We thank reviewer for the comments.

Most of the comments have been responded in the short comments by Mi Liao and Sean Healy. So here we'd like to combine those responses as follows.

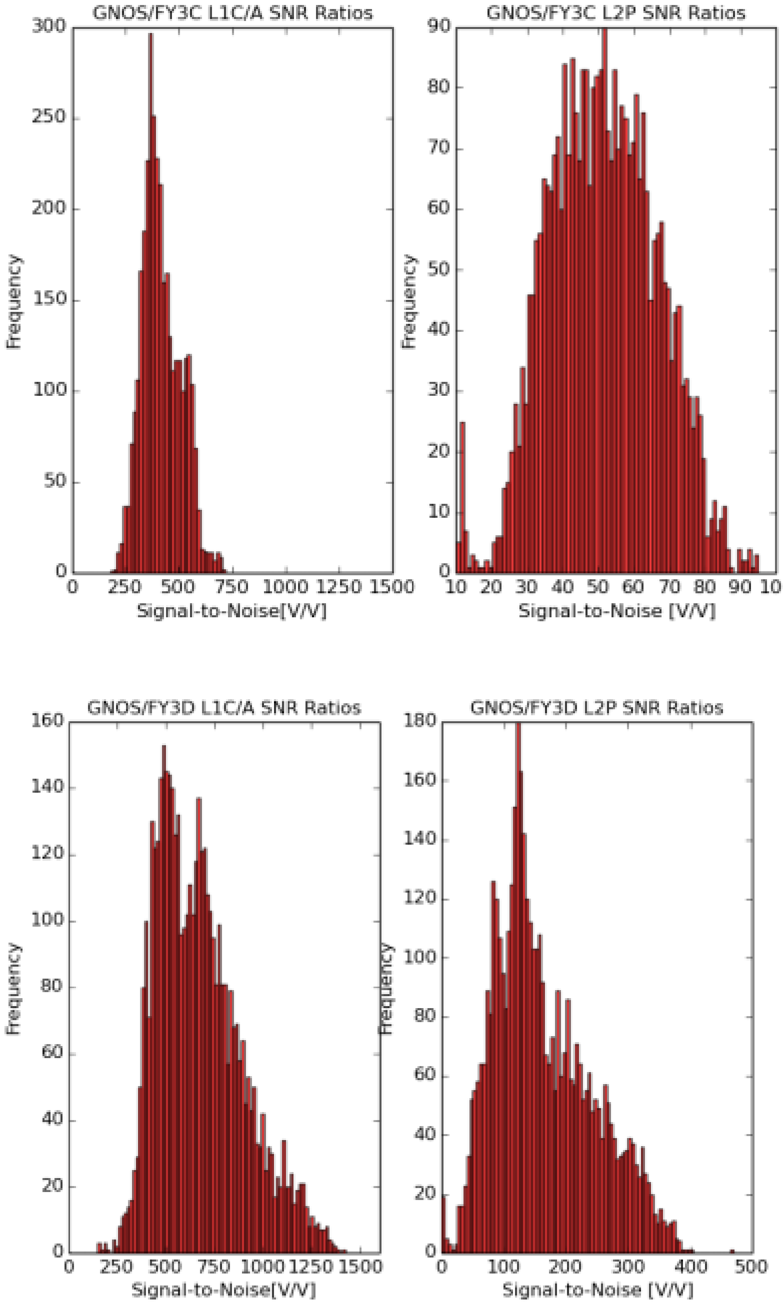
Responses to the specific comments

1) Introduction. The manuscript lacks motivation. Since the authors present a new methodology to correct the L2 signal bending, the "old" ROPP L2 signal correction approach should be described. Additionally, the differences between the "old" and the "new" approaches should be emphasized and discussed in detail. Currently, the reader cannot understand why the current ROPP approach does not work for the GNOS retrievals and all relevant references are missing.

A: Thank you for pointing out the problem. We will add the relevant references and additional discussion about the old and approaches to clarify the GNOS retrievals in the revised manuscript. In the response to the reviewer #2, we explain why the current ROPP approach does not work for the GNOS. Generally, the old approach requires the L2 penetrating down into 20km at least.

2) Introduction: P. 3; Line 30. "These biases are not seen with other RO missions." Yes, the L2 signal is weaker than the L1 signal. However, other RO missions do not lose L2 signal tracking that much high up in the neutral atmosphere. The authors should explain why GNOS loses L2 signal tracking in the stratosphere at ~ 20 km, unlike all other RO missions. The authors state that the most prominent quality issue was the large departures biases, in the vertical range of 5 – 30 km. This altitude covers the middle troposphere up to the middle stratosphere. Then, within this context, if GNOS loses 30% of the profiles below 20 km (see P. 5; Line 11), then the authors should explain how does GNOS contribute to Numerical Weather Prediction (NWP) and specify the most effective altitude range of the GNOS RO profiles.

A: The reason for GNOS losing L2 signal tracking is that GNOS has a lower SNR compared to other missions. Additionally, the GNOS antenna is smaller and not well located on the satellite. Consequently, we have to use additional cables, which results in a larger decrease of SNR than expected. Scientists from EUMETSAT confirmed that GRAS can get down to 15 km for more than 90% of the cases, but it is not the case for GNOS. Only 70% of L2 can reach below 20km. However, note that GNOS on FY3C is just the first Chinese GPS-RO mission. For the second satellite, FY3D, GNOS has more antenna units and in turn, has higher SNR than FY3C. Thus, the L2 signal tracking gets better. The proportion of the large departures biases in FY3D is smaller than in FY3C as well.


GNOS/FY3C L1C/A SNR Ratios
Frequency
Signal-to-Noise[V/V]
0
50
100
150
200
250
300
0
250
500
750
1000
1250
1500
GNOS/FY3C L2P SNR Ratios
Frequency
Signal-to-Noise [V/V]
0
10
20
30
40
50
60
70
80
90
10
20
30
40
50
60
70
80
90
100
GNOS/FY3D L1C/A SNR Ratios
Frequency
Signal-to-Noise[V/V]
0
20
40
60
80
100
120
140
160
0
250
500
750
1000
1250
1500
GNOS/FY3D L2P SNR Ratios
Frequency
Signal-to-Noise [V/V]
0
20
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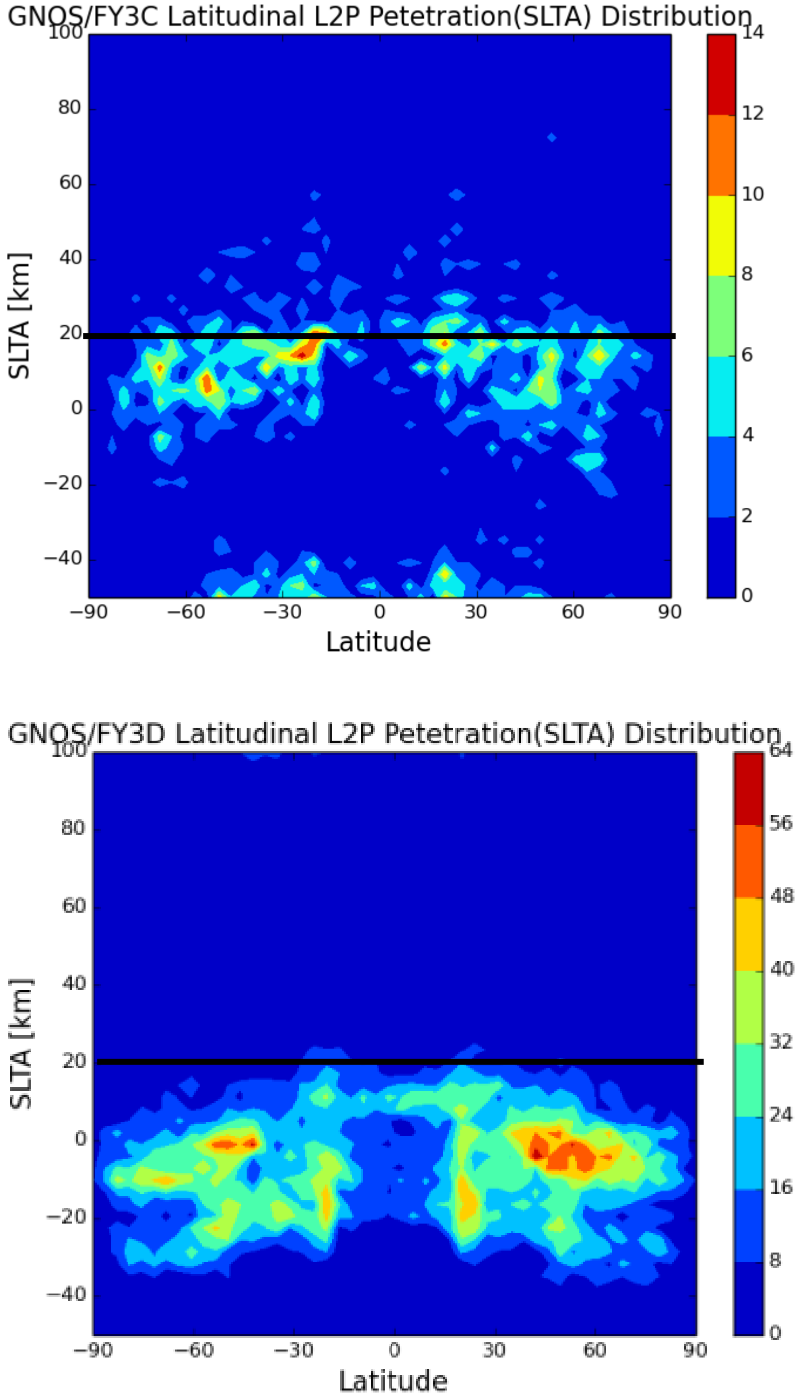

Figure 1

It is true that GNOS initially lost 30% of the profiles below 20 km, but that was before applying the new L2 extrapolation method outlined in the paper. After adopting the new method, we can process more GNOS profiles successfully. .

Regarding the impact on numerical weather prediction, GNOS was tested in the ECMWF assimilation system for the period November 23, 2017 to March 5,2018, prior to operational assimilation in the ECMWF system in March 2018. GNOS is assimilated operationally in the impact height interval from 8 km to 50 km in the extra-tropics, and from 10 km to 50 km in the tropics. Although the medium-range forecast scores were generally neutral, in the short-range, the assimilation of GNOS data clearly improved the fit to other GPS-RO data, such as Metop GRAS A,B GRAS, COSMIC-6 etc. Figure 2 shows the improvement in the GPS-RO departure statistics for short-range forecasts when GNOS data is assimilated. This Figure could be added the final manuscript, but the main focus of the paper is how the current operational FY3C GNOS data is processed, rather than the impact in NWP systems.

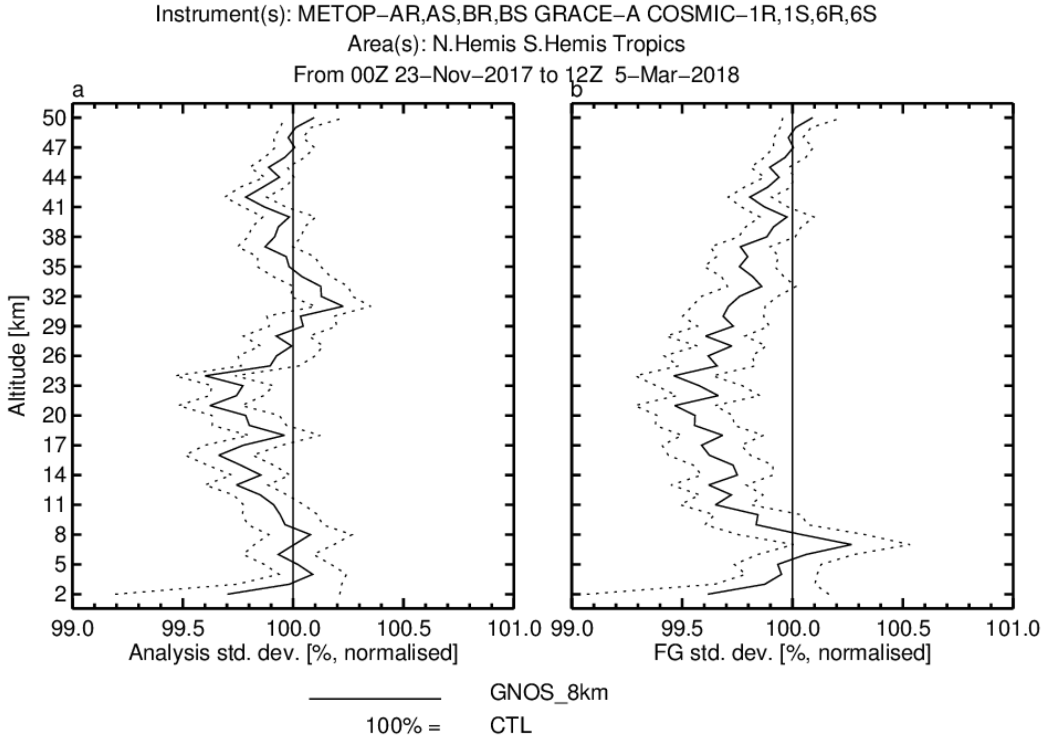

Figure 2: The percentage change in the GPS-RO departure statistics as a result of assimilating the GNOS measurements. The change in the standard deviation of the background (o-b) departures are on the right, and the analysis (o-a) departures are on the left. The statistics are globally averaged, and the dotted lines indicated 95 % statistical significance. Values less than 100 % on the left hand side indicate that the short-range forecasts fit the other GPS-RO data more closely as a result of assimilating GNOS.

3) New L2 extrapolation: Equation (3.4) states that the bending angle in L2 frequency equals the bending angle in L1 frequency plus a correction factor, which is proportional to the ionospheric TEC. The problem in Equation (3.3) is that it is derived using Equation (3.2), which is valid only for ionospheric bending and not for neutral atmosphere bending, as specifically mentioned in Culverwell and Healy (2015). Within the neutral atmosphere the ionospheric bending becomes negligible and the signal bending at tropospheric and stratospheric altitudes has an exponential dependency on the impact parameter – different than Equation (3.2). Therefore, how could the authors apply Equation (3.2) to correct for the L2 bending angle within the neutral atmosphere using bending angle approximations derived for ionospheric bending only – particularly when applying this method from the lowest altitude the L2 signal is lost and 20 km up with a maximum upper limit of 70 km that is around the bottom side of the ionospheric D layer?

A: As to this comment, Sean Healy gave a detailed response in SC1.

4) Equation (4.1): The Xso is estimated from the least squares fit between the observed L1 and L2 bending angles. Then again, the new noise_estimate the authors introduce defines a new statistical metric based on how close the Xso is to the observed L1 and L2 bending angle difference. But, the Xso was estimated in Equation (3.4) to fit the minimum bending angle difference in L1 and L2. This noise_estimate appears to be misleading, without physical underpinning and with an over-fitting nature that beats down the scatter. Additionally, P. 9; Line 8: “The physical meaning of noise_estimate is easy to understand.” Is not easy to understand and the authors should explain the rationale of defining it, because the Xso has already been estimated well via Equation (3.4). Also, how do the authors decide on the 20 microradiances as the threshold value?

A: The “noise_estimate” provides information about how well we are able to fit the L2-L1 bending angle differences in the in the fitting interval where we trust the data, using the retrieved value Xso. Hence, the noise estimate is the least squares solution cost function value, divided by the number of points in the 20 km fitting interval. The fitting model is physically based, albeit assuming a simple ionospheric model, as discussed below. If the fitting model can reproduce the L2-L1 bending angle differences accurately, we can use the Xso to extrapolate the L2-L1 differences below 25 km, to produce ionospheric corrected bending angles used for NWP applications. The 20 microradian threshold is empirical, but it is informed by the assumed bending angle error statistics used in the assimilation of GNSS-RO data. Typically, the assumed bending angle error is 1.25 % from around 10 km to ~32 km. For example, this translates into around 6 microradians at 25 km, increasing to 13 microradians at 20 km. The 20 microradian threshold is designed to screen out cases where the L2-L1 extrapolation could introduce significant additional errors. We agree that the “easy to understand” statement should be clarified and expanded upon. However, the “over-fitting” comment is not clear.

5) Section 4.2: The authors do not explain why is it necessary to monitor the performance of GNOS mean L1 and L2 phase delays in the height interval of 60 to 80 km. Also, why the mean phase and not the phase variation with altitude within this height range? What GNOS product is assimilated in NWP models and how does monitoring the 60-80 km phase delays help us to QC the profile below?

A: We take these phase delays as one of QC factors because empirically it was found to determine the performance of GNOS when compared with reanalysis data. When encountering the bad profiles, the rising L1 and L2 mean phase delays have small values. The result is only based on FY3C. Subsequently, when we look at FY3D, this phenomenon disappears. Thus this factor is not a general one. We are considering cutting this part of from the manuscript.

6) P. 10; Line 21: “...these have been tested with one day of data...” The statistical sampling used in the determination of the statistical performance of the QC methods is low and does not represent the statistical performance of the GNOS profiles around the globe and under different

seasons.

A: One day of data was used to initially estimate the various QC parameters and then these were tested over longer periods. Clearly, the new L2 extrapolation method is rather effective at eliminating the large errors for the longer period, globally (See Figure 13,14)The plot shown here is just an example.

7) Section 5: The authors explanation of the 15% disagreement between the GNOS and GRAS profiles below 10 km is inadequate. Ideally, collocated profiles between GNOS and GRAS should be used to quantify the degree of agreement or disagreement. However, if there are not enough collocated profiles between July 6 and August 2, 2018, perhaps the authors could use the entire time period GNOS provides RO profiles and if there are still not enough collocated profiles the authors could bin their profiles either into latitude sectors or seasons and then compare with GRAS to create an ensemble study to greatly increase the statistical sampling. The results represent a limited statistical sampling to support the authors' claims.

A: Statistics for matched occultations are routinely available from the ROM SAF web pages. See,
http://www.romsaf.org/monitoring/matched.php
An example for GNOS versus Metop-A GRAS is attached. The GNOS data presented on these pages is processed with the method outlined in the paper. However, we do not believe that the matched occultation statistics provide any additional information, relative to the bending angle departure statistics computed with an accurate short-range forecast.

Minor comments:
a) P. 2; Line 16: "...velocity and anti-velocity antennas..." Do you mean fore and aft antennas?
A: Yes
b) P. 2; Line 19: What is the GNOS inclination in Table 1?
A: The inclination of FY3C/GNOS is 98.75 °
c) P. 2; Line 17: Is BDS global or region constellation. Mention geographic restrictions of RO.
A: BDS both has global and region constellation. The distribution of BDS RO can be shown as follows, also it can be refered to Mi Liao et al.,2016

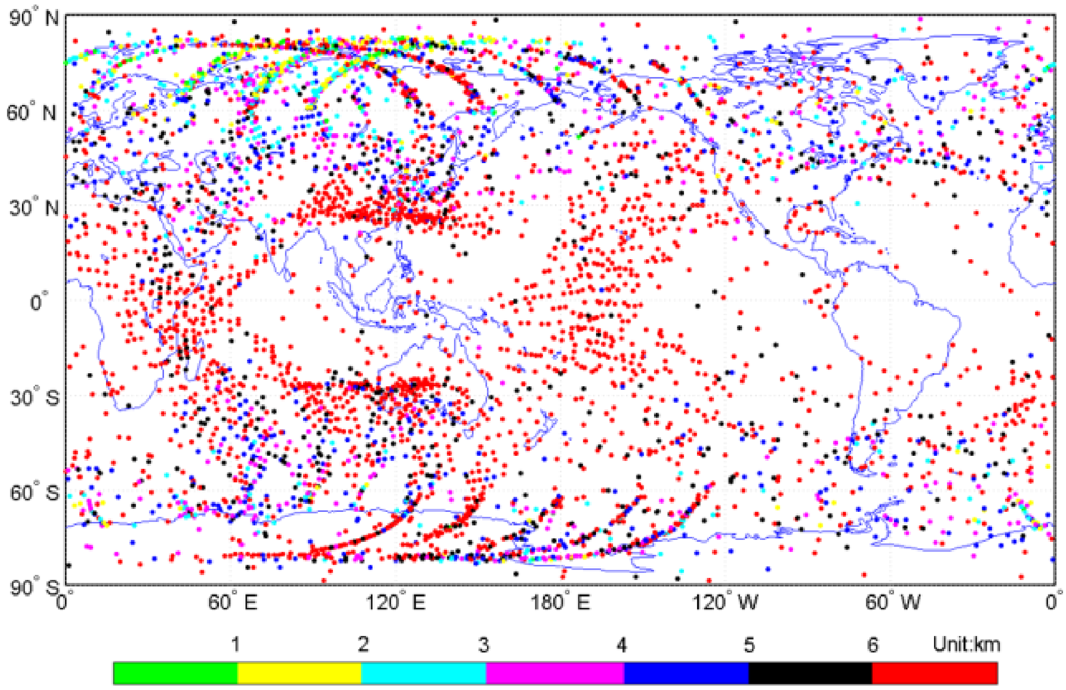

Figure 3. Map of the GNOS BDS occultation coverage from
1 November to 31 December 2013, with a total of 4648 samples.
Different colours indicate different penetration depths.

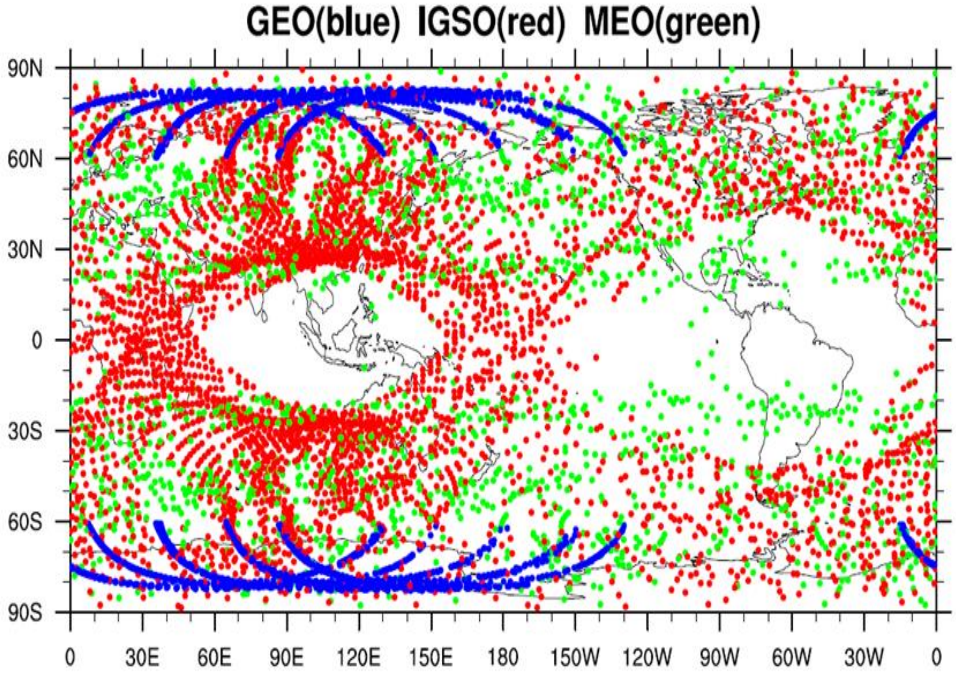

Figure 4. Map of the GNOS BDS occultation coverage
Different colours indicate different constellations. MEO have the same altitude as GPS.

d) P. 3; Line 22: “...departure statistics...” From what?

A: From background data, such as forecast data.

e) P. 3; Line 25: Why more than 20% levels of the profile? How was this threshold selected?

Explain.

A: Compared with background data, the bad profiles are defined as the mean biases greater than 10% (100*(O-B)/B) from 5km to 30 km. As we know that the bias of RO at that height is about 1% in normal case. If the threshold is set as 10%, the large departure profiles can be identified.

f) P. 4; Line 10: What is the most effective altitude range that GNOS provides the best RO profiles and explain how this information is used in NWP and how does it improve NWP. Include references to support claims.

A: Currently, there are no published papers talking about the GNOS in NWP. Only some technical reports from personal communications. However, see Figure 2 above.

g) P. 4; Line 14: "...may..." replace with "...could be..."

A: Fine.

h) P. 5; Line 11: Is this L2 signal loss at 20 km normal? Usually L2 signal is lost in the middle troposphere which is about 5 km. Explain.

A: This can be seen from my reply to your second major comment.

i) P. 5; Line 27: "...consistency..." replace with "...agreement..."

A: Fine.

j) P. 6; Line 5: Define "obvious errors".

A: Fine.

k) P. 6; Line 9: Define "other profiles".

A: Fine.

l) P. 6; Line 11: This definition of the ionosphere is crude, general, and unrealistic. Usually, the ionosphere is represented with multiple Chapman profiles with different scale heights. Mathematically, the Dirac function obtains a value of 0 at altitudes outside a very small neighborhood of the peak height.

A: The ionospheric model is crude, and it would not be valid if we were attempting to retrieve ionospheric information. However, we are only interested in modelling the impact of the ionosphere on bending angles with a tangent height well below the ionosphere, typically in the 25-60 km vertical interval. The ionospheric bending in this interval varies slowly with height (impact parameter). For example, adding a sporadic E layer would not change the *shape* of the L2-L2 difference curve below 60 km significantly. Conversely, we cannot retrieve an E-Layer from the L2-L1 differences below 60 km. Some authors assume that the L2-L1 is a constant. We use the delta function model because it produces a more realistic, slow variation of L2-L1 with height.

m) P. 6; Line 27: Why the peak height is 300 km? What led to this selection? The rule of thumbs says that per 100 km different in ionospheric shell height leads to 1 TECU error in the ionospheric total electron content. How sensitive is the estimation of Xso to the ionospheric TEC?

A: Xso should be proportional to the ionospheric TEC because the L2-L1 differences should be proportional to the TEC. However, we are not trying to retrieve the TEC here. We estimate Xso in order to extrapolate the L2-L1 differences below 25 km using a reasonable curve. We apply the Chapman layer ionospheric model. Statistically, the peak height is around 300km, see the

Culverwell and Healy, 2015 (ROM SAF). Experiments for testing the sensitivity of the peak height from 250km to 350km, in 10km increments, show that the final corrected bending angle is not sensitive to the peak height. The largest difference is about 10^{-5} urad. The plot (not shown here) is hard to differentiate the different results. Thus we think the 300km is reasonable. This will be noted in the revised paper.

n) P. 7; Equation (3.4): This equation describes the ionospheric bending angle and not the neutral atmosphere. How can the authors apply this equation to correct for the L2 bending in the neutral atmosphere?

A: This can be found in the comment of SC1 by Sean Healy.