Review for "GNSS radio occultation excess phase processing for climate applications including uncertainty estimation":

This paper "GNSS radio occultation excess phase processing for climate applications including uncertainty estimation" by Innerkofler et al. describes a new RO excess phase processing system including excess phase uncertainty estimation for Metop series satellites. The excess phase profiles derived with such system are compared against those from different processing centers with different POD and excess phase algorithms. The uncertainty estimation of excess phase thus can be helpful to trace the excess phase errors back to SI standard. The main purpose of such "reprocessing" of operational missions is to provide climate quality data records. First there indeed exist the needs in RO community for reprocessing of Metop A/B/C excess phase datasets for inter-center comparison so that the structural uncertainties in the dry temperature can be traced back to excess phase or observational level. There are CDR products from EUMETSAT ROM SAF, but their RO products are based on existing excess phase profiles from other processing centers. UCAR CDAAC also has different versions of RO datasets for the same missions. Second, determining the uncertainty of RO bending angle retrievals are often limited to local spectral width (LSW), which is hard to connect with the excess phase uncertainty. Thus this study, the excess phase processing with uncertainty estimation, is scientifically important and a significant contribution to GNSS RO community, not only because it can be used for quality control for excess phase profiles, but also because the excess phase uncertainties can be further possibly quantified to derive the bending angle uncertainties. Technically, the processing system uses improved GNSS/Leo POD solutions, follows the standard excess phase processing procedure adopted by other missions/centers but with rigorous quality control. It uses the zero-differencing clock bias removal algorithm which depends on the ultra-stable clock onboard the Metop-Satellites. The RO excess phase processing algorithm description is solid and covers all the related aspects. The quality control relies on the excess phase modeling, including geometric and atmospheric modeling, which is a significant step in excess phase algorithm. Overall, the excess phase processing of three three-months periods for Metop A/B/C shows successful reprocessing of Metop RO excess phase profiles, with uncertainty estimation, and within expected differences compared with datasets from other centers. The system can be used to generate a long time series for climate applications. Overall, this paper is well written and organized, with technical description in details, and presents the results clearly. The logic of the study is scientifically sound. The excess phase uncertainty estimation can be applied to other missions. I recommended this paper to be published at AMT after some minor revision.

I am little bit concerned the large difference in excess phase in lower atmosphere (Figure 15) from UCAR. What's the main reason caused the large difference in standard deviation/biases? Is this related to how the excess phase model and/or the filtering/smoothing algorithm used for excess phase processing? The author should explain that in depth. Is this a proof that the actual uncertainties maybe larger than proposed (e.g: the STD compared with UCAR at 3.5 km MSL is more than 40cm, but the uncertainty in excess phase is less than 4cm.)?

Though the excess phase uncertainty estimation is important, how this uncertainty can be translated into the Doppler shift and then into bending angle is not clearly mentioned. Some discussion on how the excess phase uncertainty propagates further into bending angle should be given for the cases given. After all, the bending angle or derived temperature products are the Essential Climate Variable.

Technically, the excess phase processing in this study seem ignored both the GNSS and LEO satellite attitude information, please explain in detail how this can affect the error budget in excess phase.

Figure 15, please explain why the STD profiles in figure 15 (e.g. left dotted line and right dotted line in any subfigure) are not symmetric even systematic bias approaches zero?

Minor Comments:

Line 63, Is excess phase measurement accuracy/uncertainty really SI traceable given the excess phase model used, the GPS bit time series used, and the cycle slip correction uncertainty in the lower atmosphere?

Figure 2, Are the attitude data belong to the auxiliary datasets from IERS? Aren't they provided by the mission operation?

Line 106, In table I, I believe the LEO attitude is important and should be labeled. It looks the usage of the LEO attitude is optional. But how could you convert the antenna offsets from space body frame to ECI without attitude/quaternion information?

Line 130, does this reconstruction include the POD phase/pseudo-range also (RINEX files)?

Line 138, I believe UCAR have a more specific data address (url) to point to the exact location of the datasets used.

Line 205, this has puzzled me. I think this is different from that used by UCAR. At the mean event time, the straight line may not be tangent to the WGS-84 ellipsoid surface. Unless the tangent point can be defined first and then the time difference (really small though) can be neglected. Please explain. How sensible the different profile location definition can affect the excess phase quality control (atmospheric modeling), especially at lower atmosphere?

Line 240, 'is used T and ln(p)', should be 'is used for T and ln(p)'? It would be better to give a reference for this interpolation scheme or a reason why these schemes are the best (e.g. ROPP manual compares different interpolation schemes). Different interpolation scheme can certainly affect how the bending angle bias look alike in different altitude.

Line 260, the angle ζ should be between the velocity vector and the leo position vector, please label correctly in Figure. 3.

Line 285, Carries phase can't be called phase pseudo-range, since the time measurements and phase measurements use different mechanisms in GNSS positioning techniques. It would be more appropriate to use its name 'carrier phase' than 'phase pseudo range.'

Line 337, Rewrite Eq. 5 to be consistent with Eq. 4, such as the ionosphere correction has opposite sign with atmospheric delay term, missed C in the third item in Eq. 5, inconsistent sign (+/-) between receiver/transmitter clock bias correction, etc.

Line 346-349, some terms are misleading. You do not need to correct the clock bias, but to remove it. the antenna offset needs to be calculated in the proper coordinate system and added to the mass center of the satellites. The distance is not between satellites, but between receiver and transmitter antennas (pcvs/or offset since pcvs may not be used here). Please rewrite accurately.

Figure 6 and from other context, why the LEO/GNSS satellites attitude input is optional? Are all the antennas offsets/pcvs defined in such a way that the attitude is not needed? How does this affect the error budget and excess phase itself? If attitude are not needed, you may also need to explicitly explain how the antenna offsets are applied.

Line 395-397, I do not understand the sentence ' common coordinate transformation from satellite body frame to ECI', isn't this the satellite attitude information (usually given as quaternions).

Line 410: Here the time delay correction does not consider the GNSS antenna offset. There is neglected time bias of about 2/C (assume GNSS antenna offset length of 2m) about 7 ns. Please justify how this affects the excess phase calculation with zero-differencing methods. For single differencing, this may be absorbed by differencing itself.

Line 436-437, down sampling of RS data to 50HZ, the authors used the 20 samples arithmetic mean. Please explain how the 20 samples arithmetic mean affect the cycle slips (if not corrected yet) especially for lower atmosphere.

Line 453, the Metop POD antenna are not designed to track high rate GNSS signals thus the single differencing may not be effectively used (as COSMIC does) with low rate POD antenna observations.

Line 505, Aren't the sampling rate defined at the receiver time with a constant interval? Please explain what caused the drift.

Line 549, what's the criteria to use 7.5 m/s.

Line 614, DLL already defined at line 310.

Line 619, please define the t_{bot}^{Dll} and t_{top}^{DLL}. This looks quite small. Given one minute of travel time in the lower atmosphere, the cycle slip error is only 0.001m=1mm? If this is true, how do you explain large excess phase difference in lower troposphere between different processing centers?

Line 655, Why does the Metop-C have less daily RO profiles than Metop-A/B?

Line 731-732, it is hard to follow what the authors talk about. Are they trying to compare the setting and rising differences in total profile numbers or to compare inter-center difference?