Response to Reviewer #2

We appreciate your very meaningful comments.
It gave us a deeper understanding of what we overlooked and didn't take into account, which enriched the manuscript.

Section 1, paragraph 3
The authors introduce two methods to deal with polarized light. One requires a scrambler and the other requires a PMD. The discussion of the two seems asymmetric because the authors state GEMS does not have a PMD but there is no mention of the scrambler. The authors could mention that a scrambler is difficult to implement in large aperture instruments such as GEMS. There is at least a third method for dealing with atmospheric polarization, and perhaps more. sensor optics can be designed in such a way that they are relatively insensitive to the polarization state of the incoming radiation. The design can be aided by including a polarization compensator in the optical train. The purpose of the compensator is to offset the polarization sensitivty caused by the remaining optical train in the sensor. It is likely that such an approach was not practical or effective for the GEMS viewing conditions, but the authors should acknowledge that there are more than two approaches to reducing polarization sensitivity.

→ Thank you. We were only focusing on the two well-known methods. By presenting a third method, we were able to enrich the content. Also, as you suggested, we made an additional comment about the difficulty of implementation on large apertures like GEMS.

Section 1, paragraph 4
It may be clearer to say, "In terms of a similar approach the MODIS and VIIRS instruments also lack both scramblers and PMDs. Polarization characteristics are measured during pre-launch testing ..."

→ Revised, we have changed in manuscript as you suggested.

Section 1, paragraph 5
The first sentence is somewhat awkward. The authors say, "we describe a newly developed polarization correction algorithm" after summarizing the GEMS polarization correction approach in the previous paragraph. The wording of this first sentence implies that there is yet another, new, approach that is different than the one summarized in paragraph 3. It would be better to simply say, "we describe the polarization correction algorithm for GEMS."
In the second sentence the language is again unclear. Are the authors trying to say that the GEMS algorithm is unique for considering clear-sky conditions, or that older approaches only considered clear-sky conditions and the GEMS algorithm now considers partly clouded conditions? Please use a few extra words so there is no misinterpretation of what you are trying to say.

→ Revised. In order to avoid confusing expression, we revised it to be concise as you suggested. The second sentence was meant that the polarization correction algorithm takes into account the polarization error in the cloud region as well as the clear sky region by including the cloud retrieval algorithm. We have reorganized the sentence.

Section 2.2, line 126
Please define 'SMA'. Is it Scan Mirror Assembly or Scan Mirror Angle? The definition should be stated explicitly the first time the abbreviation is used.

→ Revised, it denotes “Scan Mirror Assembly (SMA)”. I wrote down the full word of the SMA acronym.

Section 2.2, line 130
The sentence beginning "However, since the signal ..." is difficult to understand. I recommend defining central position in a separate sentence to make this sentence easier to understand.

→ Revised, we have separated complex sentence expressions into two sentences.

Section 2.2
The authors treat the results of Figure 2 as the true polarization characteristic for GEMS. Yet these results may include the characteristics of the polarizer response as a function of wavelength. I do not expect the authors to know the details of the analysis performed by Ball, but they should acknowledge that the imperfect polarization of the source may not be fully accounted for in these results. It is not clear if the authors are saying the mirror coating and stray light represent features in the PF spectrum that have been captured or errors in that spectrum. The authors should clarify this. This is also a useful point in the paper to discuss why these features are so important. It is in fact the spectral dependence of the PF rather than the absolute level that affects the final science products. If the PF was a flat line at 1% or 2% the authors may not be considering a polarization correction at all. Are the retrieval algorithms not immune to wavelength-indpendent polarization sensitivity?

→ Revised. We clarified that we mean the spectrum of PF/PA polarization error with mirror coating and stray light. We further clarified that due to their non-uniform polarization characteristics, they respond with non-uniform intensity depending on the wavelength, which can lead to the performance of the retrieval algorithm.

Section 3.1, line 156
It would help the reader if they could see a figure showing the meridian plane and the instrument plane together. It is hard to visualize these angles and their coordinate frames based simply on the verbal description.

→ Revised. In the supplement, we have attached an image of the coordinate system that is transformed to define the reference frame in each part of the payload, even though the coordinate axis that defined the local meridian plane is not the same as the coordinate axis that defined the local meridian plane. (However, the details have been reinterpreted and simplified due to the confidential issues).

Section 3.1, final paragraph
This paragraph raises some questions about the GEMS polarization correction. If the LUTs require as independent parameters surface pressure, albedo, and trace gas concentrations, how are these derived at Level 1B since this product generally does not have such information? Some of

these parameters are discussed in the next section, but it is worth noting in this paragraph that the polarization correction uses preliminary estimates for these parameters rather than final retrieved quantities.
A single sentence is devoted to derivation of the surface pressure. This deserves as much or more discussion than the derivation of ozone or terrain height, and I recommend expanding the LER discussion in Section 3.3.2 to include characterization of the reflecting surface.

→ Surface pressure, albedo, and trace gas concentration, which are LUT configuration parameters, use the auxiliary climatological data. As mentioned in Section 3.3, total ozone amount is adopted from climatological data based on OMI data, surface pressure is conversed from the terrain height of ETOPO-2, and the cloud area is estimated through a separate retrieval algorithm. Surface reflectivity is from GOME-2 LER database. The process of deriving the surface pressure is estimated by converting it into atmospheric pressure by the barometric formula using Terrain Height data (ETOPO-2).

Section 3.3.1, paragraph 2
It is useful to cite the DOI for the OMI data. In this way you need not discuss the details of exactly which product you used (for instance, that it is from Collection 3). The DOI can be obtained from the GES DISC.

→ Revised. We cite the DOI for OMI data (http://doi.org/10.5067/Aura/OMI/DATA204) as founded from GES DISC.

Section 3.3.3, line 310
Simply say that the correction algorithm is not very sensitive to the reflecting pressure under cloud-free conditions and that use of a terrain height pressure results in a negligible error.

→ Revised. We additionally mentioned in the manuscript as you suggested.

Section 4.1
The second largest source of error in the polarization correction (after the GEMS characterization) is probably the VLIDORT simulation of TOA radiances. The authors provide no estimation of this error. Instead they assume the dominant error comes from simplifications in the model assumptions (used to generate the LUT). The LUT errors may be significant, but that does not mean the full VLIDORT simulation errors are negligible. Clearly, the results shown in the right hand side of Figure 7 represent an underestimation of these errors. I view this as a major flaw in this paper. Can the authors provide an independent estimation of the missing error? How much larger could the true errors be? There is a brief mention of aerosol errors toward the end of Section 4.1, and there is a limited discussion of model deficiencies in Section 5, paragraph 2. This is the kind of discussion I am talking about, and it needs to be expanded.

→ Revised, I agree that it is important to present the factors that cause polarization errors. The uncertainty caused by the simplification and interpolation of the LUT were quantified and presented. In addition, we presented the uncertainty by citing a paper that calculated the simulation error by benchmarking VLIDORT. (>0.1%)(Castellanos et al., 2018).the polarization errors caused by the use of LUTs did not affect significantly in defining DOLP and polarization angles. Perhaps, we think that the large factor of the residual error is the estimation error for the cloud surface pressure to input value to the LUT and the fact that aerosols are not considered. As you said, we have improved and refined the Discussion Section by adding parts that can be quantitatively presented about the factors that can cause these errors. This is same as follows comment for Section 5.2 below.

Figure 8 caption
It will be clearer to label these as polarization error rather than radiance difference. Using the term radiance difference leaves the reader asking: difference between what and what?

→ Revised, we have corrected expression as polarization error to avoid confusing the reader. We also corrected the labeling of the x-axis in the figure.

Figure 9 caption
The left vs. right description in the figure caption is reversed.

→ Revised

Section 4.1, last sentence
I am not familiar with the term "dump point." Please choose different terminology or explain what is meant by this phrase.

→ Revised, we totally agree that "dump point" is not a common phrase. We changed the wording to "raggedness points".

Section 4.2, first paragraph
Please consider rewriting or removing this paragraph. It lacks a point and seems out of place. The first problem is that it is not obvious to the average reader why SNR and shift/squeeze (not shist/squeeze) should be a consideration for the polarization effect. You do eventually explain the problem of wavelength registration, but in a complicated way. Please use simple statements such as, "The polarization and polarization corrections affect the spectral structure of radiances. Since the wavelength registration of each Earth scene relies on radiance spectral structure these results can be affected." Also, please explain the effect on SNR. The second issue with this paragraph is that the authors raise the problems but do not resolve them. How large are the errors in wavelength registration? How much is SNR affected? Is there anything that can be done to reduce the uncertainty? If the authors simply wish to say that these are problems to be considered then this discussion best belongs in Section 5 as 'future work'.

→ Revised. We agree with your suggestions. Overall, SNR is independent of polarization calibration. (We did mention that SNR error remains after correction because it is independent of polarization correction. Therefore, we removed the misleading SNR statement). The next main point is, as you said, the issue of wavelength calibration. As the polarization error (PF/PA) is a function of wavelength, it is necessary to allocate the wavelength value at the exact location. The polarization correction algorithm assumes that the wavelength calibration was done well in the previous L1B step, and the error due to wavelength calibration is difficult to calculate here. These points have been moved to Section 5 and simply mentioned, rather than being discussed in this section.

Figure 12 caption
To be clear, these are polarization errors prior to correction.

→ Revised. We clearly mentioned that the polarization error illustrated in the box-plot is the polarization error corrected by the polarization algorithm.

Section 4.2, second paragraph

This is an important discussion about how the polarization error can alias into diurnal variation in the data products. It starts off well, but ends up in the wrong place. The authors' conclusion is that it is important to apply the polarization correction properly. That is stating the obvious. It will be a more useful discussion if the authors can estimate the residual diurnal errors (after correction). For example, Figure 12 could instead be a plot of the radiometric uncertainty as a function of time-of-day. This requires the authors to have some idea of the uncertainties in the combined ground characterization + VLIDORT correction. As I have stated previously, the lack of such uncertainty is a major omission in this paper.

→ Yes, it would be obvious, but what I wanted to show with the actual GEMS data was that there was an unwanted polarization error that varied in diurnal variation, and wanted to quantify it. Due to our limited information, we do not know how much polarization error is actually contained in every pixel in the GEMS domain (we do not know the residual error after polarization correction). What we show in this section is the amount of polarization error that can be corrected with the information we have, and at least the polarization error included in the radiation amount can be corrected as shown. As for the uncertainty in the polarization error, as you suggested, we will quantify it more in Section 5 and discuss the possibilities further.

→ Yes, we missed the important point in this section at the end. We consider it important to suggest the possibility that diurnal variability in non-constant polarization error may affect the performance of L2 products. This is why it is important to do polarization correction, and it is necessary to analyze its effect in future L2 products.

Section 5, paragraph 2

The discussion here of areas of uncertainty in the polarization correction is very important. These uncertainties deserve to be quantified rather than simply listed. The reader cannot assess the validity of the polarization correction without some estimation of these uncertainties. I understand it is a lot of work to come up with reasonable uncertainties, but that does not mean the authors can ignore the issue. The lack of PF information as a function of SMA angle is a good example. The authors offer a plausible approach to improving the characterization, and it is understandable they do not include such improvements in this paper. But they should include estimates of the uncertainties as a result of the SMA spatial dependence. Even though the authors do not have access to the original test data, there are ways of estimating the degree of S and P polarization from a reflecting aluminum surface given the incidence and view angles. It's true that we do not know exactly how the scan mirror is coated, but the goal here is to bound the error rather than to improve the characterization.

→ Revised, As answered for Section 4.1 above, we discussed uncertainty a bit more in the Discussion section. If aerosol is not taken into account and clear skies are assumed, the actual atmospheric polarization state can be misunderstood as large, and then overcorrection. Along the same line, If the cloud surface pressure is estimated lower/higher than the actual value, the polarization effect can be over/under corrected. In addition, the factor of shift/squeeze of the GEMS wavelength is also mentioned here (since the polarization error of GEMS is a function of wavelength, it is important to apply the correction at the correct wavelength position). Based on the results of the BATC model (as below figure), the change in the polarization spectrum of 350 to 400 nm can increase up to 6 times (in the N/S direction). Assuming the model results, a maximum polarization error can be 0.4% (worst case). Then, the polarization error of ~0.3% can be remained even after correction with the polarization correction algorithm proposed in this study.

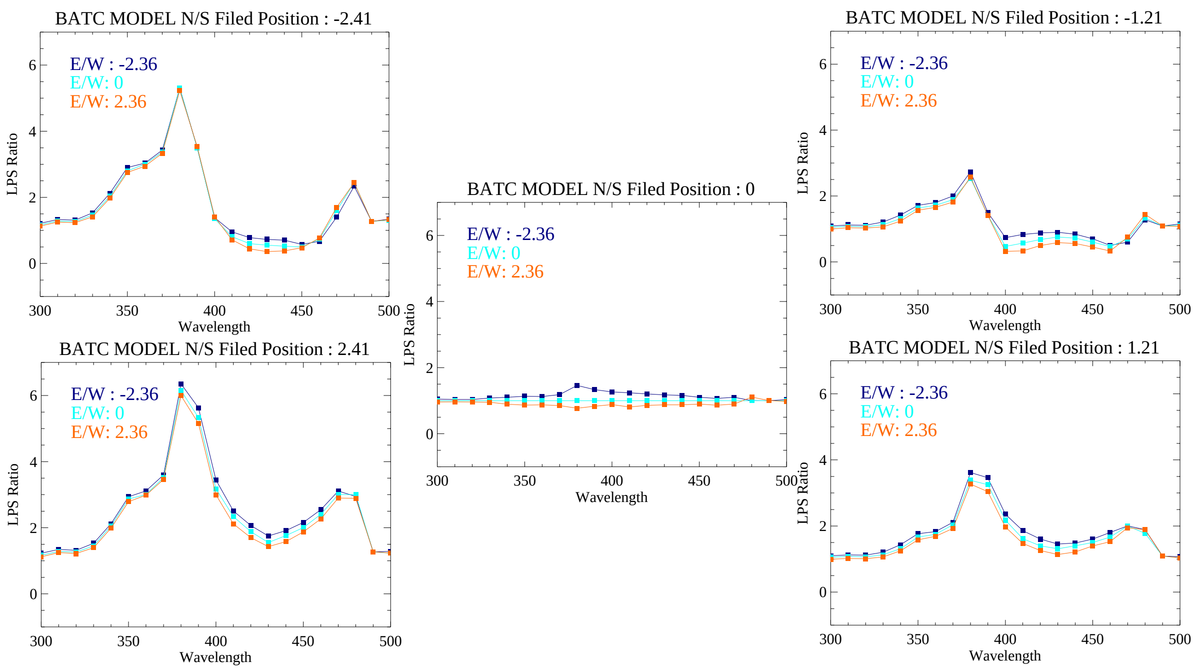

Fig. The variability of LPS(=PF) ratio with regards to E/W and N/S direction. The results are from BATC model. It didn't include in manuscript, but you can check it out for reference.

Section 5, paragraph 3

I cannot understand what the authors are saying here. Please rewrite this paragraph and simplify the sentences.

→ Revised. The wording of the sentence was a little unclear. Since the polarization characteristics are wavelength-dependent, it was said that the calculation accuracy could be improved by evaluating the effect of the presence or absence of polarization correction of the L2 product with respect to the spatiotemporal polarization correction effect. The sentence has been rewritten by simplifying it so that it is not complicated.