Responses to the referees' reports on (MS#angeo-2020-3) "Relation between the asymmetric ring current effect and the anti-sunward auroral currents, as deduced from CHAMP observations"
by Lühr and Zhou

We would like to thank the two referees for their effort in carefully reading the manuscript and for making constructive comments. We are pleased that both of them regard the study as relevant and ask only for minor revisions. All their comments have been considered seriously and appropriate changes have been made in the revised manuscript. We are convinced that the paper has gained significantly by the revision. For the convenience of the referees, we first repeat below their comments and then add our responses in blue text. Major revisions in the manuscript are highlighted in bold face.

Referee #1

This manuscript studies average characteristics of anti-sunward net currents flowing in the high-latitude ionosphere (…)
The data analysis is sound and the results are very clear. However, previous studies reporting the similar results are completely ignored. The manuscript should refer to these studies and discuss their new findings. Also, there are some points to be clarified. The reviewer thinks that the manuscript is worth publishing in Annales Geophysicae after it is revised according to the following comments.

1. Similar previous studies
The anti-sunward net currents have been studied in detail by the following papers. These studies should be referred to in the introduction. It should be also discussed how the present results are similar to/different from these studies.
Iyemori (1990), JGG, doi:10.5636/jgg.42.1249.
Iyemori (2000), AGU Monograph #118, doi:10.1029/GM118p0331.
Nakano et al. (2002), JGR, doi:10.1029/2001JA900177.
Yamashita et al. (2002), JGR, doi:10.1029/2001JA900160.
Nakano and Iyemori (2005), JGR, doi:10.1029/2004JA010737.

Thank you for making us aware of the additional works of Japanese scientists on anti-sunward current studies. However, they are only partly relevant for this paper. All of the listed works make use of the magnetic azimuthal, *By*, component for estimating FACs and related anti-sunward currents. This approach depends on important assumptions and can only provide qualitative relations. Conversely, our ring integral of the along-track component is a more straight-forward approach that return quantitative values for the net current passing the polar region.
Even though, we now have made reference to these papers in the Introduction and Discussion sections.

2. Lines 207–226, Figures 4 and 5.
These sentences and figures do not focus on the sunward/anti-sunward net ionospheric currents and will confuse readers. The referee suggests omitting these parts.

We only partly agree with the reviewer's opinion. The reader first has to be introduced in the full distribution auroral net currents. It has to be made clear that the dawn to dusk net currents across the polar cap are dominating the distribution (Fig. 4). The anti-sunward component, of interest here, are just a secondary constituent.
For these arguments we prefer to keep Figure 4, but drop Figure 5 and the related text.

3. Tables.
(a) There are four tables, each of which contains a lot of numbers. Although Tables 2–4 include important results, it is very difficult to understand what they show. With these tables, readers cannot follow section 6. These data should be displayed in figures (instead of deleting Figures 4 and 5 as suggested in comment 2).

We largely followed the suggestion and significantly revised and improved Section 6 about the ground-based observations. Now the new Figure 10 displays the mean H component deflections on the dawn and dusk sides during disturbed periods at the 5 considered observatories separately for the seasons. Except for Wingst quite consistent results emerge. By reanalyzing the ground-based data, we have put more emphasis on determining the quiet-time backgrounds and removed spikes and jumps in the data. Numerical values for the mean dawn and dusk field values are listed in Table 2 and shown in Figure 11.
The new Table 3 lists the resulting dawn/dusk differences at the observatories separately for the seasons. The mean levels of magnetic activity, listed in Table 4, are needed for a proper interpretation of the derived asymmetries.
Overall, we are convinced that the manuscript gained significantly from the revision of the ground-based observations.

(b) In Tables 3 and 4, some numbers do not match, although they are expected to be the same. For example, Hermanus in December has 0.62 and 0.6 in Table 3, but Hermanus in local winter has 0.76 and 0.77 in Table 4 (other stations have the identical values). Please confirm.

We are afraid, this is a misunderstanding. In the old Table 3 the ratios had been sorted by global seasons: June, Dec. etc. While in Table 4 values had been sorted by local seasons: summer, winter, etc. But this is of no concern any more with the new tables in the revised manuscript.

4. Lines 451–479.
These hanging paragraphs should be moved to a new subsection, probably, section 7.1 and the following subsections being renumbered.

We followed the suggestion and added a new subsection heading:
7.1 Dependence on season and solar wind input

5. Typos.
Line 41. closing –> closes
Has been corrected, thank you

Lines 383. UT –> LT

Here the time in UT is correct for representing the dawn and dusk observations. The observatories are located between 0° and 30° longitude. This is now mentioned also in the text (lines 402-402).

Line 541 week –> weak
Has been corrected, thank you

Referee #2

This paper by Luehr and Zhou, is a reworking of champ data to look into the ground signatures of the asymmetric ring current in relation to the higher latitude auroral currents. They determine a number of aspects of current closure relating to storm time conditions (defined by Em) which are indicated by event and statistical analysis. The results will be of interest to the community. It is a clear account and presents a convincing statistical analysis. I recommend publication but have the following minor comments the authors may wish to consider. These are not critical on publication.

1. I would suggest the authors clarify better their meaning of the terms 'summer hemisphere' and 'winter hemisphere' in the abstract. The term is clear in the discussion but not perhaps when reading the abstract for the first time.

Now we make it clearer in the Abstract that we are comparing currents flowing through the polar regions in the summer and winter hemispheres.

2. I wonder if Figure 1 can be made a little clearer. It is hard to grasp the first time.

We have tried to make our schematic drawing of integration approach in Fig. 1 a little clearer. Now the directions of integration are indicated by arrows in the two loops. Also, the caption gives a more detailed description.

3. The discussion of effects hinges on calculation of the total current. I realised this is discussed in detail in a previous paper, but since further assumptions have to be made, perhaps some indication on the possible error (e.g. missed current), depending on conditions and sampling, could be added.

Uncertainties involved in our approach of determining net currents across the polar region are now mentioned at the end of Section 2 (lines 204ff). The additional assumption in this work is the neglection of contributions from the central vertical path elements to the current estimate. Any deviation from that assumption will not change the resulting amount of net current passing the polar region, but it will just affect it partitioning between the dawn and dusk sides.
Furthermore, we have added uncertainty bars to the mean annual variations of net currents in the new Fig. 6 (line 263).