Monitoring vegetation using DOAS satellite observations: creating a set of reference spectra

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Abstract

Vegetation-cycles are of general interest for many applications, e.g. for harvest-predictions, global monitoring of climate-change or as input to atmospheric models. From novel spectrally resolving UV/vis satellite instruments (like GOME-1 and -2 or SCIAMACHY) the spectral signatures of different types of vegetation can be identified and analysed using the DOAS technique. Although the spatial resolution of GOME-1, -2 and SCIAMACHY observations is much coarser than those of conventional satellite instruments for vegetation monitoring, our data sets on different vegetation types add new and useful information, not obtainable from other sensors.

1. INTRODUCTION

Common vegetation indices (e.g. for MERIS, SPOT or LandsatTM) are based on the fact that the difference between red and near infrared reflection is higher than in any other material on Earth's surface. The spectrally resolving data from GOME-1, -2 and SCIAMACHY provide the chance to measure finer spectral features throughout the red and near infrared spectrum.

We analyse these features using the technique of Differential Optical Absorption Spectroscopy (DOAS). Although originally developed to retrieve information on trace gasses in the atmosphere, it can also be used to gain information on vegetation. Another advantage is that this method automatically corrects for atmospheric effects. In addition, high-frequency-structures from vegetation also effect the retrieval of tropospheric trace gasses and aerosols.

To optimize vegetation monitoring with DOAS we produce spectrally resolved reference spectra from different vegetation types using our own instrumentation. Applying these results we investigate how well we can distinguish vegetation types from space.

2. MOTIVATION

To optimize DOAS retrievals of trace-gasses from the atmosphere, Wagner et. al. (2007) had a closer look at the spectral residual. They noted distinct structures in the residual, especially when they sampled pixels over vegetated land. To test the theory, they fitted spectral vegetation-data from he ASTER spectral library and the reduced amplitude of the residual confirmed the expectation that the residual was caused by vegetation. It was also suggested that investigating the spectral reflectance of vegetation might yield completely new information (Wagner et al. 2007).

Using reference data from the ASTER spectral library in the DOAS-fit improved the fit quality, but still leaves some serious inconsistencies which suggest the production of new reference-data for vegetation at equivalent spectral resolutions (compared to GOME-1, -2 and SCIAMACHY).

The value of this kind of vegetation retrieval could be in many fields, it could be used as:

- input for models at similar resolution
- to increase accuracy of DOAS trace-gas-retrievals from the same satellites to study vegetation-cycles at global level – allowing almost global cover at a daily basis (with GOME-2)
- provide additional input to traditional land cover classifications

In the end, we hope to be able to connect the finer spectral structures to plant characteristics like e.g. individual pigments. This could provide entirely new kinds of information on vegetation.

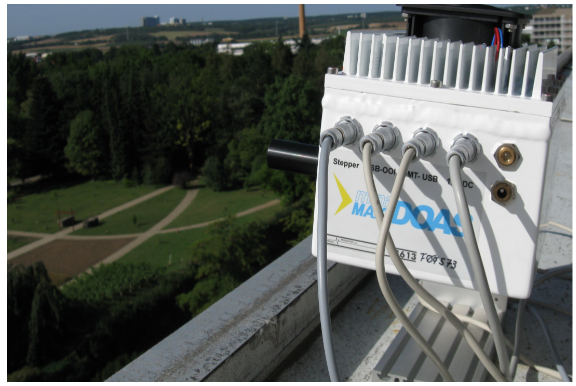

Figure 1: Mini-MAX-DOAS instrument

We aim to improve the vegetation-fits by producing our own reference-spectra, using a Mini-MAX-DOAS instrument (see Fig.1). It contains an Ocean Optics USB 2000+ spectrometer in the range of 500 to 800 nm and with an effective spectral resolution of 0.6 nm. The sensor is encased to provide a temperature-controlled environment and a motor for an adjustable viewing-angle.

3. MEASUREMENTS

Originally we planned to collect reference spectra in the Botanical Garden of Mainz University under clear-sky conditions using the sun as light source, as presented in Fig. 2:

Figure 2: measurements with sun light

But we had to notice that the methods we applied did not completely remove the effects of the fast changes of absorptions of O_2, H_2O and the optical depth of the Fraunhofer-lines (most probably due to changes of the Ring-effect). So we resumed data collection under more controlled conditions: totally excluding daylight and providing an artificial light-source. Fig. 3 (left) shows the „tent“ of light-impenetrable cloth in the Botanical Garden, Fig. 3 (right) gives an impression of the measurement conditions underneath.

Figure 3: measuring with artificial light source

To eliminate the effects of the light source, we take measurements over vegetation and then over a reference. In our case we chose to use salt, since in the spectral range of our instrument (500 - 800 nm), it does not produce spectral structures of it's own while yielding high reflection. The resulting vegetation spectra are then divided by the Reference spectra.

4. METHODS OF DATA-PROCESSING

On the resulting quotient we then apply the following mathematical steps (also demonstrated in Fig. 4):

- logarithm
- highpass filter (lowpass 7.8nm subtracted)
- lowpass to smoothe highpass, FWHM: 1.7 nm

For the rest of this article we always show data processed this way.

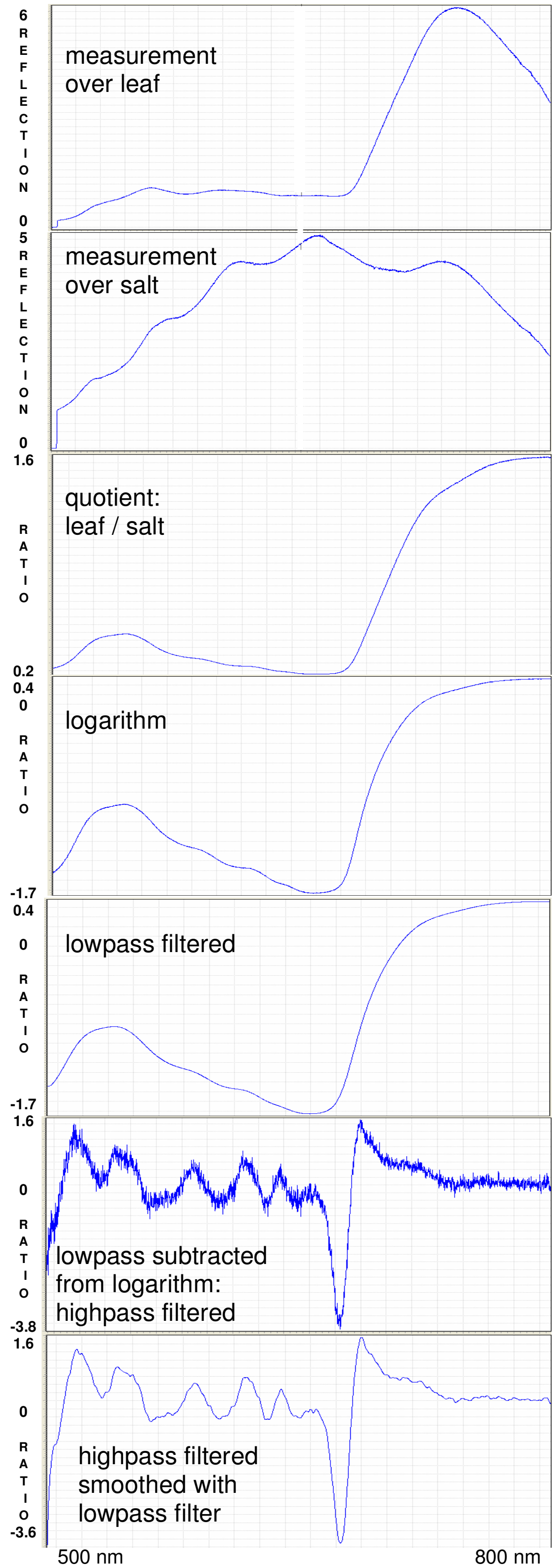

Figure 4: steps of data processing example measured over a beech-leave

5. FIRST RESULTS

We investigated the influence of changing angles of illumination and viewing-angle. Fig. 5 shows the effect of changing angles on the reflectance from a leave of Norway Maple. In both cases changes are minor for wavelengths up to about 650 nm. Towards higher wavelength the spectral structures

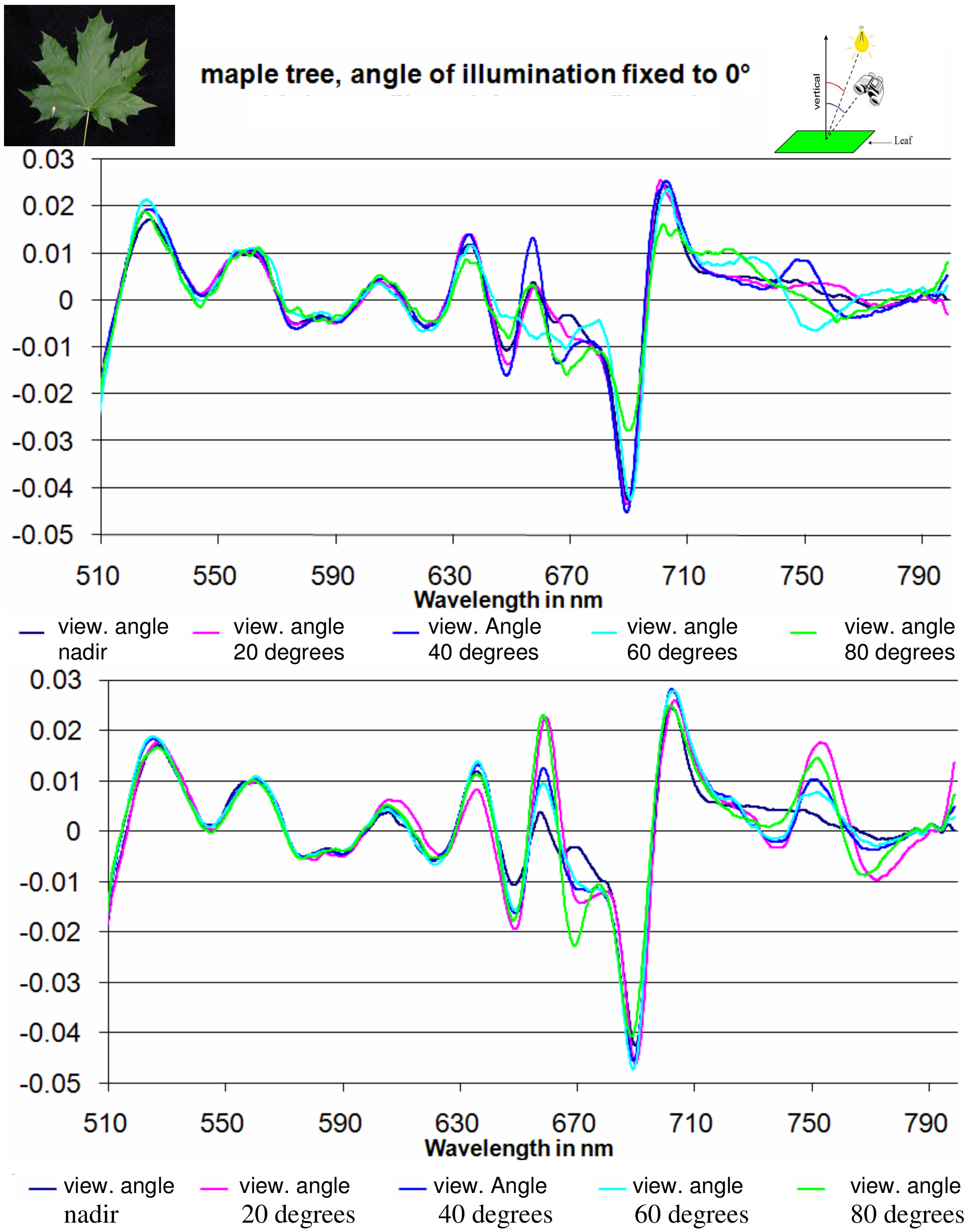

Figure 5: reflection over maple leaf with changing geometries. The top graph shows the effects of altered viewing angle, the lower graph of altered illumination angle.

become variable.
Please note that the alterations are different for changes of illumination and viewing angle. This also applies to measurements over other leaves.

We also started investigating where we can produce averages of different species and where we can differentiate between groups. Fig. 6 shows the measurements over different Pines and the resulting average.

While reasonable agreement is found within the plant-family, pronounced differences occur compared to other conifers. (see Fig. 7) This suggests that we might be able to differentiate between different groups of conifers in the future.

The results for deciduous trees are more divers (that may simply be the effect of the higher amount of species measured). To improve visibility we calculated averages for different plant-families. We present them together with the average of Pine in Figure 8. Again we see mainly changes in amplitudes below about 650 nm and variations for wavelengths above.

Another aspect is the orientation of the leave towards the sensor. In general, leaves are seen by satellites mainly from the top. But wind may influence the position and also expose the backside to satellite view.

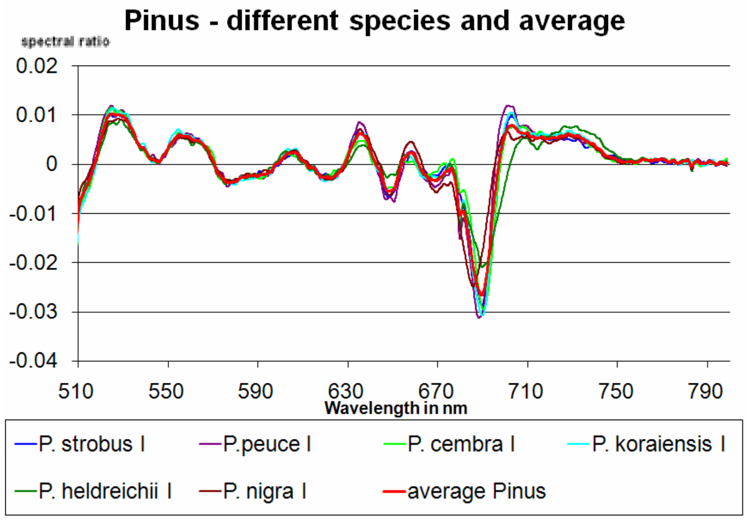

Figure 6: reflection from different pines and calculated average

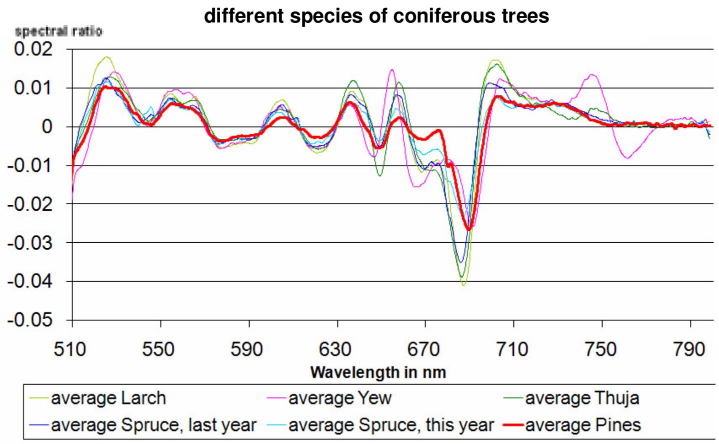

Figure 7: reflection from different conifers and calculated average for pine

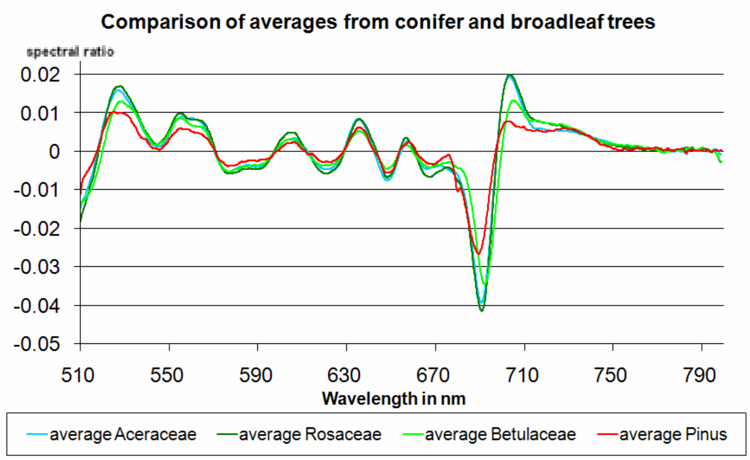

Figure 8: reflection from different deciduous plant-families and pine

This can also alter the signal, as demonstrated in Fig. 9 for six different leaves. To enhance readability, we produced averages for front (red) and back (orange) measurements, leaving in the background the original measurements to demonstrate the range of variability.

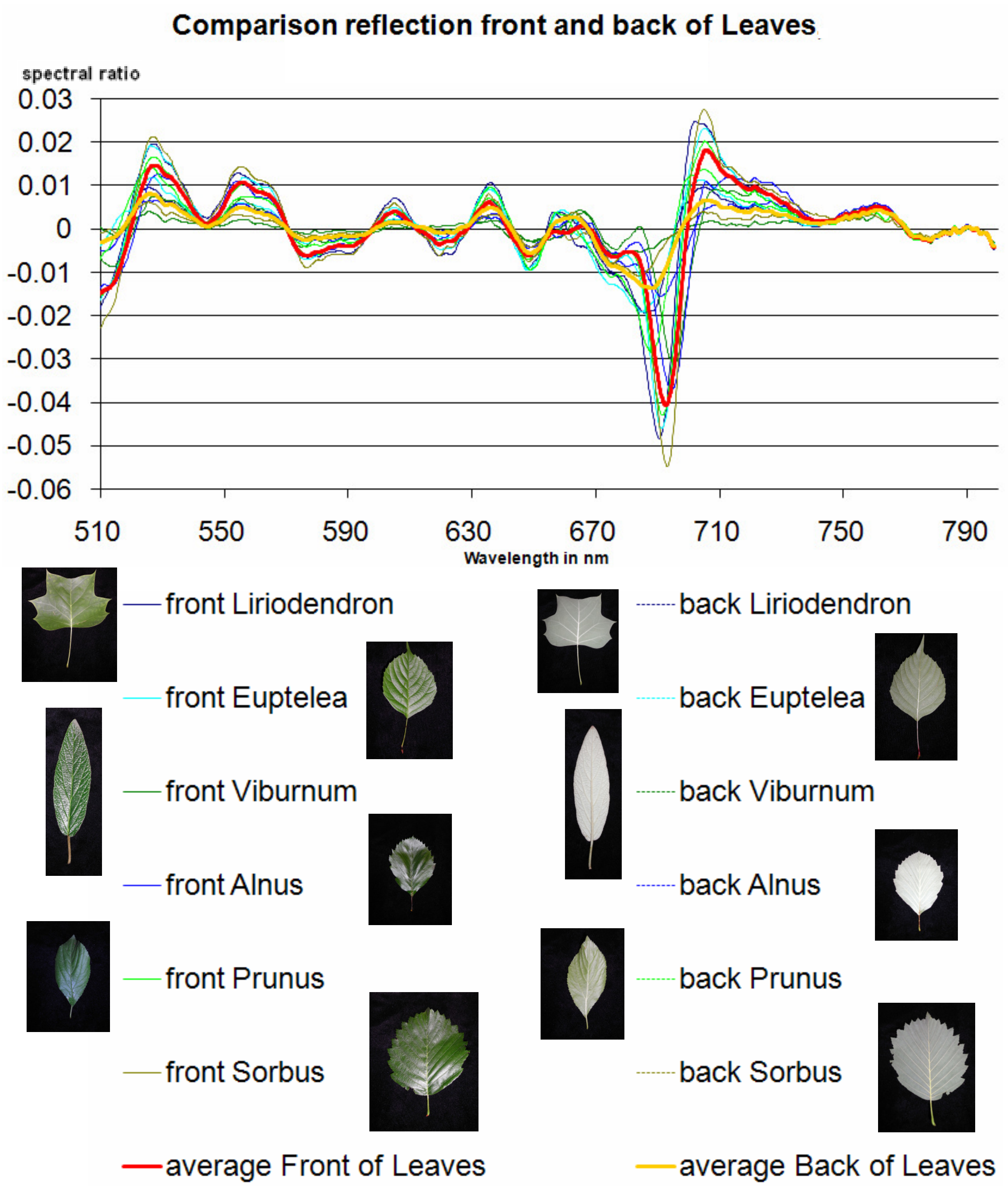

Figure 9: comparing front and back side of leaves

6. CONCLUSION AND OUTLOOK

We performed measurements of the spectral reflectance of a large variety of species (11 conifers, 23 deciduous, etc.). The spectral structures showed great consistency for wavelengths < 650nm. For wavelengths > 650nm, however, a large variability was found for the different species.

The initial results are very encouraging. But before we can start to produce "vegetation-classes" with common spectral signatures, we need to collect more vegetation measurements.

When we understand those and the pigments that also influence the reflection, we can start to identify similarities and differences and relate them to physiological plant properties. That will help us to produce vegetation classes that are identifiable with DOAS. For each of those we than can develop our own vegetation cross-sections for DOAS satellite-retrievals.

7. ACKNOWLEDGEMENTS:

Fig. 2 was photographed by Thomas Hartmann.

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