Reply (in blue) to Referee #1

We thank the referee #1 for the positive assessment of the paper. Our reply is included after the referee comments.

1. The paper describes a novel method to derive the geometry dependent Lambert Equivalent Reflectance of the Earth scene, which is an important parameter needed for the retrieval of trace gases. The method is shown to have many benefits over the use of a climatology, as has been used often for past missions. The introduction of the paper is well written and of good quality, nonetheless, the remainder of the paper is a bit thin when it comes to provide evidence of the improvements over existing climatologies. Only comparisons with OMI are given while there exists more climatologies based on other missions. Also the directional aspect of the GE_LER needs more validation. The paper covers new and interesting topics and techniques, and after the comments (some of which major) and corrections have been adequately addressed, the paper could certainly be published.

In the updated paper we include comparisons with OMI and GOME-2 LER

2. Although the paper stresses the importance of the inclusion of BRDF in the newly derived TROPOMI surface reflectivity, this is not the only factor that plays a role, and probably not the strongest factor. Since the radiation field in the UV is largely diffuse, the actual BRDF of the surface is not so important. The better inclusion of snow/ice areas and the higher spatial resolution probably play a stronger role. Please discuss this point, and try to separate the effects of the three factors: BRDF, snow/ice, and spatial resolution in the comparison of TROPOMI GE-LER with OMI-LER climatology. The improvement that is found in the TROPOMI total ozone retrieval in Fig. 11 when using the TROPOMI GE-LER instead of the OMI-LER is apparently due to the better snow/ice mapping at high latitudes, not to BRDF effects.

The reviewer is certainly right; in the UV the main improvements are from the accurate snow/ice retrievals whereas in the VIS the BRDF effects are stronger.

To better balance the different benefits from GE_LER we have:

- Remove BRDF from the title, the new title is “Applying FP_ILM to the retrieval of geometry-dependent effective Lambertian equivalent reflectivity (GE_LER) daily maps from UVN satellite measurements”
- Emphasize in the introduction and conclusions the advantages of retrieving daily surface properties (especially important for snow/ice conditions) with the same spatial resolution and the same fitting window as the trace gases.

3. Are the GE_LER data available to the community? Please specify whether and how you plan to distribute the GE_LER and G3_LER data products. In order for other people to reproduce your results and claims they need open access to the data presented in this paper.

The retrieved GE_LER and the G3_LER used for each single TROPOMI ground pixel will be included in the operational S5P total ozone product. All operational S5P products are open

and free available. We will discuss with ESA/EU the possibility of disseminating the G3_LER total ozone daily maps in the same way as the operational S5P products.

4. Which are the wavelengths for which GE_LER is retrieved? In the paper it is not so clear for which wavelength the results apply. For instance, only in the caption of Figure 6 this is mentioned.

As mentioned in the Introduction and Conclusions, the GE_LER/G3_LER algorithms can be applied to any wavelength region. The examples shown for S5P are for the total ozone fitting window and the corresponding wavelengths are given in the first sentence of section 4 "…using the fitting window of 325-335 nm".

Additionally we added the fitting window information for the S5P examples in Section 4.2 and in the Conclusions.

Specific comments

1 p1 The title is hardly readable due to the many acronyms. Please make the title clearer. In the rest of the paper the construction "FP_ILM GE_LER" is hardly readable. Can you think of a better name?

We simplified the title by removing the BRDF part. See the reply to the general comment#2

FP_ILM GE_LER together is indeed hard to read; in the updated paper we use only GE_LER.

2 p2 l16 These are not fundamental problems of a climatology itself, but rather information missing in the currently available climatologies. It would definitely be possible to create a climatology that includes the viewing angle dependency, or address separately snow and snow-free conditions.

That is correct, the sentence is reformulated to "common problems with typical LER climatologies"

3 p3 l15 The drawbacks mentioned for lookup tables are not very convincing, consider rephrasing this sentence.

This sentence reads now "The main drawbacks of look-up tables representing high dimensional RTM simulations (common in atmospheric composition retrievals) are that the memory requirements increase exponentially with the number of input dimensions, the interpolation/extrapolation in this multi-dimensional space are computational expensive, and the interpolation/extrapolation errors could be significant."

4 p4 l8 The smart sampling technique should be explained in a bit more detail because readers may not want to read the full paper referred to.

The following text is included in Section 2.2. “Training data is traditionally created at fixed intervals uniformly distributed for each input variable; as a consequence the training samples are grouped around the node points and a very poor coverage of the multidimensional input space is reached. Deterministic sampling methods provide a more uniform distribution of the training data covering the entire space of each input variable” and “For this work we select a Halton sequence that uses prime numbers for creating sample points in each input dimension and a radiative transfer model computes the corresponding simulated radiances”.

5 p4 l16 I do not understand this sentence: “Machine learning techniques perform best with low-dimensional datasets by avoiding the effects of the curse of dimensionality.”

This second part of the sentence “by avoiding the effects of the curse of dimensionality” is removed.

6 p5 l27 What about the azimuth dependence of \rho ? This also holds for other places in the paper. Please clarify in Sect. 2 how you deal with the solar zenith angle and relative azimuth dependence of the BRDF.

The following clarification is included in Section 3 “solar zenith angel dependencies can be ignored when combining GE_LER data from Sun-synchronous satellites over the same position because the angle of sunlight upon the Earth's surface is consistently maintained. Likewise relative azimuth angle dependencies are negligible in the UV.”.

7 p7 l9 How did you calculate the standard deviation, is it the based on all simulations in the validation training set? Figure 5 on page 22 seems to indicate larger errors (up to 0.01) for individual LER retrievals. What are these red error bars in this figure? How does this error propagate in the final accuracy of the trace gasses?

Correct, we use all simulations in the validation dataset.

The following clarification is included in section 4.1 “the x-axes are divided in bins and the mean and standard deviation (red bars) are calculated for each bin.”

The larger errors correspond to high SZA. The effects of LER errors on the trace gasses accuracy is discussed in the first sentence of the Introduction.

8 p7 l15 Why do you use Z as symbol for pressure and not P? Z can easily be confused with height.

Thanks for pointing out this inconsistency. The retrieval is actually based on surface height and not pressure. The symbol Z is correct, the text in Section 2 and 4 is updated.

9 p7 l21 The histograms presented in Figure 7 are not discussed in detail.

In chapter 4 we include a new section describing the comparison with GOME-2 and OMI LER.

10 p7 section 4.3 / Figure 9: This should become a separate main section, with a thorough and complete validation of the product. The comparison that is presented is not sufficient. Comparisons can be performed with a number of the surface LER -databases that were mentioned in the introduction (OMI, SCIAMACHY, GOME-2), but also with BRDF information from MODIS. Using MODIS BRDF would mean adjusting the retrieval to retrieve wavelengths of the nearest MODIS band. Can this be done?

The main focus of this paper is to present the algorithms for obtaining G3_LER and G3_LER, the results for S5P total ozone are shown as demonstration.

In chapter 4 we include a new section describing the comparison with GOME-2 and OMI LER.

The MODIS BRDF is available only in the VIS. As explained in the Conclusions, GE_LER retrievals in the VIS are planned for future work.

The differences have to be analysed properly. The difference plot in Figure 9(b) does not allow the reader to study differences on the order of 0.02, which is the typical difference/error one would expect for snow-free areas.

In chapter 4 we include a new section describing the comparison with GOME-2 and OMI LER.

11 p8 l2 "from the couple of days": how many days did you use?

This sentence is reformulated as follows "The TROPOMI G3_LER map for a given day is created by regridding (using a 0.1° x 0.1° resolution) the clear-sky LER data from the same day with the G3_LER map based on the LER data from previous days"

11 p8 l11 Figure 8 needs more explanation, what order polynomial is used, what do the blue error bars represent? Why do land, water and snow scenes all have more or less the same relative albedo (around 1.0 – 1.6)? Have you calculated this average using all global pixels? This implies that you have mixed different land types in the calculation of the average. How representative is the viewing angle dependency then for individual land types?

The data for each surface type are normalised relative to the central detector pixel (nadir) therefore the range is around 1. This explanation is included in Section 4.3 and Figure 8.

12 p8 l15 Please check which version of the OMI LER was used; the second version covers 5 years of data between 2005 – 2009, released in 2010.

The data used here are the 4 years data released in 2008. In an early stage of the S5P project we compared both the 2008 and the 2010 versions and found some systematic structures in the 2010 version especially in the 328 nm dataset. Therefore we decided to use 2008 version.

13 p8 Which field of the OMI-LER is used to compare with? Is it the "MonthlyMinimumSurfaceReflectance" field or is it the "MonthlySurfaceReflectance" field?

We use the MonthlyMinimumSurfaceReflectance field.

14 p11ff References: please put all references in alphabetical order.

Done

15 Fig 5 Did you also consider the sensitivity of the GE_LER error due to ozone profile assumptions?

We are using ozone profile climatologies organized as function of the total ozone (the total ozone and the ozone profile are strongly correlated). Therefore the sensitivity of the GE_LER to the ozone profiles is covered by the total ozone dependency.

16 Fig 8 What do you mean with "relative mean albedo"? Can you please also provide the GE_LER itself?

Please clarify, "relative mean albedo" is not mentioned in Fig. 8.

17 Fig 19 These maps are not very informative because the dynamic range is too large. Please choose a color scale and albedo range that provides spatial information on the distribution of surface albedo in the UV.

Maps updated