Reply on RC2

Filomena Catapano et al.

Author comment on "Swarm Langmuir probes' data quality validation and future improvements" by Filomena Catapano et al., Geosci. Instrum. Method. Data Syst. Discuss., https://doi.org/10.5194/gi-2021-17-AC2, 2021

1.Answer: We thank the reviewer for the accurate review and for expressing the interest on the subject reported in this paper. We found very stimulating and interesting comments on this report that we tried to address as reported in the following.

The reviewer's concern for the LP positions relatively close to the spacecraft, possibly within its plasma sheath, may very well affect the Te estimates. But for Ne estimates we had early on decided to rather use the ion current, obtained at a negative bias repelling the electrons. In this case, owing to the high orbital velocity of about 7.5 km/s, the existence of a plasma sheath around the spacecraft is less important. The current is simply determined by ions that ballistically hit the probes. O+ ions have an energy of about 4.8 eV in the spacecraft frame, and typically overcome the sheath potential. The data show that the ion current (and admittance) is relatively free from disturbances and spikes compared to the electron current at positive bias. Also the faceplate is kept at negative bias, Te or the spacecraft potential are not measured with it. Therefore the 16 Hz current is also "good" in spite of the plasma sheath. The downside of this approach is that we need to assume a fixed ion composition (O+), and have to ignore possible along track plasma drifts that would modify the effective spacecraft velocity. Such ion drifts would have to be relatively large to significantly influence the density estimate, but they actually may occur at high latitudes. Indeed a comparison with 16 Hz data, the "true" electron density, and other external density estimates show offsets that vary systematically. This could be related to the caveats above, and is under investigation (as projects within the SWARM DISC).

In a revision we will improve the description of the method and possible issues with it.

2.Regarding the title, I would suggest the following modifications:

Swarm Langmuir Probes' data quality validation and plans for future improvements

2.Answer: We are grateful for this suggestion that we kindly accept. The title has been modified accordingly.

 Reviewer's detailed comments

3.Line 2: « very accurate » needs to be quantified. One knows that LP measurements are not that accurate in absolute terms.

3.Answer: We agree with the referee's comment and we replaced "very accurate" with "in situ".

4.Line 4: Clarify the « operational use » that is being made of LP measurements

4.Answer: In that sentence operational was intended more as technical applications. An example of the technical application would be the development of some ionospheric models, or the usage of LP measurements as input for more complex data processing algorithms to derive other related quantities, as for example the ionospheric plasma irregularity index derived in L2 Swarm data products (IPIR). However we realised that the term "operation" is misleading and we replaced it with "technical".

5.Line 9: Replace « conduced » by « conducted »

5.Answer: We agree with this correction and we modified the word accordingly.

6.Line 9: Note sure that how the feed back from the user community is addressed in the manuscript. It should be noted that the intend to involve the feedback from the science community is excellent and will certainly contribute to the data product quality.

6.Answer: We completely agree with the referee that the users community feedback are essentials to improve the Swarm data product quality. Most of this feedback actually results in recommendations discussed at yearly Swarm Data Quality workshops which are used as a roadmap for future data processing algorithm evolution. To emphasise the importance of the feedback from the community we have added a relevant sentence.

7.Line 12: add « in the derived plasma parameters » after « improvements »

7.Answer: We agree with this suggestion and the sentence has been modified accordingly.

8.Line 17: I am wondering whether the accurate determination of the plasma parameters contributes to the improvement of the magnetic field measurement analysis? If not, please ignore my question, if yes it would be interesting to say a few words on the subject.

8.Answer: Currently, LP measurements are not used to improve magnetic field analysis. It had been suggested that a spacecraft plasma wake might affect the magnetic field measurements. But an early study showed that the differences between data from both magnetometer types on each Swarm satellite (VFM and ASM) are not strongly correlated with the density (they seem to be rather correlated with temperature variations caused by the sun shining on the booms).

9.Line 18: Replace « divers » by « diverse »

9.Answer: We thank the referee for this correction which is now implemented in the

manuscript.

10.Line 31: Rephrase « insights on the space weather »

10.Answer: We modified this part by using "brought more understanding". We thank the referee for that comment.

11.Line 33: Replace « reveled » by « revealed »

11.Answer: We actually removed this sentence from the new version of the manuscript because we realised that we were referring to a paper where EFI-TII data only were used.

12.Line 41: remove the comma after « mission »

12.Answer: Removed, we thank the referee for this correction.

13.Line 41: I doubt the word « climatology » is the right word. Would « meteorology » be more appropriate? as it seems related to space weather effects.

13.Answer: We thank the referee for this comment that actually brought to us the following consideration. The word "climatology" identifies the analysis of changes in ionospheric phenomena, while "meteorology" is generally intended as the study of these phenomena on a daily basis, in order to register the changes of the ionospheric parameters. This is a general definition which, even if it can be a little confusing, it is generally accepted by the community. For this reason we preferred to keep the word "climatology" in that sentence.

14.Line 42: add the word « performed » after « variations »

14.Answer: In agreement with the concept suggested by the referee we added the word "observed by" in that sentence.

15.Line 45: replace « this new statistics » by « This new statistical study »

15.Answer: We agree with this suggestion and we modified the sentence accordingly.

16.Line 47: Precise « Antarctic » which usually refers to the continent

16.Answer: We agree with this observation and we specified the region by using "southern polar cap".

Line 59: Provide a reference to the « PLASMA operational processor »

17.Answer: We thank the referee for this observation. We actually use the reference for the PLASMA processor algorithm in the sentence just after the one here mentioned.

18.Line 60: Is « PLASMA processor » the same thing as « PLASMA operational processor »?

18.Answer: We are grateful for this question that gives us the chance to specify the difference between the two. In line 60 we refer to the PLASMA processor algorithm, which is identified as the scientific code developed to process the data. The PLASMA operational processor basically consists of the implementation of the PLASMA processor algorithm in a dedicated server able to maintain a constant data flow and expected processing performance.

19.Line 61: add a comma after « research »

19.Answer: We agree with the suggestion that has been implemented accordingly.

20.Line 63: Precise if you refer to « data quality » or « Plasma parameters quality »

20.Answer: In that sentence we were actually referring to data quality, not strictly related to plasma parameters. As discussed in the other sections, an improvement in the data quality is for example the better data flagging method applied in the new baseline.

21.Line 68: Explain « admittance »

21.Answer: Admittance is a measure of how easily a circuit or device will allow a current to flow, which is the reciprocal of impedance. We have added this definition in the manuscript.

22.Line 69: Precise « given biases »

22.Answer: We thank the referee for this comment. Here, given biases are intended as predefined values of the voltage. However these values can be changed according to the operational requests or triggered to optimize the plasma parameter derivation. In order to not add confusing information and to not elengute this description much, we prefer to avoid further definitions and we simply used the reference of Knudsen et al 2017 for further details.

23.Line 71-73: The position of the LP sensor real close to the Satellite skin probably affects the accuracy of the spacecraft potential measurements (and probably to a certain extent plasma density and temperature) , as the LPs are most likely inside the plasma sheath of the satellite. The Debye Length of the effect should be discussed. This is a potential issue which is not addressed in the paper. Perhaps it was addressed in a

reference publication. Its impact on the accuracy of the plasma parameters measurements should be addressed in this paper.

23.Answer: We are grateful for this comment. Indeed, within a typical orbit the Debye length exceeds the probe-spacecraft distance at low densities, especially at high latitudes near the dark pole, in the mid-latitude trough/sub-auroral polarization streams and sometimes inside equatorial plasma bubbles. As already replied above, we think that the density estimates based on the ion current are not affected by the plasma sheath of the satellite. The estimates of Te and the spacecraft potential Vs could be effected, and this will be mentioned in the revised manuscript., citing relevant publications, e.g. Wang et al., (2015).

24.Line 74 (and 77): Replace « signal » by « current »?

24.Answer: We thank the referee for this observation. Here the signal is more intended as the response of the instrument during in situ measurements, while current can be considered as a derived quantity in a certain way. Thus we think it is more appropriate to maintain the word "signal"instead of replacing it with "current".

25.Line 78: replace « interfere » by « interfer »

25.Answer: Here we have to disagree with the referee, because interfere is more frequently used to intend some interference.

26.Line 82: What was the rationale for the gain switch between the two probes in 2019?

26.Answer: The rationale for probe switching was mainly to compare both probes. If their gains are equal, then their surface material is still different (TiN vs Au), and their position at the spacecraft. The effects of both might become more obvious if the gains are equal. The test has been done for a limited time in the solar minimum, when ADC overflows are relatively fewer. The comparison of the data has not yet been concluded.

27.Line 84-86: The sentence « Out of concern »… ; please discuss whether if there is a difference in terms of degradation between Au and Ti due to Atomic oxygen. Knowing the subject, I may add that, one of the concerns, was also the oxidation of TiN on ground.

27.Answer: We thank the reviewer for this comment. A laboratory test of an LP flight spare had shown that indeed the TiN surface contained some TiO, i.e. oxidation had occurred in the normal atmosphere. The PI of the LP on the DEMETER satellite, J.-P. Lebreton had expressed his suspicion that the DEMETER data were possibly affected by oxidation of Ti in orbit (oral communication). We decided to replace one of the probes, but because of already completed vibration tests we could not use a heavier material such as brass which is often used for gold-plating. Thus the only option was to gold-plate the Ti.

28.Line 87: Explain what « testing before launch » was made

28.Answer: We thank the referee for this comment. Well, we tried to verify that the Au would stick to the probe by baking the probe in an oven to more than 300 C and putting it in an ultrasonic cleaner. There was no possibility to test in an atomic oxygen atmosphere.

29.Line 90 and following It's rather hard for the reviewer (and will most likely be hard for the readers) to follow the meaning of all acronyms used. A list of acronyms would be useful.

29.Answer: We are grateful for this suggestion. However the manuscript guidelines recommended defining the acronyms in line through the manuscript.

30.Line 103-104. I am myself not aware of a previous use of the HM method in space. I am wondering how the set point of the applied bias signal (and its amplitude) is selected and adjusted as satellite potential must significantly vary along the orbit. I note that it is written that « Sweep mode data are not used in the PLASMA processor… ». Has a comparison of the plasma parameters regularly obtainable from the I-V sweeps and the HM method been made.?

30.Answer: The bias for the ion current and admittance is fixed (-2.5 V has so far always been used). The measurement cycle for the electron currents/admittances starts with iteratively finding the bias for a very small current, which is called "zero-tracking". The iteration starts from the 0-tracked bias of the previous measurement, and normally converges within a few iterations. To this 0-tracked bias a constant offset (0.7 V) is added to determine the bias in the region of the linear (or saturated) electron current. Current and admittance, i.e. slope of the I-V curve, at this linear bias is determined. Extrapolating with help of the slope the bias for the retarded electron region, the "knee" of the I-V curve, can be reliably obtained. All this is controlled by the LP electronics on-board. At ground we then have bias, current, and admittance in the three regions of ion, retarded and linear electron regions. From these Ne, Te, and Vs are estimated. The document https ://earth.esa.int/eogateway/documents/20142/37627/swarm-level-1b-plasma-processor-algorithm.pdf/bae64759-b901-d961-4d18-0a5b317f8c12 describes the algorithm in more detail.

We had hoped to merge sweep mode data with the HM results, but they differ causing "spikes" in the time series of Ne, Te, and Vs every 128 s when a sweep derived data point occurs. A comparison of sweep and HM mode data has not yet been published. The preferred strategy is to calibrate the HM data using external data sets as in Lomidze et al. (2018), and Smirnov et al. (2021).

31.Line 112: Replace « sessions » by « sections »

31.Answer: The suggestion has been implemented in the manuscript.

32.Line 115 and following Would it be useful to summarize in a table, the differences between the baselines 04 and 05?

32.Answer: We thank the referee for this suggestion. We added a table to summarise the main differences between the two baseline.

33.Line 129-130. Clarify « second shunt resistor ». What's the role of the first one?

33.Answer: We removed that sentence from the manuscript because it did not add any useful information.

34.Line 132: The sentence « In practice the values often differ which we suspect is because of the different probe gain » is problematic. The sudden jumps mentioned in line 135 should be further discussed. Also, statement in line 138-139 casts doubts on the accuracy of the measurements at the gain transition. It seems to point to the fact that the measurements performance in high and low gain are not fully understood, thus question the validation of the derived plasma parameters. It may be useful to look at this issue by looking at the regular sweeping I-V characteristics.

34.Answer: We thank the referee for this comment. We expanded the discussion on this point in the manuscript to explain that unfortunately, from our analysis, we do not have a conclusion yet that can support the observed difference between the two values.

35.Line 139 and following: Provide details on the method used to derive the ion density rather than the electron density. This should be supported by modelling the ion sheath in the vicinity of the LPs. Assumption the Ni=Ne at the LP location may be questioned.

35.Answer: We agree with the referee that the assumption of Ni=Ne may be not fully correct. Indeed, we are introducing on our algorithm the computation of both the variables Ni and Ne so that the users can have the possibility to compare the two and to use the two separately. This part of the algorithm is currently under development and we reserve to discuss the details in future works.

36.Line 147-148: « .. the region (singular) . ; are (plural) « . Correction needed.

36.Answer: Line modified according to the referee's suggestion.

37.Line 147: « Larger » than what? use « large «?

37.Answer: Line modified according to the referee's suggestion.

38.Line 176: Replace « where » by « were »

38.Answer: Line modified according to the referee's suggestion.

39.Line 178; add «, the » after « 05 »

39.Answer: Line modified according to the referee's suggestion.

40.Line 179: Add « the » after « gaps »

40.Answer: Line modified according to the referee's suggestion.

41.Line 186: replace « today » by a specific date

41.Answer: We replaced "today" with "onwards". Giving a specific date will reduce the data coverage with baseline 05, which will actually exist until a new baseline will be introduced.

42.Line 210: How « good » is good?. Quantify goodness.

42.Answer: We thank the referee for this question. However we preferred to remove the word "good" because it is always difficult to unequivocally quantify goodness.

43.Line 212: Add « the reader » after « refer »

43.Answer: Line modified according to the referee's suggestion.

44.Line 220. LP can't measure negative plasma densities!!!. The processing provides negative densities which obviously points to the limitations of the used algorithm.

44.Answer: We thank the referee for this comment. We modified the sentence to specify that the density derived from the data processing was negative.

45.Line 221: Are measurements invalid or is the processing invalid?

45.Answer: The processing algorithm returns invalid density data. We modified the sentence to reflect this aspect.

46.Line 230 and following Figure 8. Indeed, the correlation for the night side is low. Looking closely at the figure, I have explored in my own way the figure. There is a pretty good correlation on the night side for one of the lobes of the scatter point distribution. See figure below, where the red lines figure the 1:1 correlation.

On the day side, the correlation seems to be better for lower densities than it is for higher ones. In order to put forward a possible explanation, it would be required to know the nature of the surface coating of the FP, and be reminded of which of the LP is used (Aucoated or TiN-coated) for the figure.

The assumption that the plasma composition (O+ only) is relevant because the Ion density is determined rather that than Ne. It would certainly be useful to show as well the determined Ne (which is independent of the ion composition)

46.Answer: We thank the referee for this useful comment. For producing this figure we mainly used the density derived mainly from TiN probe. However, the densities derived

from Tin and Au probe are pretty much in agreement (not shown). Also the faceplate surface is made of Ti. Unfortunately, the algorithm to derive the actual Ne from LP data is under development. We reserve to present in a future work a similar analysis, as soon as the Ne data will be available.

47.Line 239-240. The statement: « the comparison between the LP and FP … » is not well supported by the Fig 8 results on the night side.

47.Answer: We added a few sentences in this section to clarify our findings.

48.Line 247-248. Indeed there a few anomalies which would need to be further worked in order to validate the plasma parameters. A clear statement on the validation and the validity of the determined plasma parameters would need to appear in the conclusions (and on the data server). I am looking forward to the description of the LP calibration measurements in baseline 06.

48.Answer: We thank the referee for this comment. We are indeed putting much effort to further improve the LP measurements.

49.Line 255-256. It would be needed to ascertain that the 20 000 K Te values are not a result of processor being out of limit (as is probably the case for the negative densities). A correlation between the derived spacecraft potential and the setting bias value of the applied LP bias waveform would certainly be informative.

49.Answer: We thank the referee for this suggestion. We are not reporting much details on this investigation because we do not have a clear conclusion yet, but we will certainly consider this suggestion for the ongoing investigations.

50.Line 267; It would be informative for the reader to provide the range of the specific solar illumination angle. For information I am aware of a paper (currently under revision, I cannot say more) that discusses LP « measurement peculiarities » at specific solar illumination angles at both the day-night and night-day transition. Providing the solar illumination range when the anomalies occur would be useful to the reader.

50.Answer: We thank the referee for this suggestion. However, as explained in the manuscript and in the previous point, we are not really sure about the source of this anomaly. For this reason, we think that reporting details that are not yet verified could be confusing to the reader. We reserve to discuss this topic more on a future work as soon as we will reach a consolidated conclusion.

51.Line 282. Earlier it is said that the LP calibration would be introduced in the baseline 06. What LP calibration are you referring to here in this paper?

51.Answer: We have modified this sentence specifying the calibration we were referring to.

52.Line 290. It's hard to assess the improvement made in baseline 05. A table comparing the baselines would help.

52.Answer: We agree with the referee and we added a table to summarise the main updates introduced in baseline 05.

53.Line 294-295: « plasma density measurements are more accurate during higher solar activity » I can't remember a discussion earlier in the paper that allows this conclusion. Please expand.

53.Answer: In order to not repeat the discussion, we have added the relevant Figure as reference.