SWAMP SCIENTIFIC REPORT - GROUP B

RETRIEVAL OF BIOPHYSICAL PARAMETER (LAI) FROM REMOTE SENSED DATA

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1. INTRODUCTION

Wetlands areas are, due to provided many ecosystems services, considered as very precious areas (i,ii). They play a significant role in flood protection, water quality, water retaining, methane and CO_2 sink, food production (agriculture and pastures), eco-tourism and animals' migration routes, providing natural habitats for many rare or almost extinct species of animals or plants. Despite their high value for society and environment, wetlands are not an often studied topic. Lack of knowledge about the functionality or basic characteristics of vegetation may lead to major simplification that can affect the quality of complex hydrological models.

Wetlands are ecosystems that vary depending on climatological conditions, e.g. ground and surface water. From the point of water and energy balance, evapotranspiration is one of the most important processes that in case of wetlands is strongly related to the vegetation cover. Research performed on trees (iii,iv,v) has proven that the interception, considered as insignificant part of evaporation, is actually an important part of evapotranspiration calculation. As it was mentioned above, there is an existing gap in knowledge about the wetlands that scientists are trying to fill (vi,vii) with field experiments. However, in case of interception, field measurements are very time consuming and some areas in wetlands are hardly accessible [(1)]. Remote sensing methods that help in spatial estimation of interception capacity are very useful, e.g. a widely known method of calculating interception from remotely acquired LAI (Leaf Area Index) maps that was developed by de Jong and Jetten (2007)[(2)]. In case of this study, a big focus is in high resolution estimation of LAI.

LAI can be measured directly and indirectly from ground and indirectly from near ground and at airborne level ('remote sensing'). The data are collected at these different levels in order to evaluate the accuracy of LAI estimation from different heights. The ultimate goal of researchers is to be able to calculate accurately biophysical parameters from space (spaceborne measurement with satellites, e.g. Sentinel-2 is used to estimate LAI by parametric, non-parametric and physical retrieval methods (viii)). Knowledge on biophysical parameters, not only on LAI, but also chlorophyll content, chlorophyll fluorescence and others provides crucial information regarding the management and protection of certain ecosystems. The impact of stressors (e.g. drought, air pollution, soil contamination, etc.) is often expressed in the biophysical parameters (ix). A lot of research is already done on drought (x). This is also the most important stressor worldwide, certainly for threatened swamp or wetland areas. Still, more research needs to be completed on the relation between different types of stressors and the response in biophysical parameters.

The first step in the upscaling process, from ground to airborne level, is gathering ground 'truth' data for validation purposes. However, collecting reliable ground 'truth' data is also challenging. Various obstacles ('uncertainties') at the different measurement levels need to be taken in order to achieve reliable results. Starting with spectral ground 'truth' measurements, these data require at least a radiometric calibration, spectral calibration and a correction for temporal spectral heterogeneity as the light conditions vary diurnally (solar time UTC/GMT) and seasonally (xi). Also variations in temperature can have a significant impact on the output data (xii). Ideally, the equipment is kept at the same temperature all the time. Secondly, the application of UAVs (Unmanned Aerial Vehicle or drone) has several advantages for this purpose. In fact they provide fine scale data (resolution achievable of less than 1 cm), are low cost, can be used privately/independently and gather data below cloud level. When completing airborne measurements, data require additional corrections [(3)]. The illumination geometry has a big impact on the flight line orientation (BRDF: bidirectional reflectance distribution function) as it should always be in the solar plane. Furthermore, a

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[1] Yu, K., Pypker, T. G., Keim, R. F., Chen, N., Yahng, Y., Guo, S., Li, W., Wang, G., "Canopy rainfall storage capacity as affected by subalpine grassland degradation in the Qinghai - Tibetan Plateau, China," Hydrol. Process. 26 (20), 3114-3123 (2012).

[2] De Jong, S. M.., Jetten, V. G., "Estimating spatial patterns of rainfall interception from remotely sensed vegetation indices and spectral mixture analysis," Int. J. Geogr. Inf. Sci. 21(5), 529–545 (2007).

[3] Aasen, H., Burkart, A., Bolten, A., Bareth, G., "Generating 3D hyperspectral information with lightweight UAV snapshot cameras for vegetation monitoring: From camera calibration to quality assurance," ISPRS Journal of Photogrammetry and Remote Sensing", 108 (November), 245-259., doi: 10.1016/j.isprsjprs.2015.08.002, 2015

geometric correction and an atmospheric correction (ATCOR) should be performed on the data. Geometric correction is based on an inertial navigation system (INS) consisting of an inertial motion unit (IMU), combined with a GPS, to achieve correct spatial information. Atmospheric corrections, on the other hand, reduce the effects of scattering and absorption by gases and aerosols in the atmosphere between the earth's surface and the airborne sensor and it minimizes the influence of solar illumination and topography on the registered signal. If necessary - in case of rough terrains - a DEM (demographic elevation model) can be used for topographic correction. The main advantage of planes and satellites, in contrast to UAVs, is the monitored scale. Much larger regions can be investigated. The disadvantages lie in the high costs and spatial resolution. Satellite maps can be as detailed as 50 cm to 1 km and the resolution of plane maps vary from 25 cm to 10 m.

2. RESEARCH OBJECTIVES

The swamp ecosystems represent the most important source of air composition changes, their position making them recipients of inputs of matter and energy for the neighboring ecosystems and for the atmosphere *(xiii).* Throughout the last century, human activity has impacted ecosystems very intensively, modifying the air composition and the distribution of pollutant greenhouses gases - like CO, CO_2 and CH_4 - in the lower atmosphere. A natural solution for this problem is represented by the absorption process of the polluting gases by the plants. This natural form of air cleaning occurs also in wetlands. This phenomenon is representative for the largest wetlands area of the world. It is estimated that approximately 455 Pg of carbon ($1\ Pg = 10^{15} g$) (xiv) is stored in wetlands in northern hemisphere *(xv)* and, simultaneously, a large quantity of CH_4 is emitted back in the atmosphere *(xvi).* This process seems to be very important for a better understanding of the energy exchange in this type of areas. Another phenomenon of interest is represented by the mass transfer from and to the atmosphere, and this can be observed by the ground and airborne measurements. Moreover, the energy and the mass exchange depends of the type and of the health degree of the plants and for this purpose it is necessary to retrieve the biophysical parameters from remote sensing data, obtained both by the ground and airborne measurements.

Regarding these premises, the formula to obtain the desired result is very simple, being focused on LAI (Leaf area index) retrieval by remote sensing data. To obtain data on LAI we used both ground and airborne measurements applying following measuring techniques:

- hyperspectral imaging with UAV,
- Ground spectrometry using SVC,
- LAI estimates with indirect methods using SunScan.

The final scope of this study is to simulate the LAI values and to validate the experimental results with the data obtained by the mathematical and numerical simulations in the ARTMO-toolbox.

3. RESEARCH SITE

The research site called POLWET is located in Rzecin (Poland) and it represents a dynamically changing wetland ecosystem. The area is dominated by a fen. However, due to changes in groundwater depth, some of areas degraded. Experimental plots were located along the wooden path designed to help with accessing the area. Field measurements were focused on 4 vegetation classes that were divided into: [1] homogenous sedge community of *Carex elata*, [2] heterogenous community of *Typha longifolia* and grass species, [3] depredated area dominated by *Equisetum sp*. and [4] sphagnum with different species small sedges. Every class represents a wetland in a different stage of degradation (assuming that the whole area used to be a fen consisted of a homologous vegetation type and that the area is colonized by several grasses and sedges due to degradation).

As it is shown at the *Figure 1*, 8 experimental plots were established at the research site. For each one, measurements were taken during a field campaign conducted in July 11th of 2015.

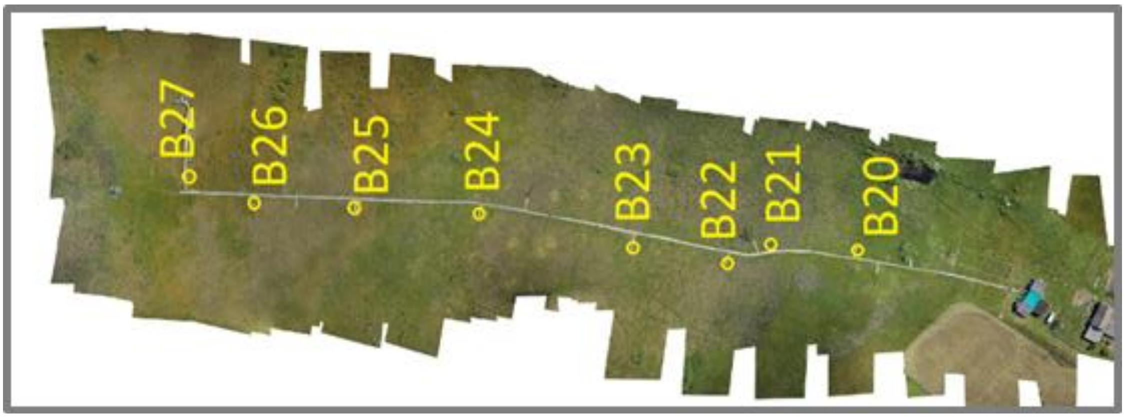

Figure 1. Map of Rzecin Site (POLWET)

Site 20. First plot was dominated by *Carex elata*. The high and dense vegetation was relatively homogenous. Correlation between LAI and fAPAR might be lower than expected, because reflected radiation was measured too low. The recommended height for measuring reflectance for dense vegetation with shiny leaves should be around 1 m, therefore in case of *Carex elata* (vegetation height is about 1 m) measurements should be taken above 2 m. The average (5 samples were taken per site) standard deviation between the 64 sensors of SunScan for transmitted radiation was74,4.

Site 21. Second plot consisted of a variety of species, but one of the most characteristic was *Typha latifolia* mixed with some grass species. The plot was heterogeneous with standard deviation, for transmitted radiation equaled to218,2.

Sites 22, 23 and 24. These plots were a mix of two dominating species: *Equisetum sp.* (Horse tail) and *Menyanthes trifoliate.* However, at plots 23 and 24 also occurred *Ranunculus sp.* For the site 22 correlation between the LAI and fAPAR was the lowest and equaled to 0,27. Standard deviation for sites 22, 23 and 24 were respectively357,4; 396,5 and 322,5.

Sites 25 and 26 were sphagnum characterized plots with high heterogeneity. Many species of a low vegetation were present, e.g. species of mosses, sedges: *Carex limosa*, *Carex rostrata, Carex nigra* and carnivorous plant *Drosera rotundifolia*. Standard deviation for site 25 was 343,5 and for site 26 the deviation value was169,5.

Site 27. The last plot was located very close to the experimental station; therefore fen was highly degraded due performed construction works around the installation. Standard deviation was149,8.

Figure 2. Typha latifolia on site B21 (top left), Carex elata on site B20 (top right), Menyanthes trifoliate on site B22 (bottom left) and phagnum on site 25 (bottom right).

4 METHODOLOGY

4.1 UAV

The measurement campaign site was located at latitude and longitude of respectively 52°45'N and 016° 18'E in the Rzecin swamp area. Two airborne sampling sessions consisting of two flights were realized in different parts of the measurement field with a UAV platform equipped with a Rikola hyperspectral camera. The first flight started at the 09.21 a.m. UTC time and was characterized by the following GPS coordinates: 52°45'42,3"N, 016°18'34,6" E. The second flight started at 01.08 PM UTC time having the following GPS characteristics: 52°45'33,6"N, 016°18'35,6" E. Moreover, the flight trajectory was built by four right lines with a length of 180 m, respectively 170 m for the second flight. The completed flight pattern can be observed in the *Figure 3*, and it was designed during the planning for the measurement campaign. There can be seen that the entire area was separated in two regions of approximately the same length and there was used 19 target points for each side for geometric correction of the acquired airborne hyperspectral images.

In *Figure 4,* the mosaic obtained using the hyperspectral images realized with Rikola camera can be observed and all the vegetation type and the area where these are situated can be distinguished. This is very important because different types of vegetation are located in a specific place. Registered LAI values vary according to the heterogeneity of the investigated wetland area. Moreover the health degree can be observed by the variation of the irradiance and of this parameter.

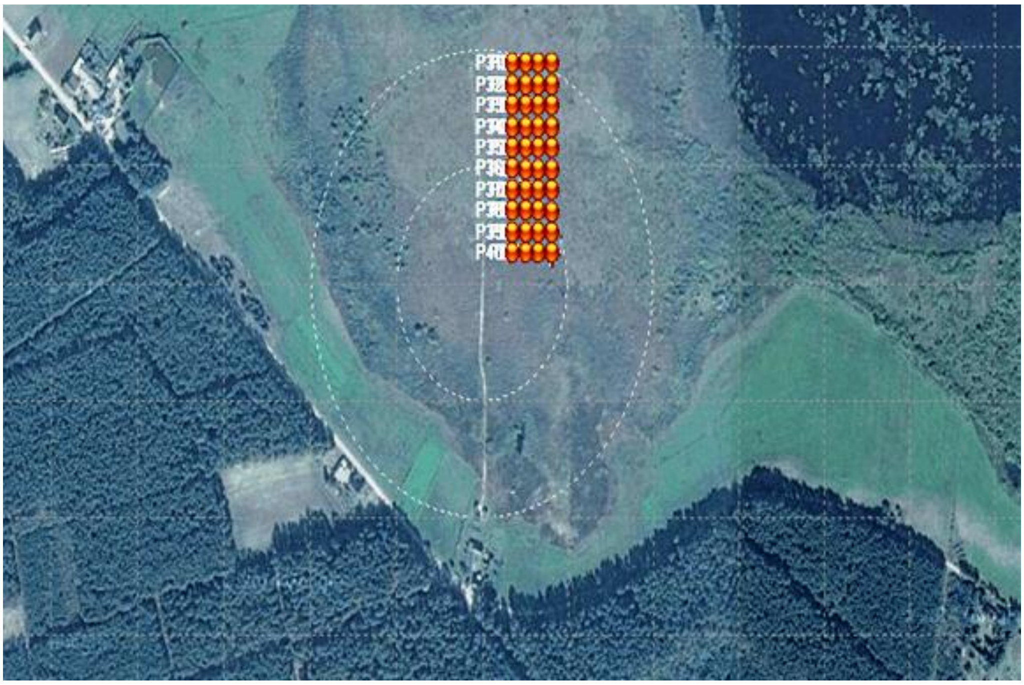

Figure 3. Flight pattern for the first measurement session

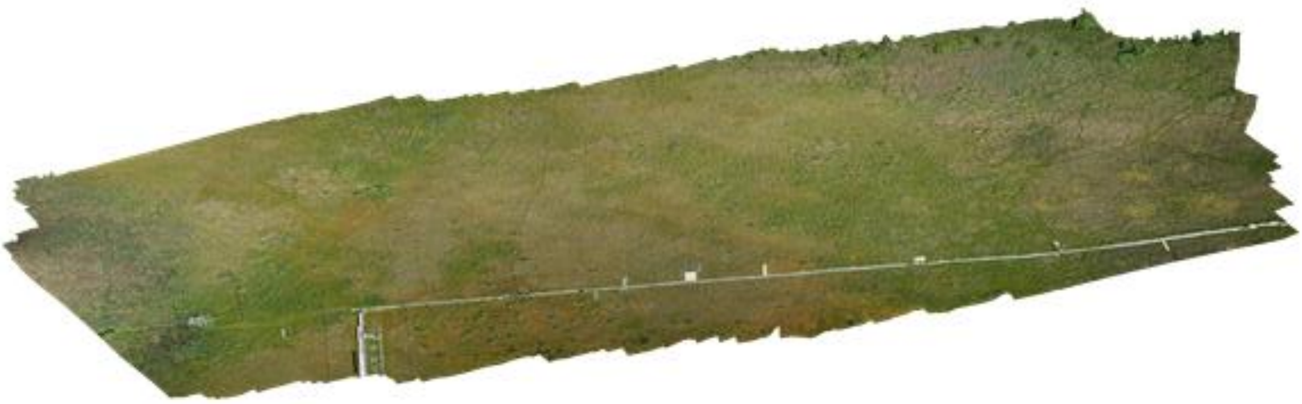

Figure 4. Hyperspectral images mosaic

At the same time with the airborne measurement, calibration measurements with the SpectraVista equipment and with the SunScan were made. The measurements have been used for irradiance and reflectance retrieval and were made periodically at 30 s distance.

4.2 Field spectroscopy

The ground measurements were achieved using the Spectra Vista HR-1024i spectrometer. In the flight time, the applied configuration on the ground was the SpectraVista spectrometer equipped with the integrating sphere and the SunScan. The measured parameters were the direct Sun light irradiance and the diffuse light irradiance. The measurements were made in pairs, at 30 seconds distance to one another. These sampling sets are relevant for the Rikola camera images calibration validation process, in order to obtain the same radiance information, but the data are not used in this report.

Between the first and the second flight, the SpectraVista was used to highlight the plant characteristics. In this scope, for each established ground target, were achieved 9 samplings in three different points, and were measured the spectral parameters for each type of vegetation. This measurement phase was realized at noon, in approximately clean sky conditions.

The reflectance for each vegetation species and the canopy retrieval was calculated based on the measurements sets for irradiance. The results will be presented hereafter.

4.3 Field measurements

Crucial for proper modeling is a field validation. Therefore, this study were performed measurements of LAI (with the use of SunScan) and surface spectrum (Spectra vista) in each experimental plot.

The SunScan collected radiation data by using two different modes (“LAI” and “All”). At every plot, samples were taken 5 times for the first mode and then 5 times for the second mode. For one sample the second mode actually requires three quick measurements and makes a short calculation to receive value of fAPAR. So, 5 samples are equal to 15 short measurements per site. LAI estimation for wetlands vegetation was done by using a model included in original software for SunScan. The fraction of photosynthetically active radiation, fAPAR, was calculated by using equation (1), where faPAR is a fraction of a radiation, I is an incoming (incident) radiation, R is a radiation reflected by a vegetation and T is the transmitted radiation.

$$faPAR = \frac{I-R-T}{I} \qquad (1)$$

Mode “All” in the SunScan collects values of radiation for every of 64 sensors separately. To calculate fAPAR, measurements have therefore to be done above vegetation (I - incident), above vegetation with rotated SunScan (R - reflected) and below the vegetation with normal position of the device (T - transmitted). This procedure is also referred to as the ‘TIR-procedure’.

4.4. Modeling

Model simulations were carried out with ARTMO, with the coupling between PROSPECT-4 and 4SAIL, because of being fast, invertible and well representing the homogeneous vegetation cover types on flat surfaces found in the SWAMP study area. The ARTMO toolbox is a graphic user interface (GUI) designed in MATLAB at the University of Valencia (xvii). It is a neural network including a lot of parameters influencing hyperspectral reflectance of vegetation. ARTMO therefore is an automated radiative transfer modeling tool allowing to make mathematical simulations of vegetation spectra according to changing parameters (e.g. chlorophyll content, LAI, etc.). This process is called ‘forward simulation’. On the other hand, it is also possible to retrieve biophysical parameters from hyperspectral reflectance data of vegetation. This process is called ‘retrieval simulations’. Simulations are validated with actual field data.

This study, completed during a summer school, will not contain all corrections mentioned earlier on, but focusses on the comparison of field data with the simulated data in ARTMO, more specifically how well simulated data predict LAI for both ground ‘truth’ and airborne hyperspectral data.

The turbid medium radiative transfer model 4SAIL (Scattering from Arbitrarily Inclined Leaves *(xviii,xix)*) was used, since it describes the canopy structure in a fairly simple way while producing nevertheless realistic results. We perform the simulations for the nominal range of LAI variation measured on the study area, LAI between (0-7). The PROSPECT4 model (xx) was used to describe leaf optical properties for varying chlorophyll C_{a+b} $(10\text{–}60\ \mu g/cm^2)$. PROSPECT simulates leaf reflectance and transmittance spectra required by the SAIL model as a function of leaf biochemical contents and leaf structure.

The retrieval of LAI from RTM inversion was carried out by minimizing the sum of squares, as in RMSE between model predicted values and measured values. *Figure 5* summarizes the methodology applied in this work.

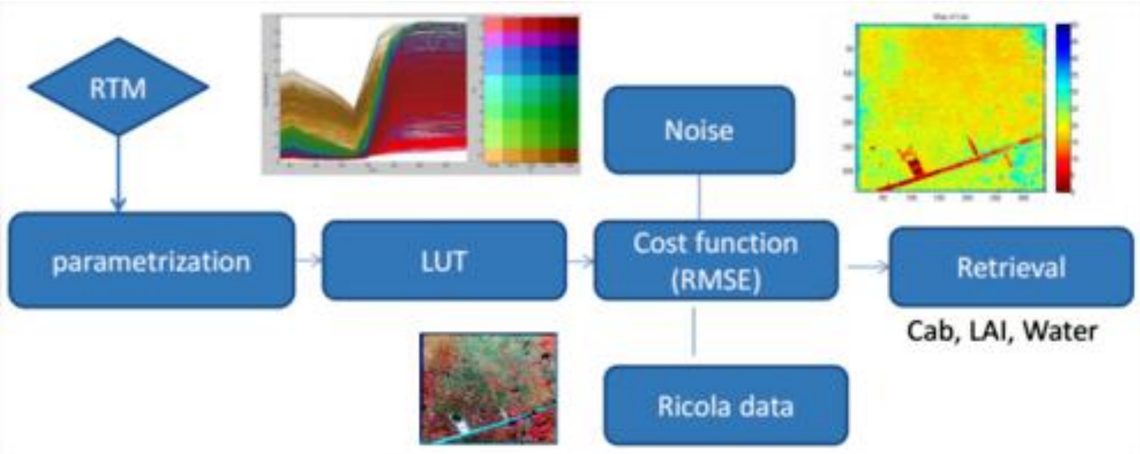

Figure 5. Methodological flowchart of model inversion strategy.

A look-up table (LUT) size of 100.000 top of vegetation (TOC) reflectance was calculated over the solar spectrum from 400 to 2500 nm at an 1 nm spectral sampling interval as a function of its biochemistry and anatomical structure. The simulations were generated for a random range of variation of Chl (chlorophyll) content and LAI within the natural range found in the SWAMP study area. Sun and viewing conditions correspond to the situation of the UAV overpass.

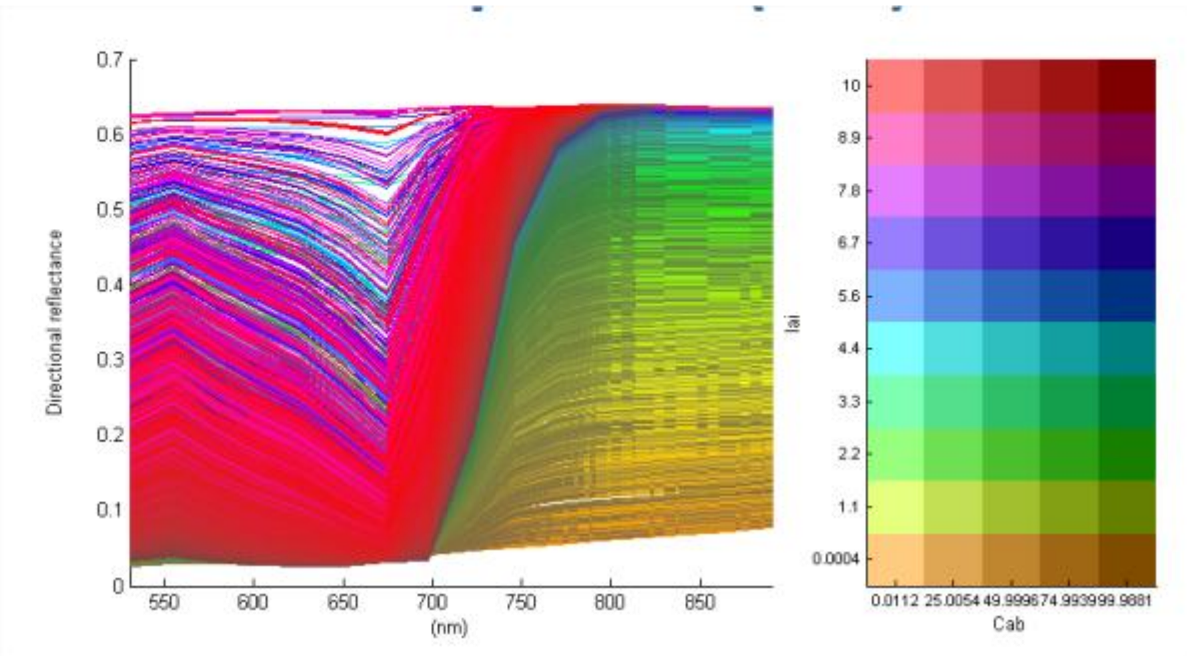

Figure 6. LUT-based simulated reflectance (a) and Cab/LAI matrix of input parameters applied for LUT-based inversion strategies

The last step of the analysis was the calculation of the cost function in retrieving LAI from Rikola image data and in situ field data measurements. Based on the statistical performance analysis, the robustness of LU-based inversion was assessed by using ARTMO toolbox[4].

5. RESULTS

5.1 LAI measurements with SunScan

Field measurements at all sites resulted in collecting data for every vegetation class. Values of measured LAI and of calculated fAPAR (equation (1)) from measured radiation were presented in the *Table 01*. The relation between LAI and fAPAR is shown on *Figure 7*. There is a strong correlation between the LAI and fAPAR, because the developed surface of leaves can absorb more radiation; however, in case of sites 22, 23 and 24, it was very difficult to evaluate the quality of measurements, because area was dominated by *Equisetum* (no leaves, just very thin stem) and depending on the position of the Sun, these plants could hardly gave any shadow (zenith) or a small long shadow of stem, that is similar to a shadow given by grass.

Table 01. Calculated values of LAI and faPAR.

Plot	LAI	faPAR	Cor (LAI;faPAR)
20	4,8	0,93	0,60
21	3,5	0,84	0,72
22	1,7	0,68	0,27
23	2,3	0,51	-0,89
24	1,4	0,20	-0,73
25	0,9	0,12	0,84
26	0,4	0,06	0,88
27	0,5	0,05	0,55

[4] Verrelst, J., Rivera, J. P., Veroustraete, F., Munoz-Mari, J., Clevers, J. G. P. W., Camps-Valls, G., Moreno, J., "Experimental Sentinel-2 LAI estimation using parametric, nonparametric and physical retrieval methods – A comparison," ISPRS Journal of Photogrammetry and Remote Sensing, 108 (MAY), 260-272, doi:10.1016/j.isprsjprs.2015.04.013.

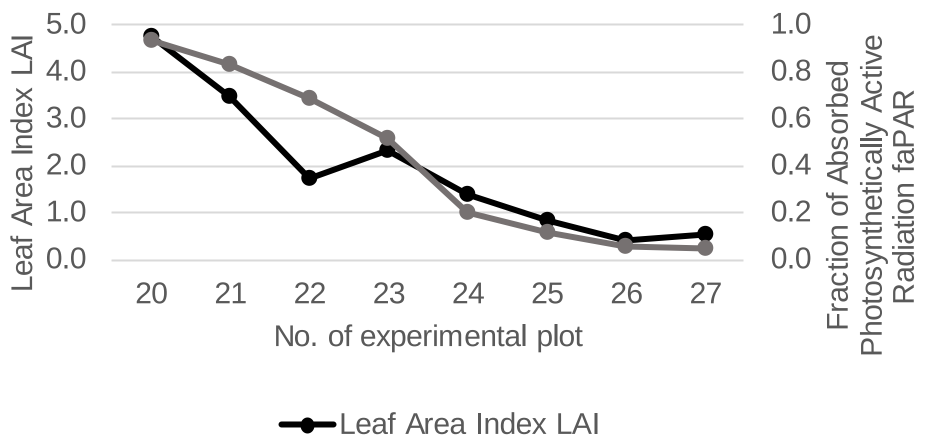

Figure 7. The relation between LAI and faPAR.

As it was mentioned in chapter "Research site", sites varied in plant composition and shown different homogeneity. *Figure 8* is showing values of radiation (incident, transmitted and reflected) for every (64) sensor collected by SunScan for site 20. Standard deviation between the 64 sensors of SunScan for transmitted radiation was 27,7. Dense, homogenous vegetation absorbed most of the light. *Figure 9*, on the contrary, is showing high heterogeneity of site 23. Changing values of transmitted light can indicate when surface was covered by leaves (low transition and high absorption) and when it was not. Standard deviation between the 64 sensors of SunScan for transmitted radiation was 454,0.

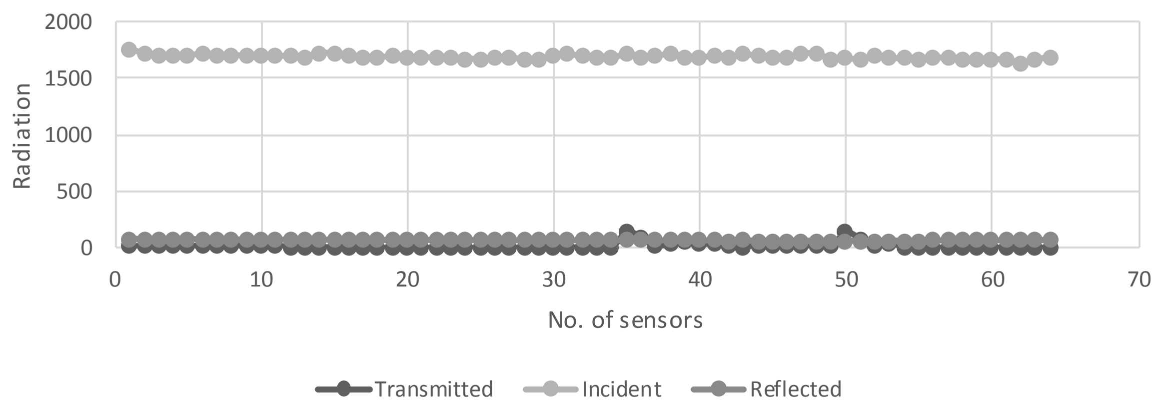

Figure 8. Measured radiation at the site 20

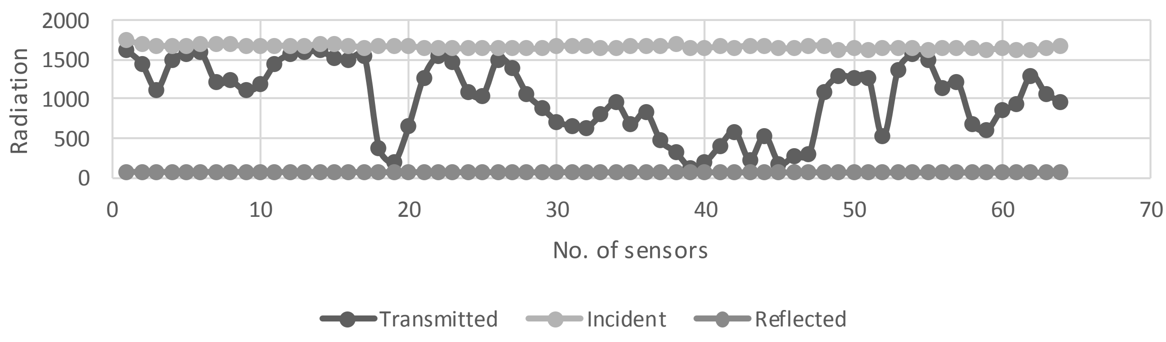

Figure 9. Measured radiation at the site 23

5.2 Hyperspectral measurements with SpectraVista

The data from the SpectraVista are visualized with Specchio (xxi). Like ARTMO, Specchio is also a graphic user interface designed in MATLAB. For each site, the average hyperspectral reflectance curves are calculated *(Figure 10).* Simulations in ARTMO (*Figure 11*) indicate an increasing reflectance with an increasing LAI. The more surface covered by leaves increases the reflectance. However the measurements gathered in the field do not support the simulations completely.

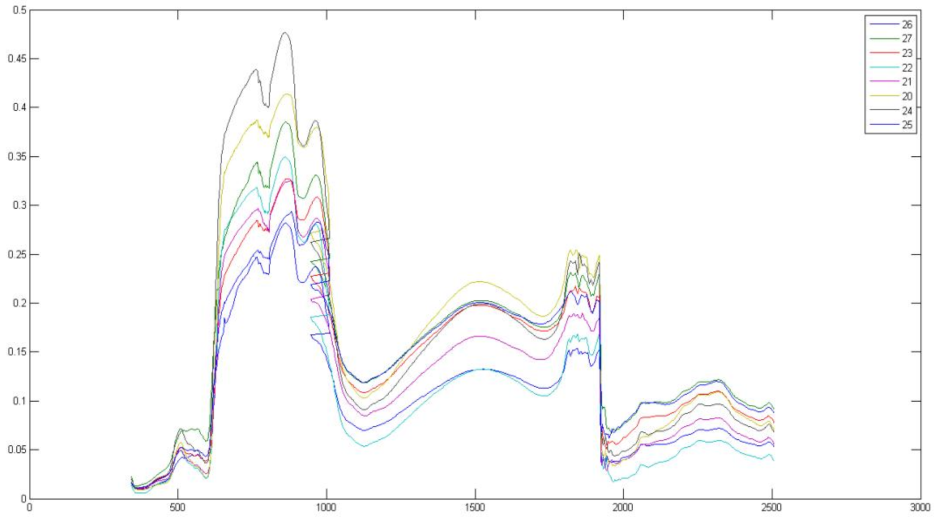

Figure 10: Calculation of average hyperspectral reflectance curves with SPECCHIO. (Not yet corrected for the spectral shift at 1000 nm)

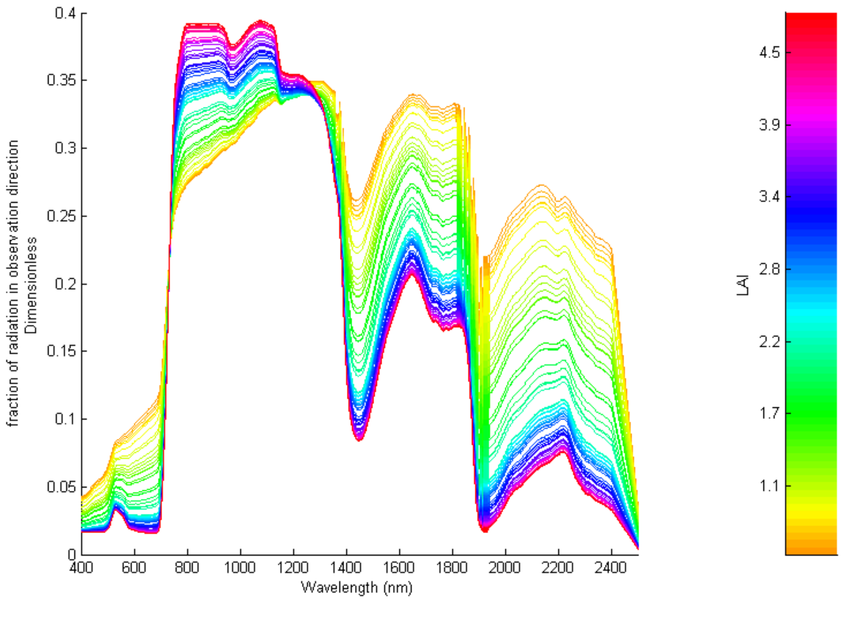

Figure 11. Forward simulation in ARTMO. Changes along the spectrum (400 nm – 2500 nm) according different LAI values

It is important to be aware of other factors that could interfere in the reflectance signal. For example, the chlorophyll content also impacts the reflectance. The higher the chlorophyll content, the more light is absorbed and the less light remains to be reflected (*Figure 6*). *Figure 12* shows both the measured and simulated spectrum for the particular case of site 26 at which low LAI values are measured. The figure indicates high discrepancy between the measured and simulated spectrum. This could be due to background influence. The color of the soil and especially the amount of water present underneath the vegetation highly impacts the measured reflectance. The impact of the background becomes larger with decreasing LAI. In this case the measured reflectance is lower than the simulated one and this suggests a dark background soil reducing the reflected light.

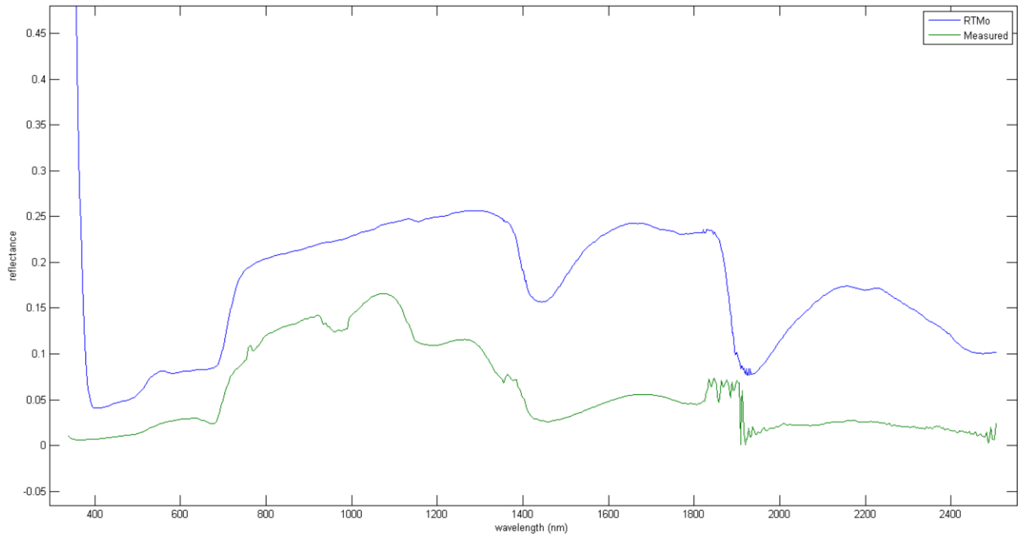

Figure 12. Measured and simulated hyperspectral reflectance of site 26 with ARTMO (canopy-retrieval by C. Van Der Tol)

5.3. Hyperspectral imaging with UAV

Based on the forward simulating data from 4SAIL model, the results can be directly applied to process the Rikola images to estimate LAI *(Figure 13).*

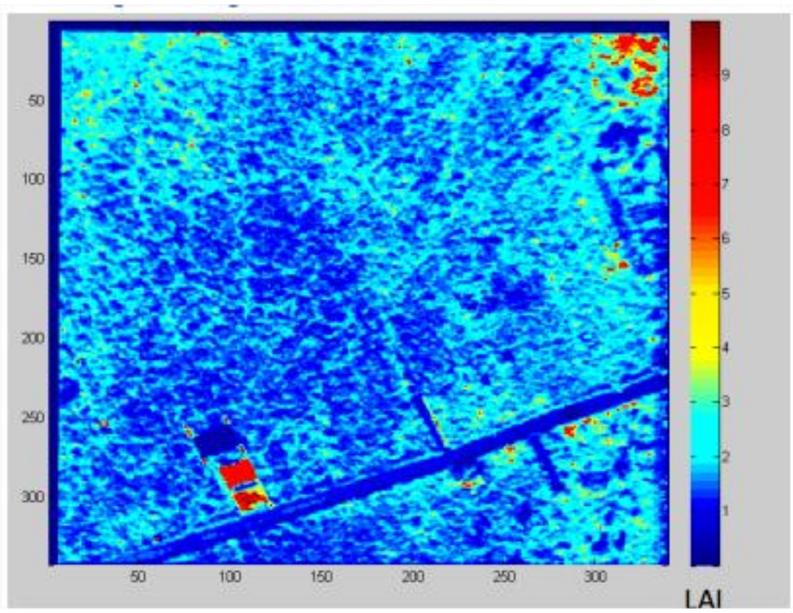

Figure 13. Results of inversion LAI based on Rikola image data in situ measurements

Figure 14 shows the scattering plot of results between simulated Rikola-based LAI and LAI field measurements. The statistical accuracy (*Table 2*) was made between in situ measured LAI and the corresponding inverted LAI. The results indicate that the inversion of LAI from Rikola data is generally reliable and satisfactory ($\mathrm{R} = 0.51, \mathrm{RMSE} = 0.29$). The analysis indicated that 4SAIL model might be used to generate simulation results of inverting LAI from high resolution Rikola image data acquired with UAV. Furthermore the results proved that this method was suitable to the vegetation type analyzed in this study area.

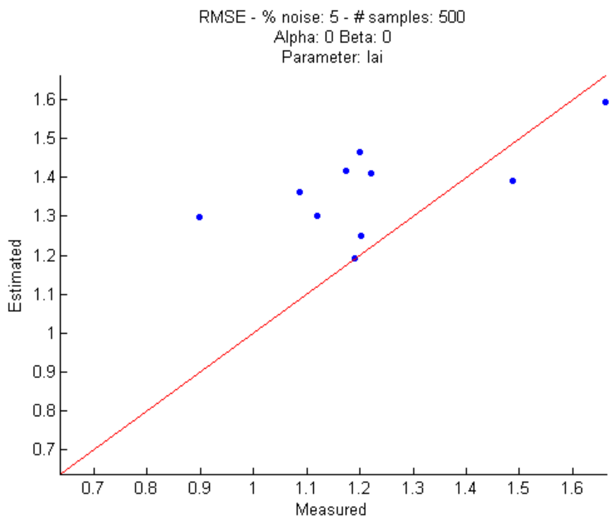

Figure 14. Validation of inverted LAI with RICOLA LAI products and in situ measurements

Table 2. Performance of the cost functions in retrieving LAI validated against the field dataset.

	Noise	# samples	% train	ME	RMSE	RELRMSE	NRMSE	MAE	R	R2	R2adj	NSE	Speed [s]
RMSE	5	500	5	-0,20	0,29	25,16	28,76	0,23	0,51	0,26	0,18	-0,34	0,05
Pearson chi-square	5	500	5	0,39	0,47	40,56	46,35	0,42	0,04	0,00	-0,11	-2,47	0,05
Shannon entropy	5	500	5	0,46	0,52	44,71	51,09	0,48	0,18	0,03	-0,08	-3,22	0,08

Additionally, *Figure 15* shows the accuracy performance of different cost functions tasted with ARTMO toolkit.

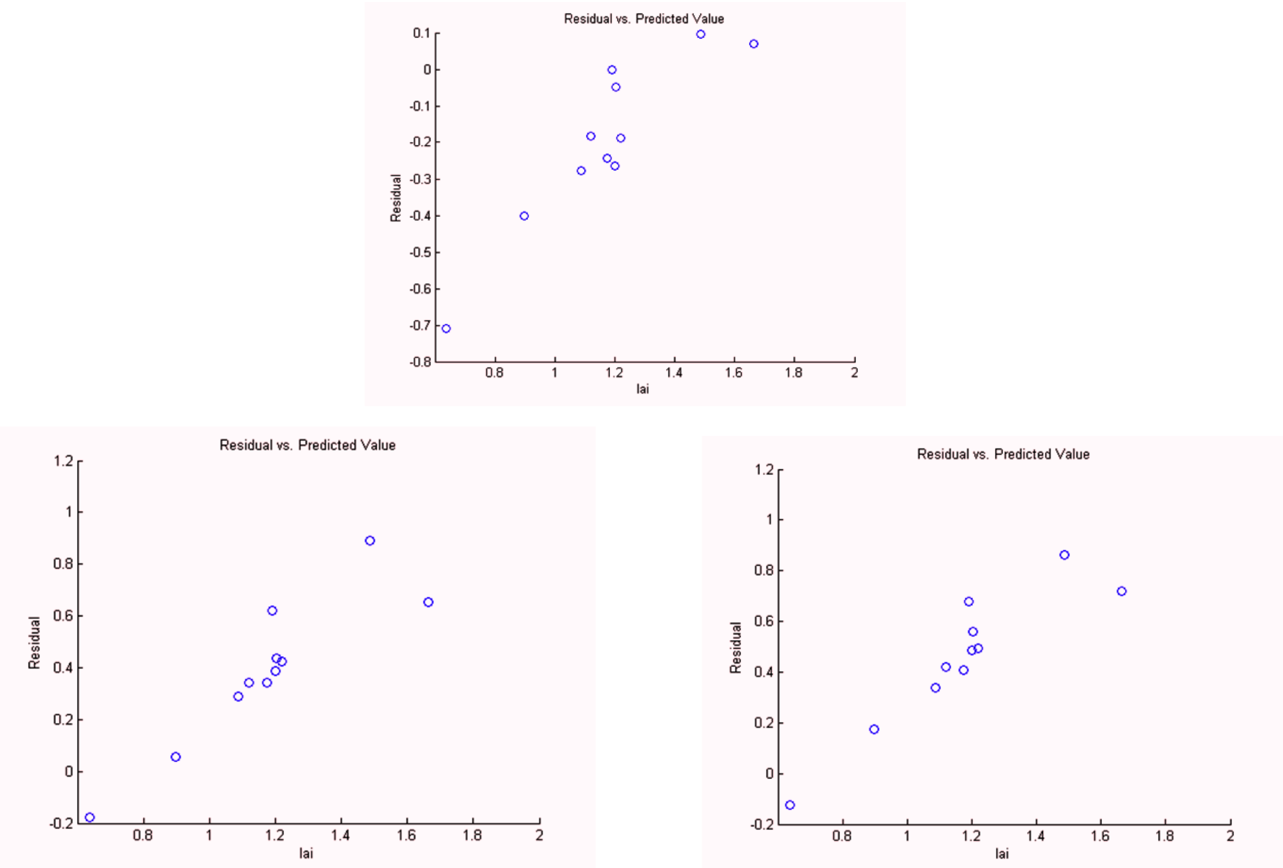

Figure 15. RMSE, Paerson and Shannon cost functions tested to evaluate the accuracy of LUT-based inversion method

6. DISCUSSON

The leaf area index (LAI) represents the amount of soil surface that is covered by vegetation. It ranges from 0 (bare ground) to 10 (dense conifer forests). It is used to predict photosynthetic primary production, evapotranspiration (xxii). The higher the LAI, the more light is intercepted and the higher the primary production will be. Vegetation with large leaves do not necessarily show a large LAI as it depends on the orientation of the leaves[5]. The investigated wetland area was mainly covered with grass species. Some of them were characterized with large leaves, but those were standing upright almost perpendicular to the soil surface. This explains the relatively low LAI values measured even in the highest and densest vegetation sites (site 20 and 21). The center of the swamp was covered by a '*moss carpet'*. The moss carpet is very dense, covering the soil very well. But this type of vegetation is also extremely low and humid. The LAI is measured with the SunScan following the TIR-procedure. However, it is impossible to insert the SunScan under the moss vegetation. Like we did in the other vegetation plots, the Sunscan was kept 5 to 10 cm above the ground level and therefore also on top of the moss carpet. This resulted in extremely low LAI values in certain plots (site 25, 26 and 27). This is a difficulty one should take into account when performing research in carpet like vegetation types.

This explains also why the LAI is considerably overestimated in ARTMO for the sites with LAI smaller than 1 (*Figure 14*). ARTMO is a toolbox developed for vegetation purposes and it performs not very well on non- or less vegetated areas. To make the modeling more reliable also bare soil and water surfaces should be incorporated. The swamp area is characterized by a high heterogeneity. Therefore, adding a priori information (xxiii) would also help to make the models more accurately approximating the reality. Identifying all vegetation types on a very large scale is not achievable let's say practical, so recent research focuses on identifying vegetation types based on hyperspectral information [6]. Anyhow, simulations or even hyperspectral measurements will never represent the true reality, but can only approximate it as closely as possible. Within the scope of the summer school (when this research was conducted) we only compared ground 'truth' data with near ground data from UAV's. The weather condition was clear with some cumulus are the most important factor influencing the outcome.

7. CONCLUSIONS

Wetlands can be characterized with high heterogeneity and therefore a high spatial variability of reflectance or biophysical parameters (e.g. LAI) can be observed. Nevertheless, biophysical parameters (e.g. LAI) can be successfully (error$< 30\%$) mapped with LUT-based inversion of RTM and airborne (UAV) hyperspectral data. Improvement of modelling can be achieved by collecting more ground truth data of plant functional traits (PFT).

This report gives insight in how LAI should be investigated on a larger scale and which difficulties should be taken into account doing so. Even in this preliminary investigation we could reliably predict LAI in a heterogeneous landscape. Perspectives for deeper research on the ecology of the swamp area could include long term research. Changes in LAI, chlorophyll content and other bio-physical parameters indicate changes in ecology. The most sensitive biophysical parameter is however chlorophyll fluorescence. When plants experience stress, for example drought or water/soil pollution in the investigated swamp area, the fluorescence will increase significantly (xxiv).

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Fluorescence is a fraction of reflected light. Stressed vegetation cannot convert light energy as efficient as non-stressed plants into chemical energy and therefore re-emit more light back into the atmosphere (fluorescence wavelength around 685 nm and 730 nm). Once again, extensive research has to be performed to include all factors influencing the reflected (fluorescence) signal to draw reliable conclusions.

Future research on the wetland ecosystems over a long term period (e.g. PhD) should involve contact leaf measurements and measurements at canopy level, both near ground and airborne. Such a data set allows comparison of information retrieved from different heights to provide extremely valuable information towards the validation of airborne and spaceborne methodologies. Also the study of a changing or degrading environment provides valuable information on the detection of stressors from hyperspectral data at an early stage. Changes can be detected from LAI and chlorophyll mapping as mentioned before in this report. However, recent articles focusing on the impact of stressors focus on fluorescence and new state of the art techniques to measure this sensitive, but tiny, signal are developed and improved continuously. As fluorescence is a delicate signal, investigation of this should be accompanied with analysis of LAI, chlorophyll content, nitrogen content, leaf water content and others parameters to be sure drawn conclusions from the fluorescence signal are reliable. This signal varies with changes in leaf structure, other stressors, etc.

Soil pollution could lead to less water uptake, but drought stress on the other hand closes stomata to avoid evapotransporation and would maximize water uptake. The interference of the different stressors and their implications on the vegetation health (fluorescence) or structure (in extreme stressful situation a destructive impact can be observed in biophysical parameters as chlorophyll content, nitrogen content, LAI, SLA (specific leaf area), etc.) is a very interesting research field. A lot of future research should focus on this topic. Findings can then be included in the ARTMO toolbox, which still lacks the ability to simulate the impact of various types of stressors. If possible, stress situations on plants can be created artificially in green houses on cultivated vegetation. Laboratory experiments allow to combine stressors as required and excludes uninteresting field conditions.

8. ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2014-2018) under grant agreement n°312609 (EUFAR: European Facility for Airborne Research in Environmental and Geo-sciences), COST Action ES1309 OPTIMISE (Innovative Optical Tools for Proximal Sensing of Ecophysiological Processes and the European Space Agency).

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