Response to RC2 by Dr. Ruediger Lang:

We would like to thank Dr. Lang for performing a thorough review and for the many helpful suggestions to improve our manuscript.

Below, we respond to each of the review comments. For the sake of clarity, the review comments are given in blue italics and our response is printed in normal font. Changes to the manuscript are printed in green.

The paper by Tilstra et al, Directionally dependent Lambertian-equivalent reflectivity (DLER) of the Earth's surface measured by the GOME-2 satellite instruments, presents the next evolution of the Lambertian-equivalent reflectivity (LER) surface databases, as derived from high spectral resolution grating spectrometers covering the UV, visible and towards the near and short-wave infrared spectral region. LER surface databases derived from such instruments have the advantage to provide their data at significantly more atmospheric window or well controlled absorption wavelengths, i.e. at higher spectral resolution, than the familiar surface databases derived from band imagers like AVHRR, MODIS, Meteosat, or Sentinel-3. However, up to now, the original LER approach assumed homogenous, non-directional reflection of the surface, which is known to lead to significant biases in particular in the backscatter direction.

The directional evolution of the LER surface retrieval approach (DLER), applied to the meanwhile considerable GOME-2 data record of more than 10 years from two Metop platforms at 9:30 LT and over an observation angle range of -55 to 55 degrees, is therefore a very significant improvement to the currently existing (and frequently used) LER databases (Tilstra et al., 2017). The results show that the anisotropy is considerable depending on surface types (in particular for vegetation), as is expected, and that at least for such surface types and at large observation angles the previously used LER databases introduces significant biases.

The paper presents a comparison to the principally more accurate bi-directional reflectance distribution function (BRDF) approach, e.g. as applied to MODIS observations, which however is limited in its available spectral resolution. The comparison of synthetic data from radiative transfer calculations shows a good correspondence between the two approaches above 500 nm improving towards longer wavelength. A validation comparing BRDF reflectivity values with DLER values for the MODIS 640 nm band confirms the significant improvements of DLER with respect to LER in the backscatter regime (West-viewing for GOME-2 daylight descending orbits).

The scientific results presented here are significant and will be of high interest to users of grating spectrometer data in the UV to near infrared. The paper is well written and I can therefore recommend it for publication in AMT, noting a couple of aspects for the authors to consider.

One of the main advantages using DLER (and LER) with respect to imager derived BRDF databases is its higher spectral resolution. While the comparison of BRDF and DLER values derived from synthetic Top-Of-Atmosphere (TOA) data identifies the spectral regime in which both perform similar and where not, the validation results of section 7 provides results only at 640 nm. A tabulated statistics of slope, intercepts and correlation wavelength at other MODIS wavelength (in particular towards the blue) would be very helpful for users to decide where to use or not to use DLER for their applications. In particular, since close to 50% of the provided DLER wavelength are in the <500 nm regime. In this respect, a comparison of DLER performance with respect to the frequently used combination of MODIS BRDF and spectral principle components provided *by the ESA ADAM surface reflectance database would be of value for follow on studies.*

The choice for 640 nm (MODIS: band 1 centred at 645 nm) was based on two considerations: (1) we need a MODIS wavelength band that coincides roughly with a DLER wavelength band, and (2) the wavelength should be longer than 500 nm because otherwise BRDF and DLER cannot be compared due to their different nature. The only suitable wavelength band meeting these two criteria is 640 nm (MODIS: band 1).

We have changed the text in the introductory paragraph of section 7 in the following way:

" We select MODIS band 1, centred around 645 nm, as a reference for the 640-nm wavelength band of the GOME-2 surface DLER database. The choice for MODIS band 1 is based on the fact that (i) it is close enough to one of the DLER wavelength bands, and (ii) based on the results presented in Sect. 3 we may expect only small differences between DLER en BRDF for wavelengths longer than 600 nm. "

For deciding whether DLER can be used as a BRDF for wavelengths below 500 nm it would be better to look at the results shown in Figure 4 of section 3.3. Because it would be very hard to isolate the "real" (theoretical) difference from the difference caused by other differences between the two databases.

Nevertheless, we have decided to add results from comparisons with other MODIS bands (at 555 and 469 nm) to the Supplement. These results are also shown here in Figure 1 of this AC.

We have added the following sentence to section 7.2 of the manuscript:

" Results for other wavelength bands can be found in Figs. S6 and S7 in the Supplement. "

Note that these additional figures for the shorter wavelengths were also requested by Reviewer 1 in RC3. Reviewer 1 also requested additional figures similar to Figure 8 in the manuscript.

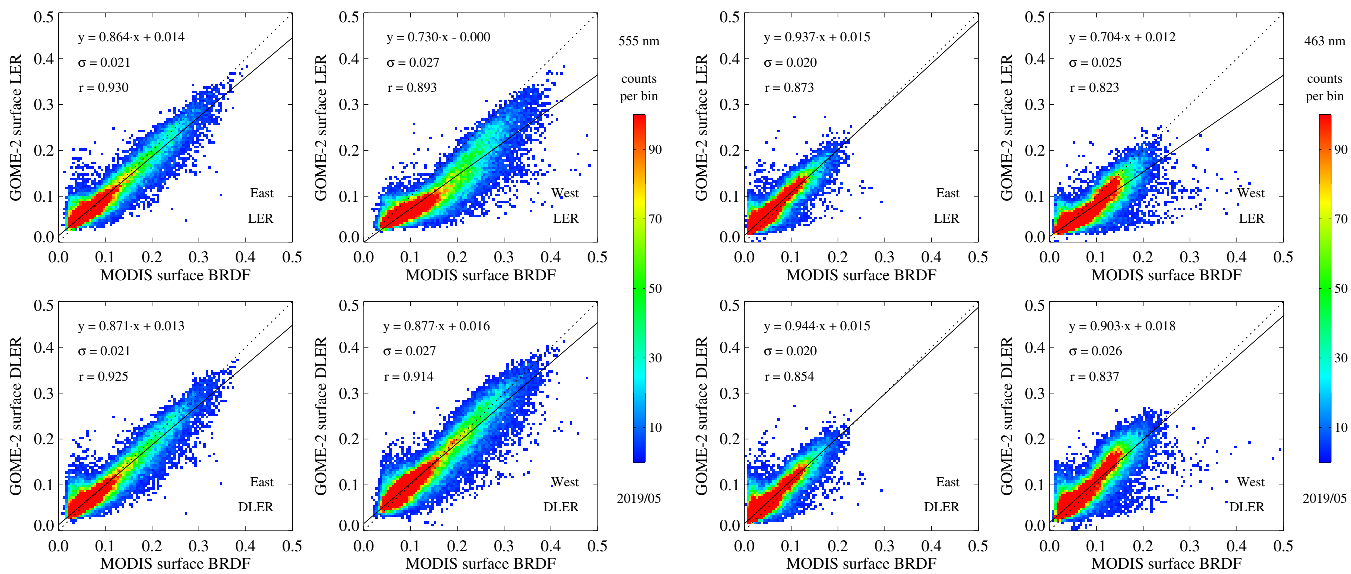

Figure 1: Pixel-to-pixel comparisons for 555 and 463 nm. These figures are new and presented as Figures S6 and S7 in the Supplement. They are to be compared with Figure 9 of the manuscript.

Also the paper is only discussing in passing DLER results over persistently snow covered (high mountains and polar regions) regions, and is not discussing ocean surfaces (or/and water bodies in general) at all. Both *surface types are either missing or filtered out in BRDF land databases like the ones derived from MODIS, because of considerable uncertainties in the BRDF coefficients for snow surfaces so far, or are generally neglected (like ocean colour variation and potentially associated directional effects apart from glint). Appendix B seems to indicate that DLER (like the previous LER database) also provides values over oceans, although this is never explicitly mentioned or even discussed in the body text of the paper, as it seems. It would surely be very interesting to understand how well DLER performs for these two surface types, which are (or seem) both included in the discussed database.*

The GOME-2 surface DLER database does in fact provide values over the oceans, but the polynomial coefficients c_0, c_1, and c_2 are equal to zero over the oceans. This is mentioned in section 2.2. Over the oceans, the database therefore provides the standard non-directional minimum LER value which was already discussed and analysed in our previous paper [Tilstra et al., 2017]. This non-directional value corresponds more to the diffuse (non-specular) component of the surface reflection over water (section 2.2, last sentence).

For snow/ice surfaces the GOME-2 surface DLER database does provide full directional LER values, so the surface anisotropy is contained in the database. Results for snow/ice surfaces are shown in Figures 6 and 7. In Figure 6 the surface anisotropy over snow/ice surfaces is shown by the blue colour (as opposed to the red colour seen for desert/vegetation). In Figure 7 results are shown for Antarctica and Greenland.

Note that we have updated Figure 6 of the manuscript, in response to a review comment made by Reviewer 3 in RC1. Figure 6 now not only shows the surface anisotropy parameter, but also presents global maps of the (non-directional) surface LER. This now makes it more clear that surface LER is also provided for the ocean. We have also updated the caption of Figure 6, which now mentions explicitly that non-directional surface LER is provided over the oceans. The updated figure and caption are shown in Figure 2 of this AC.

Finally, it is not very clear to me why in the “Case studies” part of the validation section (Section 7.1) the authors emphasize the need for focussing on largely homogenous surfaces. A proper averaging of MODIS BRDF sub-pixels to the DLER grid pixel should in principle provide an accurate comparison independent of sub-pixel surface variations. And it would be also interesting to provide the corresponding averaged MODIS BRDF results in Figure 8 for comparison with the DLER grid pixel results along with the individual ones (and ideally show similar comparisons for non-homogeneous cases too).

A higher inhomogeneity in the scenes would make the comparisons shown in section 7.1 less significant. For validation it is better to have homogeneous scenes to reduce the spread. For example, the collocation differences between GOME-2 and MODIS can cause spread. It is true that in section 7.2 we perform a proper averaging of the MODIS surface BRDF grid cells to the surface DLER grid cells. However, in section 7.1 we consider pre-defined regions (of one by one degree) and present the viewing angle dependence of the MODIS BRDF and DLER grid cells by plotting these for each of the grid cells. We on purpose do not perform any averaging in section 7.1, so that the images provide information about the variability of the surface within the one-by-one degree region.

The plots show that the inhomogeneity can be relatively large, even for scenes which we consider to be homogeneous. The curves indicate that there is considerable spread due to the inhomogeneity of the surface. This is seen in both MODIS surface BRDF and GOME-2 surface DLER.

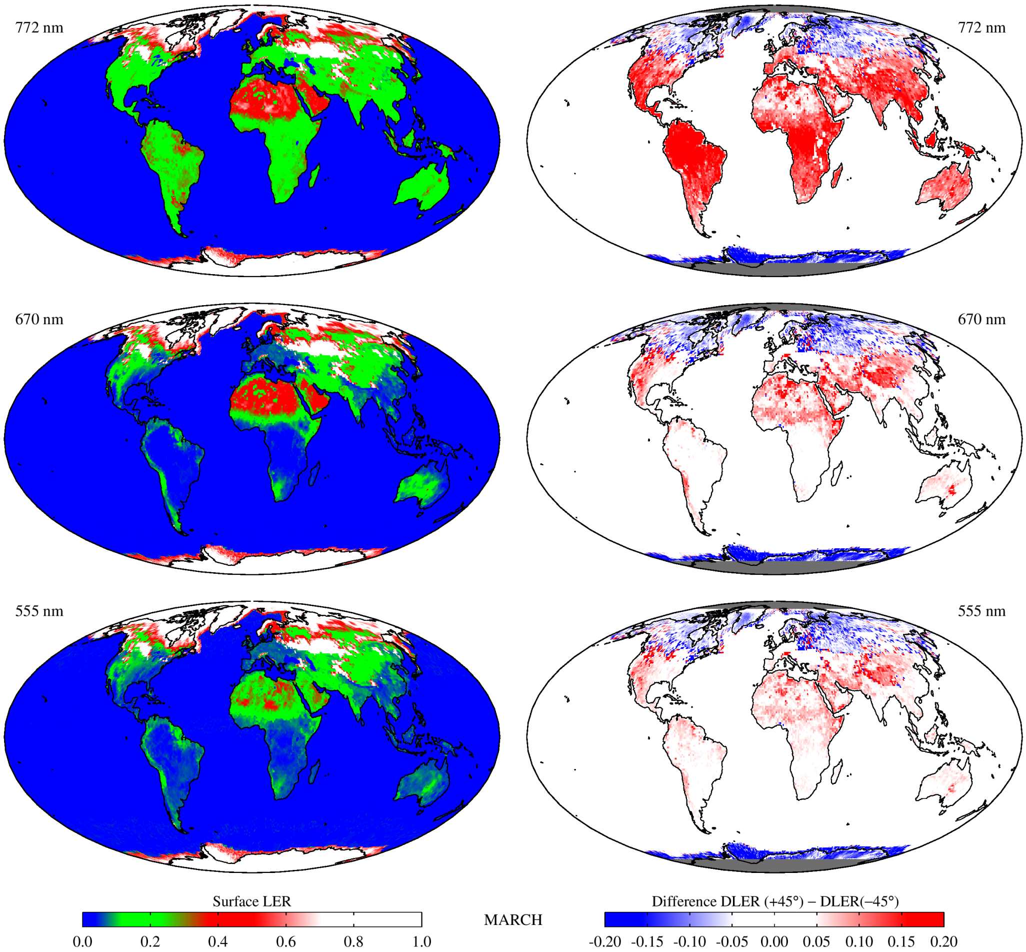

Figure 2: Left: Global maps of the GOME-2 surface LER, for calendar month March and for 772, 670, and 555 nm. Right: Global maps of the surface anisotropy parameter, defined as the difference between GOME-2 surface DLER at viewing angles of +45° and −45°. The surface anisotropy can be large, especially for vegetated surfaces at wavelengths beyond 700 nm. Over the oceans only non-directional surface LER is provided, as explained in Sect. 2.2.

To be able to draw strong conclusions from comparing MODIS BRDF and GOME-2 DLER, the spread should be as small as possible. Nevertheless, the results in section 7.1 are to be considered qualitative results, where the results from section 7.2 are to be considered quantitative results.

References:

Tilstra, L. G., Tuinder, O. N. E., Wang, P., and Stammes, P.: Surface reflectivity climatologies from UV to NIR determined from Earth observations by GOME-2 and SCIAMACHY, J. Geophys. Res.-Atmos., 122, 4084–4111, doi:10.1002/2016JD025940, 2017.