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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Satellite monitoring of different vegetation types by differential optical absorption spectroscopy (DOAS) in the red spectral range" *by* T. Wagner et al.

T. Wagner et al.

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Reply to Ref. #2

First we want to thank this (and also a second) anonymous reviewer for the positive assessment of our study and the constructive and very helpful comments and suggestions. Following these suggestions it was possible to correct and improve our method in several important aspects. Especially the recommendation to include the formulation of a forward model and the analysis of synthetic spectra put our conclusions on a much more solid basis. Before we comment the reviewers suggestions on an individual basis we give an overview on the most important changes compared to our original version of the manuscript.

1) We included the formulation of a forward model for the satellite observations of spectral albedo structures (new section 3.2). This model not only helps to understand better, under which conditions the DOAS method can be applied to the retrieval of narrow band albedo structures. It also drew our attention to two important aspects which were not treated correctly in the original version. First, it turned out that not the original albedo spectra, but the logarithms of the albedo spectra have to be included in the DOAS analysis. The fitting coefficients of the logarithms of the albedo spectra then represent the vegetation coverage of the observed satellite ground pixel. Second, it turned out that atmospheric scattering processes decrease the sensitivity of the satellite observations to the spectral signatures of the albedo. This effect is moderate (˜30%) for high sun and an atmosphere without significant scattering by aerosols and clouds. However, for large solar zenith angles (about $>80°$) and/or strong aerosol or cloud scattering the sensitivity rapidly decreases. Fortunately, even for cloudy scenes the sensitivity can in principle be easily calculated and corrected. In contrast to the correction of tropospheric trace gas observations, only the knowledge on the cloud fraction (but no information on the height of the cloud layer) is needed. We added this information (including the new figure 4) to our manuscript. According to the new findings we also modified the following statement in several parts in the text ‘One additional advantage is that the influence of atmospheric scattering and absorption is automatically corrected.’ to ‘One additional advantage is that the influence of atmospheric absorption is automatically corrected.’ According to the findings of the forward model, we also modified the (new) Figure 1 (old Figure 2). The high-pass filtering is now performed by dividing (instead of subtracting) the fitted polynomial.

2) According to the findings from the forward model, we reanalysed the whole data set using the logarithm of the vegetation spectra (instead using the vegetation spectra directly). We also excluded the spectrum of dry grass, because the respective fitting coefficients were always very close to zero. While the temporal and spatial variation of the retrieved results almost not changed, the absolute values became much more realistic. The maximum fitting coefficients found for individual spectra are about 0.5,

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which is very close to the expected maximum derived from the forward model (0.7). We changed Figures 2, 7 and 8 accordingly.

3) We included a new section (3.3) describing the modelling and analysis of synthetic spectra. This exercise allowed us not only to confirm the results of the analysis of the real spectra and of the forward model, but also allowed us to perform additional sensitivity studies. In particular we could confirm the strong influence of spectral vegetation structures on the retrieved results of the O4 absorption. Like for the measured spectra the O4 results are strongly altered (and can become even negative) if the vegetation spectra are not included in the DOAS analysis. In addition, it was possible to investigate the potential effects of too low spectral resolution and wrong spectral sampling of the vegetation spectra. These sensitivity studies confirmed the results of the analysis of the measured spectra and supported the suggestion to improve the quality of vegetation spectra. We describe the results of our sensitivity studies in detail in the new section 3.3. and added new figures (new Figures 4, 5 and 6).

4) We added an additional Figure (new Fig. 3) which compares the retrieved results for part of a satellite orbit with the vegetation spectra either included or excluded in the fitting process. Also shown in the new figure are the results of the O4 absorption in the UV spectral range, which are not affected by the spectral structures of the albedo. The results presented in this figure clearly indicate that over areas with a strong vegetation signal the retrieved O4 absorptions deviate systematically and strongly from the true values (as e.g. retrieved in the UV); they even can become negative. If the vegetation spectra are included in the fitting procedure, the O4 values become much more reasonable.

5) We included an additional co-author (Tim Deutschmann). Tim Deutschmann developed the radiative transfer model which was used for the calculation of the synthetic spectra.

Referee comments:

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General comments

The paper presents a new approach to investigation of the ground vegetation and the ocean biological activity using differential spectroscopy method. The authors obtained promising results showing that spatio-temporal patterns of vegetation fitting coefficients are similar to patterns of different types of vegetation. They also discuss limitations revealed in the DOAS analysis using available vegetation reflection spectra. The authors gave proper credit to previous works.

Specific comments

The title of paper ("Satellite monitoring of d i f f e r e n t t y p e s by differential optical absorption spectroscopy (DOAS) in the red spectral range") differ from one send by editor. Is it complete? I thing that "different" may be omitted, "monitoring of vegetation types" or "monitoring of vegetation" is enough.

Author response: Unfortunately, during the editing process, 'vegetation' was lost. We added it in the revised version.

Referee comment: Abstract "The inclusion of the vegetation spectra also significantly improves the results of the trace gas retrieval." A: The paper shows changes in the trace gas retrieval only for one specific sample and even without validation of the result. I thing that proposed conclusion is likely, but hasn't enough background in the currently presented form of the paper.

Author response: As an example for the results of part of one satellite orbit we added the new figure 2. It compares the results retrieved with the vegetation spectra included or excluded in the DOAS analysis. For O4, it also shows the results from the UV spectral region which are not affected by the interference with spectral albedo structures. While the absorptions of H2O and O2 are only weakly affected by the inclusion of the vegetation spectra, those of O4 change strongly. Only if the vegetation spectra are included they become similar to those retrieved in the UV.

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Referee comment: "Our results indicate that improved sets of vegetation spectra might lead to more accurate and more specific identification of vegetation type in the future." It is unclear here what it is "improved sets of vegetation spectra ". Obtained results show only that used set of vegetation spectra have some shortages, but can't give any information on properties of analysis with use of another set. We may only formulate hypotheses on causes of revealed shortages.

Author response: From the sensitivity studies using synthetic spectra (new section 3.3) we found that the results of the DOAS analysis are especially sensitive to an incorrect wavelength calibration. We recommend an accuracy of the wavelength calibration of better than 0.2nm (which should be easy to be achieved with modern instrumentation).

Referee comment: I. Introdcution "Over this wavelength range, the reflectivity of vegetation changes strongly (Fig. 1), caused by the absorption of various kinds of chlorophyll and pigments." I thing that a reference to Fig.2 is more appropriate than to Fig.1.

Author response: Many thanks for this hint. We changed the reference to Fig. 2 (again Fig. 1 in the revised version)

Referee comment: Data analysis Fig.1 The caption of the figure ("Results of a spectral DOAS analysis") is very fuzzy. I guess that it shows the estimation of the optical depth by the DOAS method. It is unclear what the values are shown by the red and black curves in the figure.

Author response: We added an explanation in the figure caption.

Referee comment: Fig.2 Please give parameters of the high pass filter used to produce the differential spectral albedo.

Author response: The high-pass filtering was perfomed by a division by a fitted polynomial of degree 4. We added this information to the figure caption.

Referee comment: P.7949. "It is interesting to note that in the red spectral range not only the absolute values of the albedo, but also the narrow-band spectral structures (for the spectral resolution of about 8 nm, see http://speclib.jpl.nasa.gov/ gov/) are very weak (<1%). For the corresponding weak variations of the observed radiance, it is thus possible to include the vegetation spectra directly in the DOAS fitting procedure (like the trace gas reference spectra)." I don't thing that it is enough theoretical proof on the linear dependence of radiance (or logarithm of radiance) on the vegetation spectra. Nevertheless, such an assumption may be used like a hypothesis in this paper.

Author response: Indeed we made an error when using the original vegetation spectra in the DOAS analysis. Following the formulation of the forward model (new section 3.2) the logarithm of the vegetation spectra has to be included to derive meaningful results. We reanalysed the whole data set using the logarithm of the vegetation spectra and we also added this information in the text.

Referee comment: P.7950. "We also found that the results are sensitive to variations of the selected wavelength range." In general, the results of the DOAS analysis are not stable with respect to arbitrary variation of wavelengths. Please specify more details on used wavelength ranges. In current wording it is unclear what a reader should conclude from this statement.

Author response: We investigated the dependence of the retrieved results on the wavelength range in more detail suing the synthetic spectra (new section 3.3). We found that especially if vegetation spectra with inappropriate spectral resolution of wavelength calibration were used, the results become strongly dependent on the selected wavelength range (and on the degree of the polynomial). We added this information to the text.

Referee comment: P.7952. "Besides a significant improvement of the fitting results for the atmospheric trace gases, " See comment A to Abstract.

Author response: Not only the residual gets smaller if the vegetation spectra are included in the fitting results, but also the O4 results become much more reasonable. In particular they become very similar to those retrieved in the UV, which is not affected by the interference with the spectral albedo structures.

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Referee comment: "Our results indicate that the currently available vegetation spectra are not of sufficient quality to obtain optimum DOAS fitting results, " It is unclear what is "optimum" DOAS fitting results.

Author response: We added the following sentence to make the ‘expectations’ to optimum DOAS fitting results more clear. ‘Even if the vegetation spectra are included in the DOAS analysis, the residual still shows remaining systematic structures (see Fig. 1).’

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 7945, 2006.