the ionosphere

- p9015/L7: probably missing "**ECMWF**" before T639

- p9015/L16: replace "from the beginning of the events to" by "from the **raw measurement data** to"

- p9018/L10-11: "both the forward-**modeled** refractivity and the co-located observational refractivity are vertically logarithmically interpolated to the same altitude grid (with 200 m spacing from 0–50 km)."

- p9019/L16: replace **latitude** by **altitude**

- p9019/L17: replace **accuracy** by **precision**

- p9020/L13: consider rephrasing, it is not clear whether ECMWF or the RO missions are serving as benchmarks for GNOS.

- p9020/L16: "Including GNOS GPS, GNOS BDS, COSMIC and GRAS.". Line-colours should be explained in a legend, or in the figure caption.

- p9021/L27: "after combining L1 and L2, but before the **statistical optimization**"

- p9023/L3: "[…] **outliers** are not sensitive to it. Further, as the **profiles** are based on the **non-optimized** [...]"

- p9023/L23-27: need rephrasing, difficult to comprehend: e.g. "The mean and standard deviation of the differences in rising and setting occultations for GNOS GPS in the lower troposphere are similar, apart from a slightly larger negative bias below 2km for rising occultations. This demonstrates that rising occultations have the same ability to be tracked in the lower troposphere when open-loop tracking is implemented."

- Language: other points

- p9013/L3: "other affiliated information"

- p9019/L2: "4.1 Comparison of GNOS refractivity profiles with ECMWF, MetOp/GRAS and COSMIC"

- p9021/L26: "4.2 Comparison of GNOS raw bending angle profiles with MetOp/GRAS"

Full quotes of suggested literature:

Aparicio, J. M. and Deblonde, G.: Impact of the Assimilation of CHAMP Refractivity Profiles on Environment Canada Global Forecasts, Mon. Weather Rev., 136, 257–275, 2008.

Cucurull, L. and Derber, J. C.: Operational implementation of COSMIC observations into NCEP's global data assimilation system, Weather Forecast., 23, 702–711, doi:10.1175/2008WAF2007070.1, 2008.

Dach, R., U. Hugentobler, P. Fridez, M. Meindl:
Bernese GPS Software Version 5.0. Astronomical Institute, University of Bern, Switzerland, 2007.

He, W., Ho, S. P., Chen, H., Zhou, X., Hunt, D., & Kuo, Y. H.: Assessment of radiosonde temperature measurements in the upper troposphere and lower stratosphere using COSMIC radio occultation data. Geophysical Research Letters, *36*(17), 2009.

Healy, S. B. and Thepaut, J. N.: Assimilation experiments with CHAMP GPS radio occultation measurements, Q. J. Roy. Meteorol. Soc., 132, 605–623, doi:10.1256/qj.04.182, 2006.

Ladstädter, F., Steiner, A. K., Schwärz, M., and Kirchengast, G.: Climate intercomparison of GPS radio occultation, RS90/92 radiosondes and GRUAN from 2002 to 2013, Atmos. Meas. Tech., 8, 1819-1834, doi:10.5194/amt-8-1819-2015, 2015.

Poli, P., Healy, S. B. and Dee, D. P., Assimilation of Global Positioning System radio occultation data in the ECMWF ERA–Interim reanalysis. Q.J.R. Meteorol. Soc., 136: 1972–1990. doi: 10.1002/qj.722, 2010

Rennie, M. P.: The impact of GPS radio occultation assimilation at the Met Office, Q. J. Roy. Meteorol. Soc., 136, 116–131, doi:10.1002/qj.521, 2010.

Scherllin-Pirscher, B., Steiner, A. K., Kirchengast, G., Kuo, Y.-H., and Foelsche, U.: Empirical analysis and modeling of errors of atmospheric profiles from GPS radio occultation, Atmos. Meas. Tech., 4, 1875-1890, doi:10.5194/amt-4-1875-2011, 2011.

Steiner, A. K., B. C. Lackner, F. Ladstädter, B. Scherllin-Pirscher, U. Foelsche, and G. Kirchengast, GPS radio occultation for climate monitoring and change detection, Radio Sci., 46, RS0D24, doi:10.1029/2010RS004614, 2011.