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**ABSTRACTS**

**ReSe**  
Applications  
Schläpfer



**Monday, 8<sup>th</sup> April**

**Plenary Session: Future IS Missions**

**EnMAP - Germanys Hyperspectral Earth Observation Mission: Mission status and scientific objectives**

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**Keywords:** EnMAP, hyperspectral, mission status, CDR, science plan

The German EnMAP (Environmental Mapping and Analysis Program) hyperspectral Earth observation satellite mission will provide high quality hyperspectral image data on a timely and frequent basis to the global user community. The main objective of the mission is to retrieve accurate, quantitative diagnostic bio-geochemical and geophysical parameters thus allowing the observation of a wide range of ecosystem properties. The data provided will enable research in various application fields such as natural and anthropogenic land cover, soils and mineralogy, inland waters and coastal zones and will prepare operational information services in these applications.

After successful completion of the CDR in 2012, the details of the mission are laid out, including an innovative hyperspectral sensor concept with a radiometric quality, never reached before, in the whole sensing spectrum, ranging from the VIS to SWIR.

The data provided through the mission will extend the scientific and technical know-how based on former spaceborne and present airborne hyperspectral sensors. The Science Plan developed for the mission addresses several global challenges for humankind like climate change, decrease of air and water quality, loss of biodiversity, population increase leading to growing resource needs and others to which the mission shall contribute. By measuring diagnostic parameters that quantify the state and trend of environmental change, the stability of ecosystems, and the sustainability of resource use, the EnMAP mission aims to provide critical information for an improved understanding of the relevant processes and the management of the Earth System.

The presentation will give an overview of the present status of the EnMAP mission as well as the scientific objectives and preparatory activities on-going for data exploitation.

## **A simulator for the images acquired by the optical payloads on board of PRISMA mission**

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**Keywords:** Hyperspectral data simulation, Hyperspectral sensor, At sensor radiance, PRISMA mission

PRISMA (PRecursore IperSpettrale della Missione Applicativa) is an Earth observation system with innovative electro-optical instrumentation which combines a hyperspectral sensor with a panchromatic, medium-resolution camera fed by the same telescope.

In the framework of this mission, the Italian Space Agency (ASI) granted five independent scientific research contracts for investigating the possible applications and performance of the new hyperspectral sensor and its panchromatic companion which will be placed on board of PRISMA mission. OPTIMA (“Metodologie avanzate per l’analisi, l’integrazione e l’ottimizzazione dei prodotti di livello 1 e 2 della missione PRISMA”) is one of these contracts, and it is mainly devoted to assess the performance of the hyperspectral sensor by means of simulated image data. In order to characterize the performances of the mission before the launch, an image simulator for taking into account most of the phenomena that influence the acquired hyperspectral images has been developed.

For the simulation of hyperspectral images the major effects which will characterize each PRISMA acquisition have been considered. Illumination and acquisition geometry, spatial and spectral variability of the simulated scenes, and the interaction of the electromagnetic radiation with the soil and with the atmospheric constituents are implemented in the simulator. Specifically, the simulator is composed by three independent simulation blocks:

- 1) The scenario builder which simulates a reflectance ground map starting from cartographic data and spectral reflectance libraries;
- 2) The atmospheric propagation calculator based on Modtran 5.2 code which evaluates the optical parameters of the atmosphere using as input the reflectance map provided by the scenario builder;
- 3) The sensor simulator which computes synthetic images of the considered scenario as degraded from platform vibration and orientation, foreoptic MTF, atmospheric propagation, detector sampling, and noise. By applying different transfer functions which are related to the various steps of the acquisition chain, the sensor simulator is able to model the main effects introduced by the instrument.

The algorithms designed for PRISMA mission data processing applications will be tested using the images produced by our simulator.

In this paper, the development of a software tool that is devoted to simulate the images acquired by the hyperspectral imager of the PRISMA mission is presented. Results coming from the software implementation are shown and discussed, pointing out the critical topics of each simulation block.

## **HYPXIM – An innovative spectro-imager for science, security and Defence**

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**Keywords:** Hyperspectral satellite, Imaging spectroscopy, optical sensor specifications.

This paper provides a broad overview of hyperspectral applications and data requirements gathered by an ad-hoc group of around twenty French scientists and defence users. This group known by the acronym GSH (Groupe de Synthèse sur l'Hyperspectral) has collegially addressed clear and detailed technical requirements for a high spatial resolution hyperspectral mission on the following themes: study of vegetation, coastal and inland water ecosystems, geosciences, urban environment, atmospheric studies, security and defence. The synthesis of these requirements helped substantially to set up consolidated space-based system requirements (i.e. mission requirements) in terms of spectral domain, spectral resolution, signal-to-noise ratio, spatial resolution, swath and revisiting period, which revealed the main key drivers for the design of a very innovative hyperspectral space instrument.

During the phase 0, CNES with the support of industry (Astrium and Thales Alenia Space) has compared two different scenarios. The first scenario, named HYPXIM-C (as Challenging), aims at finding out the highest possible resolution level (15m) achievable using a microsatellite platform, whereas the goals of the second scenario, called HYPXIM-P (for Performance), are to reach a higher spatial resolution (8m) and to provide a TIR hyperspectral capability. The HYPXIM phase A was recently decided and focused on the most performing concept, but without TIR capabilities. The challenges for the selected HYPXIM mission were to design an agile high resolution spectro-imager on a mini-satellite (<1 ton) .

The wide field HYPXIM core mission performances are given:

- Spatial resolution: hyperspectral mode (HX): 8 m, Panchromatic channel (PAN): 1.85 m,
- Spectral domain: 0.4 – 2.5 $\mu$ m (VIS-to-SWIR)
- Spectral resolution: 10nm
- Image Quality: the Signal-to-Noise (SNR) at L2 is better than: VIS 250:1 ; NIR 208:1 ; SWIR 133:1
- Image size: 16kmx16km
- Revisit period (function of angle of view): 19 days (nadir) and 3-days (+/- 35°).

The HYPXIM spatial segment is composed of one satellite on a sun-synchronous orbit at an altitude of 660 km (10.30-11AM Local time). Thanks to a great on-board agility, system imaging capacity is more than 250 square images per day, downloaded through X-band at 620 Mbps either to ground or to mobile stations. The HX imaging capacity is mainly limited by the need for high spatial resolution which forces the satellite to slow down when taking hyperspectral images.

Preliminary studies with industrial support show that this challenge can be taken to space around 2020/21 depending on the development of critical technologies (like specific detectors). Expected lifetime in orbit is 10 years, including end-of-life operations.

## **Parallel Session 1: Agricultural and forestry applications**

### **Spectral differentiation of *cannabis sativa L.* from maize using carotenoid indices**

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**Keywords:** *cannabis sativa L.*, maize, carotenoid reflective Index, photochemical reflective index

Cannabis is increasingly being illegally cultivated in large quantities in some parts of South Africa. Over the years the growers have been intercropping cannabis with maize to conceal it from the law enforcement and suspecting intruders. The South African Police Services have been using aerial spotter to identify cannabis from other land cover, however, it proved to be a challenge to identify it when intercropped with other plant species especially maize. The use of remote sensing techniques can aid in discriminating cannabis from maize as a result this study will investigate the use of hyperspectral spectroscopy to discriminate these two plant species. We looked at two carotenoid sensitive indices as medium for discrimination, photochemical reflective index (PRI) and carotenoid reflective Index (CRI) which are between 520 and 800 nm. To conduct the study both cannabis and maize were grown in a greenhouse environment under controlled conditions. We used an ASD spectral-radiometer to measure spectral profiles of both species in a dark room. The resulting spectral profiles were analysed using a t-test. The analysis indicated that PRI was incapable of detecting cannabis when planted with maize with a mean of 0.0311, std dev = 0.024, t-value of -1.55 and a p-value of 0.1295. CRI was nonetheless able to significantly identify cannabis when cultivated with maize with a mean of 2.1597, std dev = 0.7282 and p-value: 0.00015. As a result CRI was subsequently recommended for spectrally discriminating these plant species using carotenoid content.

## **Estimating phenological stages of barley from multi-temporal imaging and non-imaging hyperspectral data**

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**Keywords:** hyperspectral, phenology, machine learning, randomForest, libSVM, barley

In this study we tested two machine learning methods to derive phenological stages of barley based on multi-temporal hyperspectral data. Hyperspectral data are, among other things, characterised by their high dimensionality and autocorrelation. Common multivariate regression approaches, which usually include only a limited number of spectral indices as predictors, make not fully use of the available information content. In contrast, machine learning methods are supposed to be better suited to extract information on vegetation status. Additionally, we investigated whether the use of imaging vs non-imaging hyperspectral data affects the prediction performance of the methods tested.

Measurements were conducted in the Helmholtz Centre for Environmental Research (UFZ) laboratory for summer barley (*Hordeum vulgare* L.) from April 27 to July 20 in 2009, thus covering a full vegetation period on a semi-weekly basis over a total of 23 measurement days. Parallel to Analytical Spectral Devices (ASD) FieldSpec 3 (Analytical Spectral Devices, Inc., 2005) spectrometer measurements also imaging hyperspectral data using AISA-Eagle (Specim, 395-973 nm) were gathered.

Firstly, Random Forest (RF) was applied on all available spectral bands of ASD data (non-imaging) for summer barley. Based on RF BBCH stages (phenological development stages based on the 'Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie', Germany) could be predicted with  $r^2 = 0.76$ . Prediction performance decreased only slightly when only bands are selected which cover the electromagnetic spectrum of the AISA-Eagle ( $r^2 = 0.74$ ).

In the second approach Support Vector Machines (LibSVM) were tested on imaging data with a prepended recursive conditional correlation weighting selection algorithm (RCCW) to reduce the number of variables. To increase the performance of the model a 10-fold cross-validation was carried out for all statistical models. In contrast to the first approach 58 well-known published VI's were used for predicting phenological stages rather than the full amount of spectral bands. Results showed that the best prediction of BBCH macro-stages could be achieved with a combination of PRI (Photochemical Reflectance Index), Renormalized Difference Vegetation Index (RDVI) as well as Water Band Index (WBI) (classification accuracy of 82.39%).

## **Remote estimation of crop biophysical characteristics: from close range to satellites**

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**Keywords:** remote sensing, crop biophysical characteristics, GPP, LAI, Chl, N

The quantification of vegetation cover, absorbed photosynthetically active radiation (fAPAR), chlorophyll (Chl) content as well as gross primary production (GPP) in vegetation brings objective measures of the size and the functionality of its photosynthetic components. Canopy Chl content is well suited for quantifying canopy level nitrogen (N) content. Chl is a physically sound quantity since it represents the optical path in the canopy where absorption by Chl dominates the radiometric signal. Thus, Chl absorption provides the necessary link between remote sensing observations and canopy state variables that are used as indicators of N status as well as primary productivity. Success in estimating Chl content using remotely sensed data may provide equally accurate measures of N content, CO<sub>2</sub> assimilation, and RuBP carboxylase activity. However, there is still a lack of accurate, rapid, and practical methodologies available for this purpose.

This study presents the results of estimation of such crop biophysical characteristics as vegetation cover, fAPAR, green LAI, Chl, N, and GPP from close range, aircraft with hyperspectral AISA imaging spectrometer, and satellites (MODIS and ETM Landsat). Firstly, we established relationships between reflectances in visible and NIR ranges of the spectrum and biophysical characteristics at close range. Secondly, we identified optimal spectral ranges allowing accurate estimation of biophysical characteristics of maize and soybean, crops with contrasting canopy architectures and leaf structures, over a wide range of leaf area index values. These optimal spectral bands coincide well with spectral bands of near future satellite sensors Sentinel-2 and Sentinel-3, which allows monitoring crop biophysical characteristics with high spatial and temporal resolutions. Finally, the performance of developed techniques to retrieve biophysical characteristics was tested using sensors onboard of aircrafts and satellites.

## **Comparing feature selection methods for imaging spectroscopy data in the context of a tree species classification scenario in three different forest sites**

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**Keywords:** HyMap, Apex, Tree Species, Feature Selection, classification, SVM, RandomForest

In order to provide insights into the performance of feature selection methodologies in combination with classification algorithms and the significance of abundance as well as position of spectral information of different wavelengths in forested areas a comparative study in three mid-European woodland areas is performed. Eleven classification approaches to separate tree species from airborne hyperspectral data (with 3-5m pixel size) of three different forest sites are compared. Examined approaches include three advanced feature selection methods: genetic algorithm, SVM wrapper and a partial least square based method. Each of the methods was combined with two state of the art non parametric classifiers (SVM, Random Forest) and one parametric classifier (Naïve Bayes). In order to evaluate the benefit of the feature selection methods, SVM classifications without feature selection were applied on the full hyperspectral dataset and on the Minimum Noise Fraction (MNF) transformed dataset with a reduced number of bands. All classification approaches are implemented on the basis of 60 samples per tree species, which were collected in a stratified random sampling approach. For two of the test sites five species are classified while in the third site seven species are examined.

The classification workflow can be summarized with three processing steps: a) The creation of subsets of 5, 10, 15, 20, 25 and 30 bands from the original hyperspectral image using the implemented feature selection methods. The subsets were then used as input to the classification process which can be subdivided into two further steps: b) Application of a 100-times bootstrap cross-validation in order to find the optimal settings for the classification algorithm c) Realization of a 100-times cross-validation of the classification scenario with the optimal parameter settings of the classification algorithm. This cross-validation which uses again a bootstrap allows for the estimation of the variance in classification accuracies as introduced by the usage of differing combinations of training and validation samples.

First results indicate that an increased number of selected bands, in the defined range between 5 and 30, at first increases classification accuracy but seems to stagnate at a number of 20-25 bands, depending on the selected classifier and test site. In some cases also a decreased accuracy could be observed when using 25 or 30 bands. Average overall-accuracies retrieved from the 100-times cross-validation of the classification approaches conducted so far reached values ranging from 60% to over 80%, depending on the methodology used and on the test site.



## **Parallel Session 2: Data Pre-processing – Calibration – Validation**

### **Calibration and characterization of hyperspectral imaging systems**

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**Keywords:** calibration, characterization, hyperspectral, hyspex,

In order to get meaningful and scientifically valid data from a hyperspectral imaging system, it is essential that a detailed and accurate calibration of the instrument has been performed. Typically an absolute radiometric calibration is performed to enable conversion of the raw DN (Digital Number) data to radiance values ( $W/m^2 \text{ nm sr}$ ) and a spectral calibration gives the band center wavelengths for all bands.

Given the complexity and subtleties in the specifications of hyperspectral systems as well as the tight manufacturing tolerances, any high performance instrument should also undergo a detailed factory acceptance test prior to shipment. The factory acceptance test should verify and document all critical system performance parameters as well as environmental stability.

For advanced users, access to the real performance specifications of the individual instrument may enable the user to improve the final data product generated by the instrument, especially in cases where the instrument performance is not ideal (e.g. stray light correction, resampling in case of strong smile and keystone effects, etc.).

The environmental stability of the hyperspectral instrument is important in order to maintain stable data quality. Very small movements (even at the sub- $\mu\text{m}$  level) of optical components, mechanical mounts or sensor within the instrument can lead to significant deterioration of the system's performance. Such movement can be introduced by vibrations or shocks during transportation or use (e.g. in an aircraft), so it is essential that such instruments are mechanically stable.

This presentation describes the calibration and characterization procedures established by NEO over more than a decade of development of the HySpex instruments. Characterization of parameters like keystone, smile, spectral and spatial resolution, pixel spread function in both along track and across track direction, SNR, NER, bad pixels, polarization dependency, second order suppression, straylight and sensor model will be described. It will also cover topics related to stability of the calibration and characterization with regards to temperature, vibrations and over time.

## **Extending DLR's operational data quality control (QC) to a new sensor – results from the HySpex 2012 campaign**

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**Keywords:** data quality control, preprocessing, operational processing

With the acquisition of a HySpex VNIR & SWIR sensor system from NEO, DLR has added a new sensor to its OpAiRS (optical airborne remote sensing and calibration) service. This ISO9001 certified service includes the data processing from raw data up to L2 (geo & atm. correction), sensor calibration (in DLR's calibration homebase CHB and in-flight calibration) as well as sensor operation and customer contact. Over the last 16 years, DLR mostly operated the whiskbroom sensor HyMap, and for this purpose dedicated data quality control (QC) tools were developed. In a joint European approach within the FP7 EUFAR JRA HyQuaPro, data QC approaches were extended and harmonized for the the largest PAFs.

Within this presentation, the requirements and the completed methodological developments for extending the operational data QC to a two camera pushbroom scanner system are shown. To illustrate these developments, results from the analysis of the first HySpex campaign in 2012 are presented and compared to the previous HyMap campaigns. As an outlook, the similarities and differences in data QC developments for the spaceborne EnMAP are included.

## **An automated pre-processing chain for airborne hyperspectral data including radiometric calibration, atmospheric correction and direct georeferencing**

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**Keywords:** hyperspectral, pre-processing, radiometric calibration, atmospheric correction, direct georeferencing,

Airborne hyperspectral image data become more and more prominent since sensors and data take costs are decreasing. However, accurate data require a careful pre-processing utilizing an automated, consistent and standardized process chain. This study reports improved software with regards to georeferencing and mosaicking consisting of integrated, highly flexible but robust methods in terms of quality and quantity. Its design is mainly driven by the data quality and sensor characteristics.

The processing chain starts with the aggregation of required and available meta information for every single flight stripe (sensor information and configuration, orientation and illumination parameters). Incorporating such information radiometric calibration (offset, gain, spectral binning, smear correction, destriping), direct georeferencing (IMU-image synchronization, boresight calibration, warping), atmospheric correction (ATCOR) and image mosaicking are automatically performed within a sequential processing. The accuracy of the image geometry is mainly limited by the quality of the inertial measurement unit (IMU) data and the boresight calibration. Therefore, inaccuracies are improved by optimization of the synchronization between IMU and image and the improvement of outer orientation parameters employing feature-matching and feature-optimization techniques. The procedures do not require manually determined GCP's, D-GPS post processing, electronic IMU-Sensor synchronization and multiple resampling. The software was tested using AISA-DUAL data. The results of several test sites are presented showing clearly the improvements of the optimized processing chain.

## **Monitoring the spectral stability of the APEX instrument through the combination of NIST filter and atmospheric feature analysis**

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**Keywords:** APEX, smile, stability monitoring

Since its acceptance in 2010 more than 1.7 TB of hyperspectral airborne data have been acquired with the Airborne Imaging Spectrometer APEX (Airborne Prism Experiment) for users all over Europe. To ensure the highest image quality, intensive on-ground calibration campaigns are carried out at least once a year at the Calibration Home Base (CHB) situated at DLR. The infrastructure at the CHB allows to perform a full geometric, radiometric and spectral characterization/calibration of APEX. However this characterization is performed at laboratory conditions (i.e. room temperature, ground atmospheric pressure). Therefore environmental conditions during the calibration differ from those encountered during the actual APEX image flights.

To monitor sensor's performance in-flight APEX has been equipped with an onboard in-flight characterization (IFC) facility. The IFC facility has mainly been used for in-flight spectral stability monitoring: APEX IFC data are acquired with the instrument shutter closed while light from an internal stabilized QTH (Quartz Tungsten Halogen) lamp is reflected by a mirror into the optical path and spectrally filtered through a NIST filter. The NIST filter is characterized by several narrow features which are used to trace shifts in position of the spectral bands. Analysis of these IFC measurements (D'Odorico et al., 2010) revealed instabilities in the spectral performance of APEX caused mainly by difference in differential pressure and temperature. This necessitates the need for regular in-flight spectral stability monitoring. However as a full IFC run takes around 10 minutes, spectral characterization through the use of the IFC facility is often limited to the analysis of a IFC acquisition before and after each mission. This is not always sufficient to monitor and characterize the instrument's spectral stability as several data acquisitions might last up to a few hours or acquisitions are performed at different altitudes over the same area. To overcome the problem of insufficient IFC data the spectral shift analysis for the operational processing at VITO is currently performed by the analysis of atmospheric absorption features. This has as advantage that spectral shifts can be determined for each image separately allowing to characterize spectral instabilities occurring within one flight area. A drawback of this approach is that the number of useful atmospheric features is rather limited and that they are spectrally not well spread over the full spectral range of APEX which causes uncertainties in the inter/extrapolation of the observed shifts to other wavelengths.

During the 2012 flight season experimental APEX image acquisitions were performed with the NIST filter interposed in the optical path while keeping the instrument shutter open. These acquisitions can be performed quickly just before and after each flight line, for example during airplane turns to realign for the next flight line. Furthermore spectral shifts can be determined on the basis of both NIST and atmospheric features on the same image. Here we will present the results of these experimental flights for both unbinned and binned APEX acquisitions.

## **Automatic reduction of keystone – applications for EnMAP (3466)**

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**Keywords:** EnMAP, keystone, hyperspectral

The number of hyperspectral pushbroom data acquisitions is currently increasing coping with improved spatial and spectral resolutions. Geometric non-uniformities such as keystone generally aggravate succeeding spatial and spectral data analysis due to band dependent detector illumination displacements. Keystone can be considered as nonlinear across-track inter band deformation, are often visually perceptible as blurring of sharp edges or spatial gradient doubling in ratio images and need to be generally reduced.

This reduction is often performed beforehand by tie point supported image-to-image transformations between a base image and a warp image. It is necessary to select tie points that are contrast, illumination, scale, rotation and affine transformation invariant and should be sub pixel definable to achieve high rectification accuracy and to reduce sensor specific spatial asymmetries.

In this work an automatic approach for a significant keystone reduction will be presented that can be generally applied on pushbroom acquisitions. It relies on least squares sub pixel matching, invariant feature description and validation by adapted phase correlation per band. At first, local gradient extrema are determined at different spatial and blurring scales. Then, all extreme crossing points are sub pixel determined and rotation and scale invariant described. Finally, a normalised feature fitting between the tie points of the bands is applied and weighted. The fitting result is incorporated in a succeeding polynomial least squares regression. The reversed polynomial coefficients are used to apply the keystone reduction validated by a high precise phase correlation technique.

The approach was tested on numerous samples of simulated EnMAP scenes. In most cases, several thousands of tie points are identified giving a succeeding polynomial regression a high degree of freedom. In sum, an average image or keystone improvement of more than 80 % was achieved that was verified by affine variant phase correlation. The proposed method is completely unsupervised, sparse parameterised (only stopping criteria) and capable to reduce the keystone in EnMAP and other pushbroom acquisitions.

Tuesday, April 9<sup>th</sup>

**Parallel Session 3: Coastal Environment and Limnology (1)**

**Spatial and airborne remote sensing of coastal colonization by wild oysters *Crassostrea gigas***

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**Keywords:** *Crassostrea gigas*, remote sensing, hyperspectral, multispectral, stock, Spectral Angle Mapper (SAM)

The invasion of wild oyster *Crassostrea gigas* along the western European Atlantic coast generates changes in the structure and functioning of intertidal ecosystems. Initially considered as an invasive species, it is now seen as a resource by oyster farmers following summer mortalities of cultivated oysters. Indeed wild oysters are now collected both by recreational and professional fisherman but also by oyster producers to replenish their stock and this generates local conflicts. It is thus necessary to obtain spatial distribution maps of wild oysters to assess accurate stock estimates and analyze their evolution to define management strategies. In this study, spatial distribution of wild oysters was analyzed in Bourgneuf bay (France; 47°0'N, 2°10'W) with SPOT multispectral and HySpex hyperspectral images. Atmospheric correction were performed using FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) to estimate surface reflectance. Several noise corrections methods were used to improve hyperspectral images quality. First, spectra were smoothed applying a pass-band filter with FWHM (Full Width at Half Maximum) of 9 nm. The Minimum Noise Fraction transform was employed to eliminate noise bands and improve Signal/Noise ratio. The flight lines were adjusted by pair from the mosaicking parameters to correct the effects of illumination variations and optimize mapping process. Spectral signatures of microphytobenthos, macroalgae, water, bare rocks and oyster reefs were collected in situ with a FieldSpec ASD spectroradiometer covering a wavelength range of 350-2500 nm with a spectral resolution of 3 to 10 nm. It was possible to identify oyster reefs with hyperspectral images using a Spectral Angle Mapper classification based on the field spectral library, but this was not the case with multispectral images. However, a distinction between bare rocky areas and surfaces covered by macroalgae was done with SPOT images using the Normalized Difference Vegetation Index, and subsequently used to improve oyster stock estimations. This study demonstrated the interest of remote sensing for the management of shellfish ecosystems.

### **Microphytobenthos mapping of the Loire estuary by hyperspectral remote sensing**

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**Keywords:** Loire estuary, microphytobenthos, Hyperspectral images, chlorophyll a.

Estuarine intertidal sediments are colonized by assemblages of photosynthetic microorganisms grouped under the generic term of microphytobenthos. They form transient biofilms at the sediment surface at low tide and play two major roles: they can represent up to 50% of the total primary production of estuarine water, and contribute to the stabilization of sediments by exopolysaccharides secretion. These biofilms are characterized by high level of patchiness at microscale, but the spatio-temporal structures at meso- or macroscale is little known. In this work, we used airborne Hyperspectral remote sensing to map microphytobenthic assemblages at such scales, using the synoptic properties inherent to this technology and its ability to retrieve environmental variables of sites hardly accessible by conventional sampling. Currently, there is a limited number of studies dealing with the distribution of benthic microalgae at the entire scale of an estuarine ecosystem.

This study aims to map the spatial distribution of microphytobenthos in the polyhaline domain of the Loire estuary, using hyperspectral airborne images acquired with HySpex camera, in September 2010 and August 2011. Hyperspectral images were calibrated to reflectance using FLAASH (Fast Line of sight Atmospheric Analysis of Spectral Hypercubes), with ENVI® software and MODTRAN4 transfer codes for the atmospheric corrections. Spectra were smoothed by using a pass band filter to remove noise. A second atmospheric correction was applied by using field spectra from a white target. In a first step, microphytobenthos was identified, by applying the NDVI (Normalized Difference Vegetation Index) and MPBI (MicroPhytoBenthos Index). In a second step, the images were expressed as the concentration of chlorophyll a ( $\text{mg}\cdot\text{m}^{-2}$ ) was estimated, using a radiative transfer model (microphytobenthos optical model) and compared with HPLC measurements. The first results showed a significant presence (up to 90% coverage) of the biofilm in polyhaline mudflats with a differential spatial structure and biomass between these two images. These differences are discussed considering the structuring factors explaining the microphytobenthos biomasse dynamics.

## Using hyperspectral images to study *Zostera noltii* epiphyte spatial distribution

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**Keywords:** hyperspectral imager, seagrasses, epiphytes

Seagrass beds are one of the world most productive marine habitats, carrying out important ecosystem functions, e.g. supporting a high biodiversity of invertebrates, fish (including nursery species) and directly, or indirectly through epiphytic growth, acting as a food supply for a range of grazers. Seagrasses are frequently covered by epiphytes (micro and macroalgae) that can represent a significant proportion of seagrass bed primary productivity (>50%) and which also play an important role in nitrogen fixation. Epiphyte spatial distribution is highly dynamic, both temporally and spatially, with high variability at the scale of individual blades. The objective of the current work was to develop a hyperspectral imaging method to map the biomass and diversity of epiphyte growth on *Zostera noltii*. *Z. noltii* leaves from the Bay of Bourgneuf were collected at three shore levels (low, middle and high shore) and were imaged using a hyperspectral camera (Hyspex, Norsk Elektro Optikk) over 160 spectral bands between 400 to 978 nm. Spectral images were processed carrying a second derivative analysis to detect the variation in epiphyte pigment content between leaf blades, plants and shore heights. Second derivative images showed excellent resolution in separating the different epiphyte groups, with the second derivatives of 539 nm highlighting areas covered by diatoms, 568 nm isolating all the rodophyte epiphytes and 651 nm highlighting the areas that were not covered by epiphytes. These derivative images correspond to known absorption peaks of characteristic pigments from the different taxonomic groups, i.e. fucoxanthin in diatoms, phycoeritrin in rodophytes and chlorophyll b in *Z. noltii*. Visual observation by optical and scanning electron microscopy confirmed the presence of these groups associated to the derivative results. Quantitative analysis of the images showed that the low shore leaf blades had the highest epiphyte load of the three shore levels and that the epiphyte biomass decreased from leaf apex to the base. Low shore leaf blades also showed the highest epiphyte diversity, showing the presence of rodophytes and filamentous diatoms which were not present in the other shore levels. In conclusion, the application of second derivative analysis to hyperspectral images showed high potential to be used in the spatial analysis of seagrass epiphytes.



## **Microphytobenthos assessment by hyperspectral remote sensing: the first temporal survey (2002 to 2011)**

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**Keywords:** microphytobenthos, map, biomass, MPBOM

Estuaries and coastal areas are highly important natural habitats, amongst the most productive marine ecosystems on earth. They provide vital ecosystem services to mankind and are particularly valuable as habitats and feeding grounds for a variety of organisms, such as birds, demersal fish and invertebrates. Over the last two decades, it has been established that the intertidal mudflats play a central role in the productivity of these coastal areas to the enrichment of the adjacent terrestrial and marine ecosystems via related trophic (aquatic transport of organisms and mobile consumers) and hydrodynamic (tidal and wave currents) pathways. The high productivity of the intertidal mudflats is due to their intensive microbial activity mainly generated by the microphytobenthos, supporting also an important local activity: shellfishery.

Microphytobenthos consists of unicellular phototrophic microorganisms group, dominated by diatoms (Bacillariophyceae class) at north mid-latitude (Europe and America), inhabiting the first millimetres of sediment. Diatom cells are able to migrate through the sediment and form a brown biofilm at the mudflat surface during diurnal low tide. These biofilms are easily observable and can cover several hectares. However, sampling intertidal flats is a complex, and frequently difficult, task. Intertidal sediments are often dominated by small sediment particles ( $< 63 \mu\text{m}$ ) forming large mudflats that are very hard to navigate or walk. It is therefore almost impossible to monitor MPB spatial dynamics using regular field sampling. Therefore, the remote sensing became an important tool as shown in recent works (Méléder et al., 2003; Combe et al., 2005; Kazemipour et al. 2012).

Currently, mapping microphytobenthos biomass ( $\text{mg Chl a.m}^{-2}$ ) without mis-estimation should be provided using physical model rather than semi-empirical methods. Therefore, only hyperspectral remote sensing supplies accurate spectral information for model input. The physical model used to mapping microphytobenthos biomass is the MPBOM (Kazemipour et al. 2011), linking the biomass to spectral data by the mean of optical properties, absorption coefficient,  $k$  and refractive index,  $n$ . This study presents the first temporal survey of these photosynthetic micro-organisms using five images from 2002 to 2011 (one from DAIS and four from HySpex sensor). The spatial distribution of microphytobenthos is discussed, associated to groundtruthing validation.

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## **Spectral library of submersed macrophytes - how distinct is their reflectance?**

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**Keywords:** submersed macrophytes, spectral library, freshwater lakes, Bavaria, RAMSES

Do the spectral signatures of submersed macrophytes change during growing season? How can possible changes be explained? Is there a “best time” for a flight campaign? When mapping freshwater lakes by remote sensing to estimate their ecological state, these and other evident questions have to be answered. Therefore, systematic spectral measurements upon four submersed macrophytes were carried out during the vegetation periods (May to October) of 2010 and 2011, respectively. At Lake Starnberg in the south of the city of Munich (Germany), the spectral signals of the invasive species *Elodea nuttallii* and *Najas marina* and the indigenous species *Chara aspera* and *Potamogeton perfoliatus* were collected by underwater RAMSES-spectroradiometers. To calculate remote sensing reflectance, downwelling irradiance and upwelling radiance were measured simultaneously twenty times just upon the surfaces of pure stands of the mentioned plants. This process was repeated up to seven times a day, five days a year, depending on cloud coverage and waves on the water surface. Additionally, phenological data and photographs were collected for documentation. Depending on the distance of the populations to the shore, the sensors were launched from a terrestrial platform or a fixed boat.

The setup of the study enabled the comparison of the reflectance spectra within one season as well as from one year to the other. In case of *Elodea nuttallii*, additional measurements were carried out at a population at Lake Tegernsee (also south of Munich) in 2011. Hence, comparisons of one plant in two different lakes could be drawn. The spectra of the particulate species offered identical or very similar shapes from one year to the other. This argues for a certain phenology of the specific plants and for the used method to be qualified to spectrally detect these changes and to collect representative spectral signatures. Hence, for each plant, specific results could be formulated. In case of *Chara aspera* a change from one spectral shape to another was detected in both years and could be explained with the occurring calcification of the thallus. In contrast, *Potamogeton perfoliatus* produced nearly identical spectral shapes along the sampling period. By measurements of *Elodea nuttallii* at two lakes, the influence of sediment covering the plant canopy could be defined. Similarities and differences of the spectral shapes of *Najas marina* could not be explained fully, due to a complex phenology. Male and female plants of different heights occurred simultaneously next to each other. Additionally, the reflectance spectra of different degrees of coverage were collected for all macrophytes.

To sum up, the applied method was proven to be suitable, to answer the questions at the beginning. Some underwater plants show different spectral signatures along the growing season. Changes, caused by calcification or sediment coverage could be explained in case of *Chara aspera* and *Elodea nuttallii*, respectively. How far these influences also occurred for *Najas marina* or if phenological changes are overwhelming could not be cleared until now. The collected spectra and their attribution to phenological stages are planned to be summarized in a spectral library, which could be used for the interpretation of remote sensing data. To include the knowledge about the phenological spectral fingerprints into image interpretation, multiseasonal acquisition of remote sensing data is recommended. To extend the spectral library later on, research on further macrophytes is necessary.

## **NIR-red Algorithms for Estimating Chlorophyll-a Concentration in Inland and Coastal Waters**

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**Keywords:** Chlorophyll concentration, NIR-red algorithm, MERIS, Sentinel-3

We present here results that strongly support the use of MERIS-based NIR-red algorithms as standard tools for estimating chlorophyll-a (chl-a) concentration in turbid productive waters. The study was carried out as one of the steps in testing the potential of the universal applicability of previously developed NIR-red algorithms, which were originally calibrated using a limited set of MERIS imagery and in situ data from the Azov Sea and the Taganrog Bay, Russia, and data that were synthetically generated using a radiative transfer model. We used an extensive set of MERIS imagery and in situ data collected over a period of three years in the Azov Sea and the Taganrog Bay for this validation task. We found that the NIR-red algorithms gave consistently highly accurate estimates of chl-a concentration, with the root mean square error as low as 5.92 mg m<sup>-3</sup> for the two-band algorithm and 5.91 mg m<sup>-3</sup> for the three-band algorithm for the dataset with chl-a concentrations ranging from 1.09 mg m<sup>-3</sup> to 107.82 mg m<sup>-3</sup>. This obviates the need for case-specific reparameterization of the algorithms, as long as the specific absorption coefficient of phytoplankton in the water does not change drastically, and presents a strong case for the use of NIR-red algorithms as standard algorithms that can be routinely applied for near-real-time quantitative monitoring of chl-a concentration in the Azov Sea and the Taganrog Bay, and potentially elsewhere, which will be a real boon to ecologists, natural resource managers and environmental decision-makers. We also present a temporal series of chl-a maps generated using the NIR-red algorithms from images acquired by the space-borne hyperspectral sensor HICO over the Taganrog Bay. The fine spatial resolution (96 m) of HICO images allows for a detailed analysis of the spatial distribution pattern of chl-a, and the fine spectral resolution (5.7 nm) offers a great potential for phytoplankton species discrimination. With the recent demise of MERIS, HICO presents itself as a suitable alternative tool for continual remote monitoring of the Azov Sea and Taganrog Bay regions until the launch and operation of the Ocean Land Colour Instrument (OLCI) onboard Sentinel-3, which is scheduled to be launched in 2014. OLCI has all of MERIS' spectral bands and the NIR-red algorithms are expected to yield chl-a estimates of similar accuracies from the OLCI data as from the MERIS data.

## **Parallel Session 4: Terrestrial Ecosystems**

### **Advanced Earth science data products from APEX**

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**Keywords:** imaging spectroscopy, earth system, advanced products

We present latest achievements using the 4th generation imaging spectrometer, namely the Airborne Prism Experiment (APEX). We discuss a number of advanced products, ranging from improved calibration approaches, BRDF correction up to a range of Earth system products such as vertical column densities of NO<sub>2</sub>, inversion of radiance data using Bayesian approaches to pigment retrieval under a variety of conditions. Higher level products such as biomass and ecosystem services will be discussed as well. Finally, advanced integration with structural data derived from LIDAR will be demonstrated as well. We conclude on the usefulness of high-dimensional data and discuss future activities on even further improving those products.

## **Continuous fields derived from imaging spectrometer data for ecosystem parameter mapping in Alpine regions**

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**Keywords:** imaging spectrometer data, continuous fields, ecosystem

The representation of gradients of biochemical and structural properties of ecosystems using a continuous fields (CF) approach bears advantages in comparison to discrete land cover classification schemes. Mapping land cover properties as gradients with gradual differences is today considered a more realistic approach than using discrete classes with hard boundaries.

The derivation of biochemical properties from remote sensing data for ecological studies can provide information about ecosystem conditions and habitat status. This paper describes the generation of CF maps of biogeochemical and –physical ecosystem parameters in a high mountain environment, i.e., the Swiss National Park (SNP). Such maps are derived from Airborne Prism Experiment (APEX) imaging spectrometer data acquired over the SNP in June 2010 and 2011, respectively. Abundance maps of predominant land cover types are combined with individual thematic information of each land cover type, resulting in a spatially continuous product.

Imaging spectrometer data from consecutive seasons allow for the study of stable patterns or variations of ecosystem parameters (e.g., columnar water content) in the observed area over time. For instance, the availability of water in alpine grasslands is, among others, an important factor for animal forage quality and quantity. Eventually, the produced CF maps can be linked to observations of spatial distributions of ungulates as observed by the SNP staff and may serve as a valuable input for explaining animal spatial behaviour and grazing patterns.

## **Pixels, Plants, and PLS-Regression – Mapping Floristic Gradients in Vegetation with Imaging Spectroscopy**

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**Keywords:** Biodiversity, Conservation, HyMap, Ordination, Species Composition

Conservation planning and management require detailed vegetation maps. Such maps are frequently generated with classification approaches that are used to describe the floristic composition of (semi-) natural plant assemblages in discrete units. These units feature, however, boundaries that are often artificial and do not reflect the fuzzy character of vegetation. Classification approaches may thus be inappropriate for a detailed description of ecosystems with gradual changes in the floristic composition (Trodd, 1996). Alternatively, ordination methods can be used to describe the compositional variation in vegetation as floristic gradients. The generalization abilities of these methods have been used previously to generate gradient maps that show floristic patterns as continuous fields (e.g., Schmidtlein et al. 2007).

In the present study (Feilhauer et al. 2011), gradient mapping was used for the first time in a heterogeneous landscape with intricate and gradually changing floristic composition. This landscape, the Wahner Heide area near Cologne, Germany, consists of a interlaced mosaic of various heath and grassland types. Imaging spectroscopy data of the area was acquired in a flight campaign in summer 2009 with a spatial resolution of 4 m GSD using the airborne sensor HyMap. Ground surveys taken in the same period provided information on the species composition of the vegetation (n = 195 plots). We tested the versatile ordination technique Isometric Feature Mapping (Isomap, Tenenbaum et al., 2000) regarding its abilities to extract floristic gradients from the vegetation data. These gradients were related to canopy reflectance using Partial Least Squares Regression (PLSR, Wold et al., 2001). The resulting regression equations were subsequently applied onto the image for a spatial prediction of the floristic gradients. The final maps were subjected to additional analyses targeting the scale-dependence of spatial variation in species composition. Isomap was able to translate 74% of the original floristic variation inherent to the vegetation data into a three-dimensional solution. The PLSR models for the resulting floristic gradients showed model fits ranging from  $R^2 = 0.59$  to  $R^2 = 0.73$  in calibration and from  $R^2 = 0.55$  to  $R^2 = 0.69$  in tenfold cross-validation. The gradient map provided detailed information on floristic vegetation patterns and could be related to underlying environmental gradients. Multiscale analyses revealed spatial patterns in the variation of species composition. The results show that (1) imaging spectroscopy is a valuable tool for detailed mapping of complex ecosystems, (2) remote sensing is able to deal with fuzzy transitions in (semi-)natural ecosystems, and (3) image-derived vegetation maps allow for additional analysis targeting the spatial scales of biodiversity patterns.

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## **Spectral characterization and identification of halophytes related to azonal salinations in a post-mining area near Halle (Central Germany)**

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**Keywords:** hyperspectral remote sensing, HyMap, inland salt marsh, decision tree, SVM, Random Forest

The substance output of mining dumps represents a landscape-ecological problem of global character. Tailing piles of potash salt processing underlie especially intense discharges causing azonal salinations of the environment. This is due to their high share in easily soluble salts. The resulting inland salt marshes often constitute important protective biotopes for the species conservation since they form the habitat of numerous endangered floral and faunal species. The inland salt marsh in the Weitzschke-depression near Halle (Central Germany) is an unique example with regard to its size and abundance of halophytes.

In VIS- and CIR aerial images that are standardly used for biotope type mapping, the generally highly structured stocks of halophytes can only be limitedly and insufficiently identified. Therefore, time-consuming and cost-intensive field mapping has been the only solution heretofore.

From 2007 until 2012 measurements of field spectroscopy were conducted in order to gather the spectral characteristics and the identifiability of halophytes and halophilic phytosociologies as well as their variance in different phenological stages. Halophytes of extreme locations (*Salicornia europaea* and *Suaeda maritima*) usually occur as mono or dominance stands and display specific spectral characteristics (shifts from the green towards the red peak and a low NIR reflectance). Likewise, it becomes apparent that salty phytosociologies (*Juncetum gerardii*, *Spergulario-Puccinellietum distantis* in halophilic form as well as *Bolboschoenetum maritimi*) are distinguishable from ruderal and segetal communities, on account of their spectral behavior.

Based on these spectral peculiarities, an algorithm for the detection of halophytes was developed. This was accomplished by means of hyperspectral imagery (HyMap). By the use of a decision tree classification with adapted vegetation indices (ratio of green-peak at 557 nm to red-peak at 635 nm; mean increase between 760 - 975 nm as well as depth of water band at 980 nm) the abovementioned salty phytosociologies could be determined. Due to the inclusion of modern methods of machine learning (SVM and Random Forest) the preciseness of the model could be further improved. The implementation of the algorithm for other areas would significantly facilitate the complex field work und would also enable a more cost-effective monitoring for inland salt marshes.



## **ARTMO's new Vegetation Indices (VIs) module to evaluate rapidly a multitude of VIs for mapping of biophysical parameters**

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**Keywords:** ARTMO, vegetation indices, toolbox, automating, biophysical parameter mapping

With the forthcoming superspectral Sentinel-2 and Sentinel-3 missions and the planned EnMAP and PRISMA imaging spectrometers, operational Earth observation (EO) is reaching a state of maturity. This unprecedented data availability requires processing techniques that are easy and fast to apply to obtain information about the plants' growth or health status. The easiest way to obtain maps of biophysical parameters is still through the calculation of simple vegetation indices. While a broad variety of vegetation indices nowadays exists, it remains nevertheless unknown whether the most appropriate VI has been used for mapping a biophysical parameter until all of them are evaluated. Hence, there is a need for a user-friendly toolbox that rapidly evaluates all possible VIs prior to applying the most appropriate one to EO imagery. Furthermore it would be of interest to have this Vegetation Indices toolbox linked to leaf and canopy radiative models so that systematically the impact of different vegetation types on VIs can be studied.

We have recently initiated the development of an innovative toolbox called ARTMO: "Automated Radiative Transfer Models Operator" (Verrelst, et al., 2011). ARTMO brings multiple leaf- and canopy-RT models together along with essential tools required for semiautomatic retrieval of biophysical parameters in one graphical user interface. In short, the toolbox permits the user: i) to choose between various invertible leaf and canopy RTMs with varying complexity (e.g., PROSPECT-4, PROSPECT-5, 4SAIL, SLC, FLIGHT), ii) to choose between spectral band settings of various air- and space-borne sensors or defining new sensor settings, iii) to simulate a massive amount of top-of-canopy (TOC) reflectance spectra of any sensor in the range of 400 to 2500 nm based on look-up tables (LUT) which are then stored in a database, iv) to run model inversion against optical imagery given a variety of cost functions and regularization options, and finally v) to train, validate and apply a variety of state-of-the-art machine learning regression algorithms (MLRAs).

This work presents a new 'Vegetation Indices' module implemented into ARTMO. This module encompasses a large collection of established VIs, as well allows the user to calculate systematically so-called generic indices. With generic VIs all possible 2-band combinations of a sensor are calculated according to the formula of an established index, e.g. SRI, NDVI. Further, the performance of each VI to map a biophysical parameter can immediately be evaluated against in-situ data or input data coming from the RTMs using a linear regression. As such, a systematic overview of the performances is provided through all kinds of statistical indicators (e.g.,  $r^2$ , RMSE) and scattering plotting. The generated linear regression model from the best performing index (or a user-defined alternative) can subsequently be applied to an image to map the required biophysical parameter. The module guides the user through the required steps, and, because of the simple algorithms used (VIs and linear regression), the VI analysis and final maps are obtained almost instantaneously.

We have tested the Vegetation Indices module using CHRIS data over Barrax, Spain. Both in situ data from the field campaign SPARC as well simulated data using the coupled models

PROSPECT-4 and 4SAIL (i.e. PROSAIL) were used. With the module all possible 2-band combinations according to NDVI and SRI were calculated and related to chlorophyll content (Chl) and leaf area index (LAI). Correlation matrices results show the most relevant band combinations. It was found that the synthetic dataset generated by PROSAIL led to higher correlations (up to  $r^2:0.95$ ) than the SPARC dataset (up to  $r^2:0.83$ ), however, it should be taken into account modeled situations may deviate from reality. Obtained Chl and LAI maps yielded consistent spatial patterns in comparison to alternative retrieval approaches (e.g., inversion or MLRAs).

It should also be noted that in theory the VIs can be linked to any kinds of surface-based (in situ) dataset, e.g. not only pigments over vegetated areas but also over water bodies. ARTMO further offers the possibility to compare the performances of different RTMs or study the impact of one or multiple parameters. Examples from different datasets and RTMs will be provided. In conclusion, ARTMO's newly developed Vegetation Indices module is a convenient tool to rapidly map biophysical parameters from EO imagery.

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## **Coupling radiative transfer models with machine learning regression algorithms for operational retrieval of biophysical parameters: opportunities for forthcoming superspectral and hyperspectral missions**

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**Keywords:** machine learning regression algorithms, ARTMO, radiative transfer models, biophysical parameter retrieval

With the forthcoming superspectral Sentinel-2 and Sentinel-3 missions and the planned EnMAP and PRISMA imaging spectrometers, operational Earth observation is reaching a state of maturity. At the same time, this unprecedented data availability leads to an urgent need for developing robust and accurate retrieval algorithms for biophysical parameter retrieval. Current operational biophysical parameter products (e.g., LAI, FVC, fAPAR) are typically produced through a neural network (NN) that has been trained by simulated spectra generated from radiative transfer models (RTMs). However, the retrieval schemes are not perfect and limitations have been identified (Baret and Buis, 2008). The reason for such limitations is that the used RTMs (PROSPECT+SAIL) and regression algorithm (NN) face fundamental shortcomings. On the one hand, PROSAIL may be too simplistic to represent properly reality. On the other hand, NNs not only behave as a black box, but also behaves relatively unpredictable when used with input spectra that deviate even slightly from what has been presented during the training stage unless proper regularization schemes are adopted. For these reasons, alternatives that overcome these limitations have to be sought for.

We have recently initiated the development of an innovative toolbox called ARTMO: "Automated Radiative Transfer Models Operator" (Verrelst, et al., 2011). ARTMO brings multiple leaf- and canopy-RT models together along with essential tools required for semiautomatic retrieval of biophysical parameters in one graphical user interface. In short, the toolbox permits the user: i) to choose between various invertible leaf and canopy RTMs with varying complexity (e.g., PROSPECT-4, PROSPECT-5, 4SAIL, SLC, FLIGHT), ii) to choose between spectral band settings of various air- and space-borne sensors or defining new sensor settings, iii) to simulate a massive amount of top-of-canopy (TOC) reflectance spectra of any sensor in the range of 400 to 2500 nm based on look-up tables (LUT) which are then stored in a database, iv) to run model inversion against optical imagery given a variety of cost functions and regularization options, and finally v) to train, validate and apply a variety of state-of-the-art machine learning regression algorithms (MLRAs).

Particularly, MLRAs have the potential to generate adaptive, robust, non-linear relationships and, once trained by a generic LUT, they are very fast to apply to any image. MLRAs learn the relationship between the input (e.g. reflectances) and output (e.g. biophysical parameters) variables by fitting a flexible model directly from the data. Typically, MLRAs are able to cope with the strong non-linearity of the functional dependence between the parameter and the observed reflectance. Among the best known MLRAs are NNs, but it remains to be questioned whether they offer the most flexible tools for parameter estimation, gaining

insights in the retrievals and evaluating retrieval performances. This is why in the recent years NNs are being replaced by more advanced, simpler to train regression methods. Specifically, the novel family of kernel methods has recently emerged as a powerful alternative to traditional NNs in many scenarios. Kernel methods typically involve few and intuitive hyperparameters to be tuned, and can perform flexible input–output nonlinear mappings. Examples of MLRAs include kernel ridge regression (KRR), support vector regression (SVR) and Gaussian Processes regression (GPR). Particularly interesting is the case of GPR, since it is transparent in terms of model development and it not only provides per-pixel mean estimates but also confidence intervals; that is, information about the quality of the retrieval. It remains nevertheless to be evaluated how well kernel methods (e.g. GPR, SVR, KRR) perform when being trained with large datasets generated from different types of RTMs (e.g. >10000 samples). Sparsifying solutions are available in the machine learning literature but so far they have not been evaluated in the context of remote sensing data analysis.

This work will present first results of the coupling of RTMs with MLRAs for operational retrieval of biophysical parameters chlorophyll content and LAI. A systematic analysis will be conducted, taken into account: i) different types and sizes of RTMs, ii) different kinds of MLRAs, iii) regularization options such as added noise, and, iv) the use of Sentinel-2 and Sentinel-3 and hyperspectral datasets. The retrieval strategies will be evaluated against the SPARC (Barrax, Spain) validation dataset. Associated confidence intervals will provide additional insight into the retrieval quality when applied to various images over different ecosystems. It is foreseen that this exercise will lead to a new generation of retrieval schemes applicable to the forthcoming superspectral and hyperspectral data streams.

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## **Parallel Session 5: Coastal Environment and Limnology (2)**

### **Using HICO data for the preparation of the future EnMAP satellite mission**

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**Keywords:** EnMAP, HICO, atmospheric correction

This study shows first results of pre-processing products using HICO data from Venice (AAOT) in Italy in combination with data from Aqua Alta Oceanographic Towers (AERONET-OC). The primary output of this study is a first evaluation of HICO data quality in comparison to different processing algorithms, focusing primarily on atmospheric correction methods (Tafkaa 6s, ATCOR, MIP). The main objective of this study is to test and to evaluate the EnMAP (Environmental Mapping and Analysis Program) pre-processing chain using HICO hyperspectral data. A clear advantage in using HICO for testing the processing chain is the unique opportunity to have real hyperspectral satellite data with specifications comparable to the EnMAP VNIR sensor requirements. One of the foreseen standard products of the EnMAP processing chain is atmospheric correction on water and on land. Three atmospheric correction methods were employed in this investigation (Tafkaa 6s, ATCOR, MIP) and applied to two different HICO scenes for comparison on land and on water.

## **Radiometric recalibration and atmospheric correction of hyperspectral HICO/ISS images for coastal and inland waters**

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**Keywords:** Atmospheric correction, coastal waters, hyperspectral sensor, HICO, radiometric calibration

The Hyperspectral Imager for the Coastal Ocean (HICO) instrument (Lucke et al., 2011), on board of the Japanese Experiment Module Exposed Facility (JEM-EF) on the International Space Station (ISS), is a pushbroom spectrometer designed to monitor the coastal ocean and inland waters. The HICO sensor acquires top-of-Atmosphere (TOA) radiance in 128 spectral bands within the 350nm to 1080nm spectral range (5.7 nm spectral resolution) at approximately 90m of Ground Sampling Distance (GSD). Nevertheless, only bands inside the 400-900nm are currently available due to low sensitivity of the sensor out of this spectral range (Gao et al., 2012)

The HICO instrument lacks from on-board spectral/radiometric calibration devices and stray-light blocking filters due to assembly problems and project constraints. This has an impact on the quality of the acquired signal showing stray-light and spectral/radiometric problems as reported (Gao et al., 2012 and Li et al., 2012). The recalibration of the sensor is therefore needed before applying any atmospheric correction and retrieval algorithms to obtain limnological characteristics of inland and coastal water bodies.

This work, presenting the full processing chain applied on the HICO Level-1b data, was divided in three phases: 1) radiometric vicarious recalibration of the TOA radiances acquired by the sensor, 2) implementation of an atmospheric correction algorithm and 3) retrieval of Chl-a content on the Albufera Lake (Spain) for validation of the processing chain against in-situ measurements.

In the first phase, a vicarious radiometric recalibration of the sensor was carried out by comparing TOA radiances simulated by the radiative transfer code MODTRAN5 against TOA radiances (Level-1b) as acquired by the sensor. Simulated TOA radiances were generated by propagating in-situ reflectance spectra through a characterized atmosphere. On one hand, reference spectra were taken and processed to extract spectral surface reflectance over a crop field. On the other hand, the atmospheric state, defined by the Aerosol Optical Thickness (AOT) and Content of Water Vapor (CWV), was determined from the measurements taken with the Aerosol Robotic Network (AERONET).

Secondly, a specific atmospheric correction algorithm was developed for HICO data. The algorithm relies on the image itself to retrieve the atmospheric state, i.e. AOT and CWV, by inversion of a MODTRAN5 generated atmospheric Look-Up Table (LUT). Due to the high influence of the aerosols scattering in the visible range an accurate AOT retrieval is needed. This was achieved by minimization of a cost-function between simulated and acquired TOA radiances over a set of cloud free pixels with spectral contrast. An improved Atmospheric Precorrected Differential Absorption (APDA) technique, based on the methodology reported

by (Schläpfer et al., 1997), was used to derive the CWV. After atmosphere characterization, reflectance is obtained with a simple inversion using the MODTRAN5 LUT.

The proposed processing chain, i.e. radiometric vicarious recalibration and atmospheric correction, was applied over a set of HICO images acquired over the Albufera Lake (Valencia, Spain), which is characterized by a high biomass and pigment concentration. A field campaign was performed, acquiring in-situ radiometric and Chl-a content measurements simultaneously with the overpass of the sensor. These measurements were compared with the retrieved Chl-a concentration maps by using the recalibrated and atmospherically corrected images. The results show the agreement between the in-situ measurements and retrieved products validating the full processing chain.

In conclusion, an accurate full preprocessing chain for HICO data has been developed, minimizing the instrumental calibration errors and therefore exploiting the capabilities of this hyperspectral sensor. It is foreseen that the automation of the proposed data processing chain will monitor the radiometric stability of the HICO sensor. In addition, radiometrically recalibrated HICO data could be used to simulate future Sentinel-3 OLCI data.

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## **Hyperspectral signatures of turbid and extremely turbid waters**

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**Keywords:** SWIR, turbid, water

The limits of optical remote sensing of aquatic systems are being progressively pushed into more and more turbid water, because of growing interest in the environmental impacts of the world's most important river estuaries/plumes and in the monitoring of inland waters. This evolution has already led to refinement of the black pixel assumption for the near infrared (NIR: 700-1000nm) marine reflectance and to the development of NIR-based Total Suspended Matter (TSM) retrieval algorithms for moderately turbid waters (10-100 g/m<sup>3</sup>). Extension of such approaches to extremely turbid waters (TSM > 100 g/m<sup>3</sup>) requires further refinement of theory and atmospheric correction algorithms. Use of the Short Wave Infrared (SWIR, 1-3  $\mu$ m) range then offers new opportunities. In addition there are a number of new airborne and satellite instruments such as Hypispi, Enmap, Sentinel-3 OLCI, APEX that will provide data in the SWIR in the near future.

Here an ASD spectrometer and Hydrosat with extended wavelength range are used to measure the water reflectance and light backscattering in several highly turbid estuaries. The measurements are related to the TSM concentration and linked with a theoretical model. These new measurements provide warnings to apply the black pixel assumption in turbid waters and give new opportunities for TSM retrieval in these turbid and extremely turbid waters.



## **Assessment of airborne hyperspectral coastal bathymetry capabilities based on IHO standards**

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**Keywords:** hyperspectral, bathymetry, IHO

State of the art methods for estimating the bathymetry from multispectral and hyperspectral remote sensing data are briefly reviewed. Those methods can be classified into different categories, mainly including empirical methods, radiative transfer inversion methods, and methods based on differential spectroscopy concepts.

From that review we show that the radiative transfer inversion methods have some interesting advantages from an operational point of view, including the fact that field data is in principle not needed to estimate the water depth, that the approach uses the full spectral information thus leading to take full advantage of hyperspectral data, and eventually that the other parameters of the model regarding the water column and the sea bottom can possibly be estimated in the same inversion procedure.

Radiative model inversion procedures however have some drawbacks, including the fact that in most of the procedures published, the objective is often the cartography of the sea bottom and a priori knowledge on the sea bottom is needed for that, leading to difficulties in the estimation of the water depth if the sea bottom is unknown.

In that paper we propose a procedure for estimating the bathymetry that tries to face the drawbacks listed here below, that has partly been developed as part of a research project named 'HypLitt' for the French Department of Defense (DGA). The Lee semi-analytic radiative transfer model is inverted without any a priori on the sea bottom introduced in the process, leading to the possibility of a joint estimation of the water depth and the water column parameters. In order to face the difficulties of the inversion without any a priori knowledge, we introduce in the process the concepts of the differential spectroscopy, leading to an inversion in the differential space.

The results obtained from different airborne hyperspectral data sets acquired by Actimar in different areas around the world are compared with MBES data provided by the French Hydrographic Service and by research projects led by the Brest University over the French coasts, as well as with topographic and hydrographic Lidar data. The benefits of using the concepts of differential spectroscopy are shown, in particular the gain in precision with regard to the water depth, and the robustness of the algorithm to the clouds shadows, opening the way to the possibility of doing airborne hyperspectral coastal bathymetry surveys under a cloud cover.

The precision as a function of the water depth is estimated and compared to the International Hydrographic Organization Order 1 and Special Order standards for bathymetric surveys, as defined in the special publication S44. The results obtained, and the complementarity of hyperspectral and hydrographic lidar surveys are discussed.

## **Potential of imaging spectroscopy for mapping plastic litter in the marine environment - A laboratory experiment**

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**Keywords:** imaging spectroscopy, identification of plastics, absorption features, sub-pixel quantification, laboratory experiment

The pollution of marine and coastal environments with marine litter, which is mainly composed of plastics, has been identified as a long-term hazard for associated ecosystems (UNEP 2009). Continuously increasing disposal quantities and low plastic degrading rates (on the order of centuries) caused an increasing litter accumulation in these environments over the past decades. Marine litter causes several harms including entanglement of and ingestion by marine organisms (e.g., fishes, seabirds) and introduction of persistent toxic substances, such as organochlorines (e.g., PCB, DDE, DDT) and others, into the environment and into the food web.

It is known that plastic can be detected and types of plastic can be distinguished by spectroscopic measurements (Eisenreich 2000; Lanners 2011). However, the feasibility of existing imaging spectrometers for mapping plastic litter in the marine environment has not been shown, yet. Given the reported abundances of plastic litter in the marine and coastal (beach) environments (e.g., Moore 2008; Morét-Ferguson et al. 2010; Kuriyama et al. 2002) as well as the specifications of current and planned satellite, airborne and hand-held spectroscopic sensors, the main challenge of monitoring plastic litter is to detect amounts that cover only small parts of the sensor's instantaneous field of view. Therefore, the potential applicability of imaging spectroscopy to real life problems mainly depends on the lower limit of detection at a subpixel scale. To determine this lower limit as well as the accuracy of quantification a laboratory study has been conducted. An ASD FieldSpec Pro spectroradiometer was adjusted over (1) an aquarium filled with salt water and (2) a box filled with beach sand. Plastic particles (5-10 mm diameter) of the floating plastic types polypropylene (PP), polyethylene (PE), polyurethane (PUR), and polystyrene (PS) were measured in increasing concentrations starting from 1 particle to 50 particles. The resulting series of spectral measurements has been analyzed using subpixel detection and quantification methods like spectral feature fitting, linear spectral unmixing, mixture tuned matched filtering or regression based on spectral indices. The best results were achieved for polyethylene. Plastic pieces of polyethylene could be detected down to a lower detection limit of less than 1 % of surface coverage.

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**WASI-2D: A free software for inverse modeling of multi- and hyperspectral water images (**  
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**Keywords:** software, inverse modeling, hyperspectral, water

A software tool is presented which allows quantitative data analysis of optical remote sensing data from oceanic, coastal and inland waters. It can be easily adapted by the user to different sensors and to optical properties of the studied area. The software can import atmospherically corrected images from multi- and hyperspectral sensors in a number of common data formats and units like remote sensing reflectance or radiance, above or below the water surface. Data analysis is done by inverse modeling using established analytical models. The bio-optical model of the water column accounts for coloured dissolved organic matter (CDOM), detritus, and mixtures of up to 6 phytoplankton groups and 2 spectrally different types of suspended matter. The reflectance of the sea floor is modeled as sum of up to 6 substrate types. An analytic model of downwelling irradiance allows wavelength dependent modeling of sun glint and sky glint at the water surface. The provided database, which has been used successfully in inland lakes, covers the spectral range from 350 to 1000 nm in 1 nm intervals. It can be exchanged easily to represent the optical properties of water constituents, bottom types and the atmosphere of the studied area. The usage of the software is demonstrated at the example of a hyperspectral image from Lake Starnberg in southern Germany. The image has been acquired using a HySpex VNIR-1600 sensor with 160 bands from 416 to 992 nm. Goal of data analysis was to derive water depth of each image pixel in the shallow areas. The best results were achieved by treating water depth, sun glint, 2 substrate types, CDOM concentration and CDOM spectral slope as unknowns (fit parameters) during inverse modeling, and keeping all other model parameters constant.

## Parallel Session 6: Chlorophyll fluorescence

### **Steady-state chlorophyll fluorescence spectroscopy: from leaf to airborne level**

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**Keywords:** chlorophyll fluorescence, air pollution, urban environment, stress monitoring

Among several fluorescence techniques, solar-induced steady-state chlorophyll fluorescence (Fs) has received an increased attention over the last years, as it is applicable in remote sensing as a non-invasive technique to map stress of vegetation ecosystems. Methods for the retrieval of the weak fluorescence signal from the intense background solar radiation were refined in recent years (Alonso et al., 2008; Guanter et al., 2010; Meroni et al., 2010). Further, the ESA's Fluorescence Explorer (FLEX) mission, aiming a satellite launch to enable a global monitoring of steady-state chlorophyll fluorescence of terrestrial vegetation, has currently been approved to go into phase A/B1 of the 8th ESA Earth Explorer Program. Remote chlorophyll fluorescence detection would allow the scientific community to increase the knowledge on the Earth's system dynamics by retrieval of information on actual photosynthesis compared to the more often used reflectance data. Nevertheless, studies on stress detection, making use of solar-induced steady-state fluorescence under natural field conditions are still scarce. During the BIOHYPE (Biomonitoring of urban habitat quality with airborne hyperspectral observation) project the potential of Fs as a stress parameter of urban traffic pollution in Valencia on the vegetation is investigated from the leaf to the canopy level. In Valencia, the chosen tree species were European nettle tree, White mulberry, London plane and Canary Island date palm. For the canopy level, CASI 1500i data were used, the most adequate hyperspectral sensor available at the time, to derive Fs from the infilling of the O2-A band at 760 nm by the improved Fraunhofer Line Depth (iFLD) method. Therefore, a very precise determination of the atmospheric profile and aerosol content is required to obtain top of canopy (TOC) reflectance through atmospheric correction, especially within the absorption bands. At leaf level, Fs is measured with an ASD FieldSpec spectrometer coupled with the in-house developed FluoWat leaf clip, a portable leaf clip able to measure real leaf reflectance (R), transmittance (T) and fluorescence (F) emission under artificial and natural light conditions. Several fluorescence yield (FY) indices based on the upward and downward emission peaks at 687 and 741 nm were defined.

At leaf level, we found that stress induced by traffic pollution can be detected by steady-state FY indices for leaves of two of the four urban trees tested. Specifically, both upward and downward  $FY(687)/FY(741)$  peak ratio increased significantly for London plane and Canary Island date palm, indicating a change of their functional status (Van Wittenberghe et al., 2013).

After atmospheric correction and applying a simplified iFLD method, it was concluded that the signal level in the O2-A is sufficient to detect fluorescence remotely with CASI, and that most factors that introduce noise to the retrieved fluorescence are due to the simplifications that have been applied to the iFLD method.

Our results indicate steady-state fluorescence is a more sensitive indicator of (traffic) pollution than the leaf's pigment content as such. Therefore, mapping solar-induced chlorophyll fluorescence might serve many applications on vegetation health.

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## **Assessment of the functional relationship between sun-induced chlorophyll fluorescence and plant pigments using APEX imaging spectroscopy data**

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**Keywords:** Imaging spectroscopy, APEX, chlorophyll fluorescence, Fraunhofer line depth (FLD), pigment composition, agriculture

The biological process of plant photosynthesis determines important ecosystem functions, including the production of oxygen and organic matter, and mediates roughly 90% of the gas exchange between the atmosphere and the biosphere. The investigation of ecosystem functioning and e.g., its relation to a changing environment, relies on accurate information on plant photosynthetic rates. Photosynthesis is, however, a dynamically regulated process and known to quickly adapt to actual environmental conditions.

Imaging spectroscopy (IS) is an efficient and non-destructive technique to measure plant functional traits related to the actual physiological status of plants. A suite of approaches have been proposed to measure the concentration of important plant pigments, e.g, chlorophylls (Chl), which absorb light energy to drive photochemical processes; carotenoids (Car), which are used in light harvesting processes; or anthocyanins (Anth), which protect leaves from excessive irradiance. Further, an emerging interest is on the measurement of sun-induced chlorophyll fluorescence (FS), considered as a probe of photosynthesis. Much progress has been made in the last decade to quantifying FS from RS data. The weak FS signal and the complexity of involved processes, however, complicates the retrieval and interpretation of FS.

In this contribution, we use data of the Airborne Prism EXperiment (APEX) imaging spectrometer to consistently quantify the emitted FS signal and the composition of pigments over several crops in Switzerland. We then investigate the functional relationship between FS and the plant pigments chlorophyll, carotenoids, and anthocyanins to judge the plausibility of retrieved FS signals. This study contributes to a better understanding of the spatial variability of FS and its relation to plant pigments. Further results demonstrate the suitability of IS-based approaches to quantify plant functional traits related to the biological process of photosynthesis.

## **Mapping of sun- induced chlorophyll fluorescence at canopy scale using co-registration of hyperspectral and 3D stereo images**

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**Keywords:** Sun- induced chlorophyll fluorescence, stereo imaging, photosynthesis

Passive retrieval of sun- induced chlorophyll fluorescence (Fs) using atmospheric absorption features has become a promising remote sensing approach to bring new insight in understanding photosynthesis at canopy scale. Fluorescence emission is closely related to the status of photosynthesis in plants and therefore has the potential to track adaptations of this process to changes in environmental conditions. Yet, the extent in which Fs signal is affected by the 3D canopy structure and light conditions within it is not fully understood.

With the aim to provide detailed information of how different elements of the canopy contribute to the whole canopy fluorescence signal, and how the strength of this signal depends on the orientation of these elements, high spatial resolution hyperspectral images were combined with stereo images providing 3D information. Co-registered images were acquired at 3.5 meters nadir over different crops canopies (sugar beet, maize, barley and wheat) under field conditions. Acquisitions took place through the growing season over plants subjected to different nitrogen fertilization and irrigation levels. Spectral images were recorded using a hyperspectral camera operating in the range from 400 to 1000 nm, with a nominal spectral resolution of 2.8 nm and fluorescence signal was retrieved using the 3 Fraunhofer Line Depth (3FLD) method in the Oxygen A absorption band (760 nm). Stereo images were obtained using two commercial DSLR cameras fixed at the same height as the imaging spectrograph.

In this contribution we compared detailed canopy Fs maps with ancillary conventional measurements taken at leaf level to characterize plant physiological status. From this analysis first conclusions about the capacity of Fs to detect plant photosynthetic status at leaf/canopy level are drawn. Additionally, first co-registered images of Fs and 3D parameters are shown and used to evaluate the effect of leaf orientation in the Fs retrieved signal, indicating the main constrains and considerations for this methodology.

## **Mapping sun-induced fluorescence using the high performance imaging spectrometer HyPlant**

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**Keywords:** fluorescence, photosynthesis, high performance imaging spectroscopy, oxygen absorption, sun-induced fluorescence, FLEX

Sun induced fluorescence ( $F_s$ ) is a novel remote sensing signal that is emitted from the core of the photosynthetic machinery. The fluorescence signal has the potential to quantify the actual rate of photosynthesis, is closely related to vegetation stress, and reflects functional limitations of photosynthetic carbon gain.  $F_s$  is a rather weak signal, but can be measured in solar and atmospheric absorption lines using high performance spectrometers.

In this contribution we present the technical concept of the novel high performance imaging spectrometer HyPlant that was developed by the Forschungszentrum Jülich and the Finish company Specim. This airborne sensor consists of two modules and allows state-of-the-art imaging spectroscopy in combination with high spectral resolution characterizing of the red and near-infrared region. After three years of developmental time HyPlant was first employed in a campaign funded by the European Space Agency (ESA) during late summer 2012 over an agricultural area in Germany and a Norway spruce forest in the Czech Republic. More than 120 flight lines were recorded and radiometric and geometric performance of the HyPlant sensor was characterized in detail. The HyPlant sensor allows mapping surface reflected radiance between 400 and 2500 nm with a high performance spectral window between 670 and 780 nm (0.26 nm full widths at half maximum in this spectral range). The spatial resolution was set to 1 and 3 meters depending of the flight height. Airborne data are complemented by a dense network of ground data, including surface reflectance measurements, a detailed characterization of the atmosphere using LIDAR, and a characterization of the functional status of vegetation. The high performance HyPlant radiometric measurements allow the quantification of sun-induced fluorescence in two oxygen absorption features, i.e., the O2-B feature at 680nm and the O2-A feature at 760nm. First maps of sun-induced fluorescence are presented.

During the campaign we aimed to record variations in sun-induced fluorescence that occurred in the course of a single day (morning, midday, afternoon) and also characterized spatial variations between crop fields, forest patches and different vegetation types. Data are currently being processed, but we are confident that we will be able to present first maps of sun-induced fluorescence in physical units and to give first insight into the spatial and temporal variation of this novel remote sensing signal. The measurements are one important component in the preparation of the Earth Explorer candidate satellite mission FLEX, that is currently under evaluation in phase A by ESA



## **Parallel Session 7: Radiative Transfer**

### **Characterization of aerosols in an industrial plume using hyperspectral imagery: the EARTH method**

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**Keywords:** aerosol, plume, industrial emission, pollution

During the last decades, tropospheric aerosols have been widely studied using remote sensing instruments. The growing recognition of the importance of aerosols for climate and global change studies has enabled the development of a number of very significant techniques to estimate their properties from satellite data such as AVHRR, MODIS, MISR, POLDER. However, all these satellites acquire data at relatively low spatial resolution (from 250m for MODIS to several kilometers for POLDER). The characterization of aerosols emission sources at this scale is a challenge, especially for industrial sources.

Therefore, we conducted a study aiming at estimate aerosols type inside an industrial plume using data from airborne hyperspectral imagers. These instruments (e.g. CASI, HyMap, AHS) acquire data in several dozens of spectral bands in the Visible Near Infrared (VNIR) domain with a spatial resolution from one to several meters. Some techniques have been already developed to retrieve information about size and concentration of particles into a plume from hyperspectral data but require a priori information about the composition of the aerosol mixture. However, the particles emitted by factories have significantly different composition from one kind of industry to another. So we have developed a method enabling the determination of the aerosol type in a plume, without any a priori knowledge.

This method, named EARTH for Estimation of AeRosol Type using Hyperspectral data, is based on Look-Up Tables (LUT) and is specifically designed for industrial thin plume. The algorithm contains a preprocessing step, which permits to estimate the ground reflectance under the plume and then only few pixels of interest are selected for the estimation of the Aerosol Optical Thickness (AOT) and the product of the phase function and the single scattering albedo. These two parameters are then compared with pre-calculated terms stored in a LUT to determine the aerosol type. The selected pixels are located in a transition between two kinds of grounds (vegetation/asphalt for instance) or between a lighted area and a shadow area (with the same ground reflectance). That permits to use a simplified radiative transfer equation and to be sensitive only to the type of particles, regardless the granulometry.

A sensitivity analysis, using simulated data, has been conducted and the EARTH method has been applied to a hyperspectral image, acquired by the CASI sensor in 2010 over a metallurgical plant in Fos-sur-Mer (France). The obtained results are encouraging: the aerosols optical properties are retrieved with an error of less than 10% for an AOT at 550nm from 0.2 to 1.5 and the application to the CASI image shows that the EARTH method enables the recognition of metallic particles in the aerosol mixture, even in a thin plume over complex surfaces. However, the estimation of the ground reflectance under the plume appears as a critical point for a good characterization of the aerosols and is particularly challenging without spectral bands in the Short-Wave Infrared.

## **Gaseous pollutants characterization over heterogeneous ground from airborne hyperspectral measurement at high spatial resolution: case of industrial site**

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**Keywords:** hyperspectral, plume, gas, thermal infra-red, detection

The air pollution is a very important issue for industrialized society, both in terms of health (respiratory diseases, allergies...) and in terms of climate change (global warming and greenhouse gas emissions). Anthropogenic sources, especially industrial, emit into the atmosphere gases and aerosols, which play an important role in atmospheric exchanges. However emissions are poorly estimated as most of existing space sensors have a limited spectral range but also a too low spatial resolution. The use of the new hyperspectral airborne image sensors in the infrared range opens the way to new development to improve the plume production.

Hyperspectral imagery in the Vis-NIR and SWIR domains from airborne acquisitions has proven the gain brought by such technique to estimate aerosols and some gaseous species (methane, Carbone dioxide...) over biomass burning or thermal power plant. Unlike SWIR, in the thermal domain (MWIR-LWIR), where are found the signatures of the majority of gas plume, temperature plays an important role. In addition, intrinsically, only the integrated amount of gas column can be detected and gas signal is convolved by ground signature, atmospheric species characterization from airborne observation becomes very challenging. In the last ten years, several works provide a linear formalism to detect and quantify gaseous species over industrial site. These methods are based on a linearization of the differential signature between a clean pixel and a polluted pixel under strong hypothesis. Their main limitations are the heterogeneous environment impact on the performances of these methods and such technique does not take into account the spatial and vertical extent of the plume.

In this work, a new method for detecting and characterizing gas plumes is presented to overcome such limitations. This method is based on an accurate non linear formalism of cloud gas radiative impact, it includes a ground classification of the scene, in order to take account the soil's heterogeneity and spectral behaviour. Then, for each class an appropriate analysis will be followed, to initialize the inversion algorithm as better as possible. Finally, we use synthetic scenes of industrial area, and airborne acquisitions (Telops, SPIM) to validate our inversion method.

## **Correction of shadowing effects in imaging spectroscopy data by quantification of the proportion of diffuse illumination**

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**Keywords:** Atmospheric compensation, ATCOR, cast shadow correction, diffuse illumination, APAR

High spatial resolution imaging spectroscopy data is affected by various shadowing influences, be it the shadows of buildings, within forests, at forest borders, by single trees, by terrain, or by clouds. The radiometric performance of modern imaging spectroscopy systems provides a dynamic range, which is large enough to retrieve useful spectral surface information even within full cast shadows. Thus, atmospheric correction routines should provide a capability to account for all above-mentioned types of cast shadows. Our tests have shown that the use of accurate surface model does in many cases not lead to useful results as the surface representation with respect to the radiometry is never accurate enough.

A new method for cast shadow detection and correction has been implemented within the workflow of the ATCOR atmospheric compensation package. The shadows are retrieved from imagery relying on the fact that all areas in shade are illuminated by a large proportion of diffuse irradiance. The diffuse irradiance is caused by scattering in the atmosphere and thus exhibits very specific spectral characteristics compared to the direct irradiance. Specifically, the signal in the blue is significantly higher in areas affected by cast shadow than in areas directly illuminated. Specific indices have been defined to quantify the shadow fraction on a per-pixel basis, by exploiting the spectral properties of illumination. This strategy results in a continuous quantification of the shadow field. The output is used directly in the atmospheric/topographic correction on the basis of the ATCOR model.

Tests of the procedure on various imaging spectroscopy data samples show significant improvements of surface reflectance products in forests and in urban areas. Validation results demonstrate the performance and indicate limitations of the proposed methods. Implications for the retrieval of remote sensing products are discussed, with a particular focus on vegetation analysis methods, i.e., the quantification of pigment concentrations or APAR.

### **Utilization of FODIS atmospheric correction for chlorophyll content estimation**

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**Keywords:** FODIS, ATCOR-4, atmospheric correction, chlorophyll content, estimation, hyperspectral data

The CzechGlobe is owner of airborne hyperspectral system AISA Eagle since 2004 and pre-processing chain for hyperspectral data including quality estimation developed within EUFAR project (JRA2 – HYQUAPRO) was established. Atmospheric corrections are performed by means of ATCOR-4 software package with utilization of ground targets reflectance measurements for calibration and validation purposes. Such pre-processing allows achieving of best possible quality of atmospheric corrections, but is very time demanding for human as well as computer time.

AISA Eagle is equipped by downwelling irradiance sensor (FODIS) placed at top of aircraft fuselage which is designed for simple atmospheric corrections so called FODIS ratio. Signal reflected from earth surface is divided by FODIS signal which allows achieve reflectance at sensor level. FODIS signal is influenced by many effects e.g. non-cosine response of the sensor, attitude of the aircraft, sun-elevation angle, SNR ratio of sensor, etc. which reducing accuracy of atmospheric correction. On the other hand FODIS ratio correction is simple and fast with low demands on other supportive data. Therefore it might be a good option in case of studies conducted in remote and poorly available locations with no chance to organize a supportive ground campaign. Fortunately SNR ratio of FODIS sensor is highest for spectral range 600 – 800nm which is the most important for estimation of chlorophyll content as well.

## **Parallel Session 8: Soil Applications**

### **Soil analysis with hyperspectral data – an experiment with a hyperspectral frame camera and VIS-NIR spectrometers**

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**Keywords:** soil spectroscopy, imaging spectroscopy, frame camera, field spectroscopy, real-time

Soil is a complex material with an extreme variability of its physical and chemical composition. In addition to traditional wet-chemical analysis, the analysis of reflectance or absorption spectra in the visible to near infrared range (VISNIR, 0.4-2.5  $\mu\text{m}$ ) measured by spectrometers with a high spectral resolution has established as a technique for predicting many soil attributes, including chemical, physical and biological properties. VIS-NIR spectroscopy allows for a rapid and cost effective screening with minimal sample preparation, but limitations result from the need to define proper calibration models, their typically scale-specific (regional, local, field, lab) nature and a lack of transferability of calibrations between different instruments.

The use of laboratory imaging spectroscopy for soil analysis is yet limited to some very few studies. Compared to non-imaging spectroscopic measurements a hyperspectral image offers the additional potential to assess spatial heterogeneities, e.g. at the surface of soil aggregates or in the vertical of soil profiles. In our study we have combined both techniques to compare the spectra provided by different instruments and to analyse possible mismatches. The following instruments were used for the acquisition of spectral data for a total of 40 soil samples in the laboratory:

- a fibre-optics ASD FieldSpec 4 Wide-Res spectroradiometer (Analytical Spectral Devices, Boulder, CO); spectra were retrieved from bidirectional measurements (using an external light source) with an increment of 1 nm over the 0.35-2.5  $\mu\text{m}$  wavelength range,
- a FOSS XDS Rapid Content Analyzer spectrometer (FOSS NIRSystems, Laurel, MD, USA) providing diffuse reflectance spectra (0.4-2.5  $\mu\text{m}$ ) with a spectral resolution of 0.5 nm,
- a prototype of a hyperspectral frame camera (developed by the Institute of Laser Technologies in Medicine and Metrology at the University of Ulm and the Cubert GmbH, Germany) providing readings in 140 spectral channels covering a range from 0.4-1.0  $\mu\text{m}$ .

Readings were performed for raw and air-dried samples without any further pretreatment and also for crushed samples. All samples were examined for their contents of total organic carbon (OC), hot water extractable C (Chwe), total nitrogen, pH-values and soil texture. For these soil properties, the success of multivariate calibrations using partial least squares regression (PLSR) was tested for the different hyperspectral datasets. In addition to full spectrum PLSR, we combined PLSR with methods of spectral variable selection to study possible effects for calibration accuracy and model parsimony.

## **Prediction of soil organic carbon content by spectroscopy at European scale using a local partial least square regression approach**

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**Keywords:** soil organic carbon, Vis-NIR spectroscopy, LUCAS spectral library, local partial least square, European scale

Monitoring the spatial variability of soil organic carbon (SOC) requires a sampling density that can be costly and time consuming. Visible near infrared diffuse reflectance spectroscopy (Vis-NIR DRS) has been shown to be a fast, cheap and efficient tool for the prediction of SOC at fine scales. However, when applied to regional or country scales, the calibration of Vis-NIR DRS does not remain stable for it to be used as an alternative to standard laboratory SOC analysis. Under the framework of the Land Use/Cover Area Frame Statistical Survey (LUCAS) project of the European Commission's Joint Research Centre (JRC), about 20,000 samples were collected all over the European Union. Soil samples were analyzed for several physical and chemical parameters, and scanned with a Vis-NIR spectrometer in a single laboratory, and a spectral library was compiled. The scope of our research was to predict SOC content at European scale using this spectral library. We implemented a modified local partial least square regression (l-PLS) including, in addition to spectral distance, other covariates (geographical coordinates, texture, etc.) to select for each unknown sample a group of predicting neighbours. The dataset was divided in mineral and organic soils due to the diverse spectral response of the two groups. Mineral soils were split in cropland, grassland, and woodland soils according to land cover classes of the LUCAS database. Training (70%) and test (30%) sets were created to calibrate and validate the SOC prediction models. The results showed good prediction ability for mineral soils under cropland (RMSE = 3.6 g C kg<sup>-1</sup>) and grassland (RMSE = 7.2 g C kg<sup>-1</sup>). Predictions of mineral soils under woodland (RMSE = 11.9 g C kg<sup>-1</sup>) and organic soils (RMSE = 51.1 g C kg<sup>-1</sup>) were less accurate. The RMSE was lower (except for organic soils) when sand content was used as covariate in the selection of the l-PLS predicting neighbours. Although the enormous spatial variability of soils at European scale, the obtained results proved that, if a spectral library is created following a homogeneous and consistent protocol, Vis-NIR DRS spectroscopy is a powerful and cost effective tool to monitor SOC content.

## **VIS-NIR imaging spectroscopy enables upscaling of $\mu\text{m}$ -scaled SEM- and NanoSIMS information to soil horizons**

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**Keywords:** soil heterogeneity, supervised classification

Soils are heterogeneous across a wide range of spatial scales and show patterns with widely varying physical and chemical properties, e.g. permafrost affected soils (Cryosols) with zones of un-decomposed organic materials surrounded by a mineral matrix. Such soils store a large amount of organic carbon in a constantly frozen state, which will be decomposed relatively fast when the permafrost melts due to increasing temperatures. Additional to the frozen state of organic carbon, we still lack a clear understanding of soil organic matter (SOM) stabilisation processes that are active in these soils and to which extent the different mechanisms contribute. New analytical imaging techniques consider these heterogeneities on the micro- to nano-scale and enable the determination of the stabilisation mechanisms in situ. But these techniques need an intensive sample preparation and analyse the phenomena that were previously sampled. Laboratory Vis-NIR imaging spectroscopy records the reflectance of a sample with a high spectral and spatial resolution and can help to reference and upscale the information from  $\mu\text{m}$ -scale to complete soil profiles.

We analysed discs from an intact soil core from a Cryosol (Typic Aquiturbel) sampled in Northern Alaska (Barrow, USA) with nano-scaled secondary ion mass spectrometry (NanoSIMS), scanning electron microscopy (SEM) and VIS-NIR imaging spectroscopy (IS). SEM and a light microscope were employed to identify regions of interest for further NanoSIMS experiments and to visually identify organic matter particles representing the labile SOM pool. NanoSIMS is an emerging analytical imaging technique that enables the simultaneous quantification of up to seven ion species at high mass resolving power and high lateral resolution (100x100 nm/Pixel). We employed it to identify organo-mineral complexes in the Cryosol core which represent the stabilised SOM pool. IS was used to record the diffuse VIS-NIR reflectance (400 to 1000 nm in 160 bands) of the complete sample (63x63  $\mu\text{m}$ /pixel) and to upscale and reference the submicron information to the soil core discs. We used the NanoSIMS and SEM information as training areas for a supervised classification of the IS images and to quantify the contribution of the different stabilisation mechanisms.

We demonstrate the great potential of a multi-scale approach for soil system research focusing on the study of soil architecture with respect to its functional properties and soil processes.

## **Assessing Ecosystem Function by Soil Quality with Visible/Near-Infrared Reflectance Spectroscopy - Spectroscopy of Soil Quality**

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**Keywords:** Spectroscopy, soil quality, ecosystem function, VNIR, PLS-R, PLS-DA

Soil quality is one of the prime factors for evaluation of ecosystems function and can be assessed by quantifying a large number of physical, chemical, and biological indicators. These measurements are conducted in the field and the laboratory and are time and manpower demanded. Since soil quality merges together many variables, soil quality indices have been suggested in order to incorporate the various variables into one. The current study strive to evaluate the overall soil quality with hyperspectral remote sensing data of the visible, near-infrared, and short wave infrared (VIS-NIR-SWIR; 0.4–2.5  $\mu\text{m}$ ) spectral regions. Reflectance spectroscopy is a rapid, non-destructive, reproducible, and cost-effective analytical method and therefore it is a promising tool for soil quality assessment.

Research was conducted at 4 study sites in the semi-arid areas of the northern Negev Desert (about 200-300 mean annual rainfall) that represent different land-use categories: two afforestation systems (rain-fed and runoff harvesting), and three grazing systems (traditional domestic grazing, agro-pastoral, and intensive grazing) versus the natural ecosystems. Two methods were implemented: (1) correlations between soil field/laboratory measured indicators and the hyperspectral data were carried out by Partial Least Squares Regression (PLS-R) models in order to develop stable calibration models for several key soil properties; and (2) clustering between the soil quality of each land-use and the hyperspectral data was revealed by Partial Least Squares Discriminant Analysis (PLS-DA).

The PLS-R models exhibit high and significant correlations ( $R^2=0.75-0.90$ ) for most (9 from 12) of the soil quality indicators. The clustering between the soil quality and the land-use quality shows high capability for classifying land-use and identifying their soil quality value. We conclude that soil spectra can be used as an integrated measure of soil quality, so as to classify sites according to their landscape functionality and ecological quality.



## **HYSOMA software interface: Update and science case validation for surface soil moisture estimation**

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**Keywords:** hyperspectral, soil moisture, software interface

THE HYSOMA (HYperspectral SOil MAPper) is a software interface providing an experimental platform for soil mapping applications of hyperspectral imagery developed at GFZ. It is a stand alone IDL software distributed for free on the internet under the idl-virtual machine ([www.gfz-potsdam.de/hysoma](http://www.gfz-potsdam.de/hysoma)) providing expert and non-expert users with a suite of tools that can be used for soil mapping. The HYSOMA project was a joint venture initiated by scientists from the EU-FP6 HYRESSA project and supported by the FP7-EUFAR (European Facility for Airborne Research) Hyquapro program. Further developments are allowed in the frame of the EnMap (Environmental Mapping and Analysis Program) satellite science program at GFZ. The interface focuses on fully automatic generation of semi-quantitative soil maps that do not need input from spectral libraries, or ground truth data. An additional user custom option performs fully quantitative mapping when field data is available for calibration. Five key soil parameters are considered that are percent soil moisture, soil organic matter, iron oxide, clay content, and carbonate content.

In particular, the amount of surface soil moisture is a key variable in hydrologic cycle controlling processes such as infiltration and discharge with consequences for plant growth, soil erosion and land degradation. Monitoring and modeling of these processes requires a universal approach for estimating this key variable at all scales where repeatable results are an important prerequisite. In this paper, we evaluate two different automated soil moisture estimation methods implemented in the HYSOMA against surface soil water content measurements, the SMGM method from Whiting et al. (2004), and the NSMI method from Haubrock et al. (2008). The algorithms were tested on hyperspectral imagery for two study sites using two airborne sensors of different spatial and spectral resolutions, covering the visible to shortwave infrared region (0.4 - 2.5 microns). These study sites represent a wide range of soil types and properties.

The presentation will focus on an update of the interface status (algorithms and options available, HYSOMA users, further developments as EnSOMA – EnMAP Soil mAPper) and will present science case study for the validation of the soil moisture algorithms implemented. The results show high predictive accuracies for surface soil moisture estimates, although the results vary slightly depending on algorithm and field environmental conditions.

## **Implementing field and imaging spectroscopy at different spatial resolutions for identifying surface properties related to soil erosion**

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**Keywords:** Soil erosion, semiarid, hyperspectral data, unmixing, rainfed agriculture

Soil erosion within Mediterranean environments is common and often severely affects the productivity of the soils. Anthropogenic factors such as land use management related to agricultural practices affected by natural factors that include climate, topography and lithology, determine the fate of soils that are often exposed to rain erosion as a result of a lack of a protective vegetation cover. Nowadays, demographic pressure and the globalisation of markets encourage the expansion of intensive agricultural crop production and livestock breeding. As expected, potentially productive soils within easily accessible areas are overexploited. However, even marginal soils are exploited within areas where rock outcrops as well as stony, clayey or sandy soils are exposed surfaces as a consequence of soil erosion which have potentially adverse effects on crop production or soil management. The objective of this work is to determine soil erosion and accumulation stages within selected test sites representative of Mediterranean areas focused on rainfed agriculture. This is carried out for different spatial scales with the aim of developing and extrapolating a methodology that is representative for areas with contrasting soil horizons and that can be implemented on data generated by future hyperspectral space-borne sensors. Initial work includes obtaining spectral data during field campaigns with an ASD FieldSpec3 spectroradiometer, together with corresponding soil samples collected during 2011 and 2012. Furthermore, hyperspectral airborne AISA Eagle and Hawk data and ALS50 (II) airborne laser scanner data were acquired at different spatial resolutions of 6 m and 2 m on the 8th and 10th of August 2011, respectively. A pre-processing of the hyperspectral AISA Eagle and Hawk data includes radiometric, atmospheric and geometric correction. Soil morphological, physical, chemical and mineralogical analyses are carried out and incorporated into a site specific spectral library. A high resolution elevation model is obtained from the laser scanner data to derive terrain properties related to soil degradation stages. This methodology is based on spectrally detecting spatial changes of the soil surface properties that are associated to specific soil conditions at different spatial scales from the corresponding hyperspectral sensor data. In this case, reference spectra are determined for the different soil surfaces and used for identifying and selecting image derived end members from the hyperspectral data that are implemented for applying linear and partial spectral unmixing techniques. As a result, maps of abundance values of the soil erosion stages are obtained for two different altitudes. Validation of the results is carried out between the two scales and related with the field data collected at the different test sites. Preliminary results show that at the spatial resolutions of 2 and 6 m, the overall result of the distributions of the erosion stages varies little as long as contrasting surface soil horizons are present with significant compositional differences such as clay, calcium carbonate, iron oxide and organic matter content. Significant advantage using the 2 m resolution is observed in accumulation areas that are more difficult to differentiate as they are influenced by the type and kind of mixing of the eroded material as well as slope gradient and shape. In this case a high resolution elevation model further improves the spatial definition between stable, eroded and accumulation areas. Ongoing analyses in this study is focused on the importance of implementing a methodology compatible with data acquired from present as well as future sensors.

## **Parallel Session 9: Urban Ecosystems**

### **Urban Material characterization in the sun and shade of Built-up structures and trees and their Retrieval from Airborne image acquisitions (UMBRA) over two French cities**

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**Keywords:** field campaign, airborne imagery, high spatial and spectral resolution, urban areas, material optical properties

Remote sensing imagery of urban environments from airborne acquisitions still remains a major scientific issue over the last decades. As urban areas are characterized by a high variety of materials and many shadowed areas, most of the processing methods are limited. Moreover, high spatial resolution and better signal to noise ratio of the new generation of airborne sensors has made possible new developments to improve the extraction of information from such environments.

This campaign (UMBRA) aims at acquiring a new reference dataset representative of two different French cities to develop a new atmospheric correction method in sunlit and shaded urban areas and to design a future superspectral camera system for high resolution urban land cover classification, making it possible to provide data for geomatic applications.

This campaign was carried out thanks to the French collaboration of IGN and ONERA, and took place on 23th-25th October 2012 over Toulouse and Amiens cities, located respectively in the southwest and north of France. These two cities were chosen for their difference in building architecture, urbanization plan and their variety in urban materials. The campaign included airborne acquisitions with simultaneous ground measurements.

Airborne images were acquired at high spatial and spectral resolution by multispectral [1], hyperspectral and panchromatic cameras with a ground sampling distance ranging from 0.015m for panchromatic to 1.6m for hyperspectral in the SWIR channels. The images are radiometrically and geometrically calibrated and have a noticeable low signal-to-noise ratio. Image data acquisition will be completed in some areas with 3D models obtained by stereovision from overlapping flight axes.

During the airborne flight, a field campaign aimed at creating a ground truth map of urban material reflectance from spectrometer measurements in the sun and shade for different materials. Especially in Toulouse city, these ground-based measures were partly focused on tree shadows where the signal is mainly affected by the plant structural and optical properties compared to opaque 3D structures. For this study, some trees were selected and the optical properties of the plant woody stem and leaves were measured, along with the 3D geometry of the trees by a terrestrial laser scanner. Furthermore, all the targets are located using a GPS receiver. Also, a radiometer and a sunphotometer provided information about the atmosphere conditions. In Amiens city, data have been also captured by multispectral cameras and laser scanner onboard a terrestrial mobile mapping vehicle (IGN Stereopolis) and will be used to characterize building facade reflectance.

This paper details these experiments and the preprocessing performed on the different acquired data sets. Some first results of the calibration of airborne images and the ground-based measurements will be presented.

[1]J.-P. Souchon, C. Thom, C. Meynard, O. Martin, M. Pierrot-Deseilligny, 2010, "The IGN CAMv2 System",The Photogrammetric Record, Volume 25, Issue 32, pages 402–421

## **Transferring support vector regression models from airborne to EnMAP-like data from urban areas (3546)**

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**Keywords:** imaging spectroscopy, EnMAP, support vector regression, scaling, urban

With the advent of hyperspectral satellite missions, e.g. EnMAP or HySPIRI, high quality imaging spectroscopy data of large spatial extent and high temporal frequency will become available to the user community. The use of this imagery for a profound description of urban land-cover composition will, however, be a particular challenge. Ground Sampling Distances (GSD) of 30 m and higher will aggravate the mixed pixel problem and, thus, the accurate distinction between spectrally similar land-cover types. In this context, the exploration and enhancement of subpixel techniques from airborne studies appears worthwhile.

Based on HyMap data from Berlin/Germany at 3.6 we investigate the transferability of support vector regression (SVR) models to EnMAP-like, simulated data at 30 m. We quantify fractions of built-up impervious (BU), non-built-up impervious (IM), grass (GR) and tree (TR) covered areas. The models were generated on synthetically mixed training data from a spectral library. This approach overcomes the problem of missing quantitative training data by providing reliable quantitative information during training.

The combination of SVR and synthetically mixed training data yields high accuracies for quantitative mapping of the four complex urban land-cover classes at 3.6 m. At 30 m resolution, however, we observed a critical decrease in accuracy. The detailed analysis of two intermediate scales, i.e. 9 m original HyMap data and 18 m simulated data, shows a gradual deterioration in accuracy, which was expected due to an increase in mixed pixels and mixing complexity at coarser resolutions. Nevertheless, relevant differences could be observed for different cover types. Accuracies for BU and TR are considerably high for pixel sizes of up to 18 m, and for grass surfaces even at 30 m. Lower performance is observed for IM estimates, where spectral confusion with dark built-up cover types and vegetation shadow, generally points to the limits of purely spectral analyses of urban areas. Following the first investigations, we could show that extending the simple mixing approach by more complex mixtures and brightness normalizations leads to more accurate results.

Our findings underline the potential of SVR and synthetically mixed training data for quantifying urban land-cover with empirical regression techniques, on the one hand. The reduced accuracy of urban land-cover estimates at coarser resolution, e.g. at EnMAP scale, on the other hand, indicates the need for further optimization. In the near future, we will test additional strategies to better cope with more complex mixtures and urban surface characteristics. Moreover, the possibility of generating a universal model for mapping urban land-cover from EnMAP data will be explored.

## **Parallel Session 10: Image processing methods and tools**

### **The accuracy of the retrieval from airborne data is within the 10% of accuracy. Partially supervised land cover classification with MaxEnt**

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**Keywords:** partially supervised classification, one-class classification, land cover, MaxEnt

In many applications it is necessary to classify one specific land cover class only, e.g. to map a specific agricultural crop for yield estimation purposes. Thus, the essential classification task is to separate the class of interest (i.e. the positive class) against all other classes (i.e. the negative class) of the study area. Fully supervised classifiers require a training data set where all the classes of the study area are defined. Partially supervised classifiers or one-class classifiers require only reference data of the positive class. Obviously, the acquisition of a fully supervised training set can be expensive in terms of money, time, and/or expert knowledge. Thus one might argue that the use of a fully supervised classifier is inefficient, when aiming on only one single land cover class. However, this requires a feasible and accurate partially supervised classification strategy, such as MaxEnt.

MaxEnt is a machine learning method based on the maximum entropy principle. The method and the freely available software were developed at AT&T Labs Research for modeling species distributions. It became a state-of-the-art method in this field, but can also be used for partially supervised land cover classification. The approach uses unlabeled data during the learning phase, which supports the model to optimally adapt to the actual classification problem. However, the output of MaxEnt is continuous, thus a threshold must be applied to obtain the binary land cover map. A commonly used technique (rejection-based technique) is to set the threshold such that a user-specified omission rate (usually 5%-10%) is achieved. Obviously, this does not necessarily result in an optimal result - in terms of maximum classification accuracy. Therefore, a Bayesian threshold technique is proposed, which allows to find a more robust threshold without requiring any user specified parameters.

In this study, two Hyperion images (from spring and summer) are used for partially supervised classification of land cover classes. The study area is located in Saxony-Anhalt, Germany, which is dominated by agricultural land use. The main agricultural land cover classes are winter wheat, rapeseed, winter rye, winter barley, corn, grassland, and sugar beet. A fully supervised Support Vector Machine classification is used for comparison.. MaxEnt is used to classify each of the classes separately with partially supervised reference data only. The two threshold techniques mentioned above are compared in terms of accuracy and robustness. To increase the reliability of the study conclusion all classifications are repeated several times with different spatially disjoint training and test set.

The result show that - given the optimal threshold can be found - MaxEnt performs comparable to fully supervised classification. As expected, the different classes require different omission rates, to generate the optimal result. Moreover, the technique can perform very poor if the omission rate, estimated with the training data, is not accurate. The proposed Bayesian threshold technique is a promising alternative. It leads to good and more robust accuracies without any user-specified parameters.

## **Application of Distributed Compressive Sensing in Hyperspectral Image Unmixing**

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**Keywords:** Hyperspectral unmixing, distributed compressive sensing, sparse approximation

Sparse spectral unmixing (SSU) is an emerging field taking advantage of the concepts of hyperspectral unmixing and sparse approximation. Hyperspectral unmixing aims at recovering and estimating the consequent spectra and quantifying their abundance for each pixel spectra. The recovered spectra represent pure materials and are called endmembers [1]. This is often modeled as a linear combination of the endmembers forming the mixing matrix and the corresponding abundance vector. Sparse approximation is a modern method commonly used in image and signal analysis for solving underdetermined systems of equations, where the signal of interest is approximated by a linear mixture of the components of the overcomplete mixing matrix (the so-called dictionary) and weighted by the sparse abundance vector. Unlike least squares based methods, SSU allows the number of endmembers in the dictionary to exceed the number of bands in the hyperspectral pixel. Usually SSU is executed on each pixel spectrum separately without considering uniformity in the spatial domain [1, 2]. In [3] the spatial consistency is regularized by the additional total variation constraint smoothing abundances of the same endmember between neighboring spatial pixel.

In this work we address SSU as a joint spatial and spectral problem by applying a novel Distributed Compressive Sensing (DCS) algorithm described in [4]. DCS exploits both intra- and inter- signal correlation structures which allows joint recovery of multiple signals. We assume that the hyperspectral image exhibits strong spatial correlations and, therefore, simultaneously we exploit common endmembers in the neighboring pixels and then record differences between them. However, we do not enforce any smoothness in the data, but by the assumption of spatial correlation in the image we take several neighboring pixels as a joint measurement of a specified area to extract most common endmembers. This methodology increases detection accuracy for this endmembers and at the same time decreases influence of the noise by the manner of joint approximation of neighboring pixels. Additionally, our algorithm records differences between them and allow detection of the latent endmembers.

To demonstrate the efficiency of our framework we perform tests using both simulated and real hyperspectral data. The quantitative analysis is performed using simulated mixtures scenarios. These simulated images are created using randomly selected endmembers from the USGS spectral library. The qualitative analysis is performed with the AVIRIS hyperspectral image. The presented method for SSU using DCS outperforms standard SSU algorithms and allows accurate unmixing of spatially correlated natural hyperspectral images.

## Kernel based orthogonalization for change detection in hyperspectral image data

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**Keywords:** Orthogonal transformations, dual formulation, Q-mode analysis, kernel substitution, kernel trick

Kernel versions of principal component analysis (PCA) and minimum noise fraction (MNF) analysis are applied to change detection in hyperspectral image (HyMap) data. The kernel versions are based on so-called Q-mode analysis in which the data enter into the analysis via inner products in the Gram matrix only. In the kernel version the inner products are replaced by inner products between nonlinear mappings into higher dimensional feature space of the original data. Via kernel substitution also known as the kernel trick these inner products between the mappings are in turn replaced by a kernel function and all quantities needed in the analysis are expressed in terms of this kernel function. This means that we need not know the nonlinear mappings explicitly. Kernel PCA and MNF analyses handle nonlinearities by implicitly transforming data into high (even infinite) dimensional feature space via the kernel function and then performing a linear analysis in that space. An example shows the successful application of (kernel PCA and) kernel MNF analysis to change detection in HyMap data covering a small agricultural area near Lake Waging-Taching, Bavaria, in Southern Germany.

In the change detection analysis all 126 spectral bands of the HyMap are included. Changes on the ground are most likely due to harvest having taken place between the two acquisitions and solar effects (both solar elevation and azimuth have changed). Both types of kernel analysis emphasize change and unlike kernel PCA, kernel MNF analysis seems to focus on the most conspicuous changes and also it gives a strong discrimination between change and no-change regions. Ordinary linear PCA or MNF analyses do not give this beautiful discrimination between change and no-change regions.

Thanks to Andreas Müller and co-workers, DLR German Aerospace Center, Oberpfaffenhofen, Germany, for kind permission to use the HyMap data. Thanks to both Andreas Müller and Mort Canty, Research Center Juelich, Germany, for many years of interesting cooperation on the analysis of multi- and hyperspectral image data.

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## **Sensitivity analysis of temperature and emissivity separation models to radiometric noise - The effect of a sensor's photon noise on the accuracy of retrievals of temperature and emissivity**

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**Keywords:** Thermal hyperspectral, temperature and emissivity separation (TES), photon noise, signal to noise ratio (SNR), sensitivity analysis, sensor performance

Thermal Infrared (TIR) spectroscopy imager extends the range of hyperspectral sensors into the thermal infrared region. Passive thermal infrared spectrometers for the Long-Wave-InfraRed (LWIR 8.0-14.0  $\mu\text{m}$ ) wavelengths are readily available, thereby allowing wider and simultaneous wavelength coverage. The coupling of passive infrared (IR) spectroscopic techniques with airborne and imaging, greatly extended the potentiality of traditional large band IR imaging. Day and night capabilities, high spectral resolution and improved signal to noise ratio, attracts large set of applications in the civil and the defence domains.

The retrieval of Land Surface Temperature (LST) and Land Surface Emissivity (LSE) from passive thermal hyperspectral sensors is one of the leading areas of research in this field and is considered essential for several applications. Several temperature and emissivity separation methods were proposed by the scientific community and their performances have been examined from a range of perspectives, but the impacts of noise has attracted less attention.

In this study, we have investigated the effect of a sensor's photon noise on the accuracy of retrievals of temperature and emissivity using four TES models: Normalization Emissivity Method (NEM) [1], ASTER's TES [2], In-Scene Atmospheric Compensation (ISAC) [3] and the Automatic Retrieval of Temperature and Emissivity using Spectral Smoothness (ARTEMISS) [4].

The research is undertaken using simulated imagery acquired by the AHS-175, TASI LWIR and SEBASS hyperspectral sensors. We consider the noise to be composed of the photon noise (shot noise), the dark noise, the readout noise, and the digitization noise. A variety of datasets containing these types of noise are generated and processed. The retrieval of temperature and emissivity using the four TES models, with particular regard to their accuracy, are compared and analysed.

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## **Current status of the spectral database SPECCHIO**

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**Keywords:** Spectral database, field spectroscopy, metadata

SPECCHIO is a spectral database system, designed to store field spectroradiometer data and associated metadata, enabling the long-term storage of data and data sharing. The past few years have seen significant updates in terms of functionality with the main contributions being its adoption by both the Australian spectroscopy community in the framework of the Australian National Data Service (ANDS) and EuroSpec within the COST action.

The nature of the SPECCHIO system is thus no longer a mere repository but a spectral information system that can support scientists in analyzing their data in a streamlined and repeatable manner. Data analysis and information extraction in third-party research environments such as Matlab or Python are supported by direct system access interfaces.

In this paper we give an overview of the current status of the SPECCHIO system, giving examples of the functionality spanning the data life cycle from input to analysis and information generation.

Wednesday, 10<sup>th</sup> April

**Parallel Session 11: Instrument Development (1)**

**Hand-held Imaging Spectroscopy and Hyperspectral Video Technique - Non-scanning Spectral Imaging Mobile Mapping**

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**Keywords:** Hand-held, non-scanning, imaging spectroscopy, UAV, real-time spectral imaging

Hyperspectral imaging techniques are used in many scientific applications. Nowadays hyperspectral imaging is particularly dominated by scanners for both indoor and outdoor applications. Spectral scanners have successfully mastered many applications, however scanning is facing some limitations when the test object or/and camera are randomly or rapidly moving in time and space. To go over this limitation spectral imaging techniques are needed with a non-scanning principle. The higher the number of the applications the higher is the demand for rapid, high-quality and easy-to-use data acquisition tools.

The Institute of Laser Technologies in Medicine and Metrology at the University of Ulm and the Cubert GmbH, Germany have designed and developed a hyperspectral frame camera that enables non-scanning hyperspectral imaging. This novel technical approach targets the mobile and time critical applications both in laboratory and in the field. At the present stage of the development the platform provides 140 channels in a spectral range of 400-1000 nm. This time the spatial resolution is subject to change depending on applications but ranging from 50x50 pixel up to 1,3 Mpixel. The integration time of taking one hyperspectral data cube is no longer than 1 ms in an optimal illumination scenario. The camera is able to proceed more than 20 images pro second that means it can be used as spectral camcorder. The whole equipment is less than 1000 g enabling high mobility and flexibility in the field and on UAV platforms. The dynamic resolution is 14 bit.

The present development of the camera is focusing on performance optimization and ergonomic improvements resulting from application priorities. Looking at a long-term scale the development aims to extend the spectral ranges of the camera over 1000 nm.

The development is at an advanced level and external research goals, scientific and industrial cooperations can be considered and are welcome. In this paper the technical aspects and new applications will be presented.

**A Hyperspectral Thermal Infrared Imaging Instrument for Natural Resources Applications (**  
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Max Gerhards, Lucien Hoffmann, Thomas Udelhoven

**Keywords:** hyperspectral, thermal, TIR, emissivity

A new instrument has been setup at the Centre de Recherche Public - Gabriel Lippmann to measure spectral emissivity values of typical earth surface samples in the 8 to 12  $\mu\text{m}$  range at a spectral resolution of up to 0.25  $\text{cm}^{-1}$ . The instrument is based on a Hyper-Cam-LW built by Telops with a modified fore-optic for vertical measurements at ground level and a platform for airborne acquisitions. A processing chain has been developed to convert calibrated radiances into emissivity spectra. Repeat measurements taken on samples of sandstone show a high repeatability of the system with a wavelength dependent standard deviation of less than 0.01 (1.25 % of the mean emissivity). Evaluation of retrieved emissivity spectra for various rocks and minerals (quartz, calcite) indicates good agreement with reference measurements. References were obtained from directional-hemispherical reflectance measurements of the same samples. The retrieved emissivity reveals distinct spatial patterns over rock samples that can be attributed to surface roughness. The new instrument facilitates the improved assessment of land surface temperature and land surface emissivity of natural surfaces at various scales from ground and airborne platforms and thus will provide new opportunities in environmental remote sensing.

## **The geospectral camera: combining the acquisition of geometrically precise hyperspectral and high spatial resolution imagery**

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**Keywords:** Hyperspectral imaging, CMOS image sensor, image fusion

Hyperspectral imaging is a powerful technique for monitoring the earth in a variety of ways through environmental assessments, vegetation species monitoring, health and land use management studies, etc.. This is done by means of image acquisition in many and narrow spectral band to detect small features or subtle variations in the reflectance spectra of natural objects. Hyperspectral instruments for earth observation are often prism or grating based pushbroom imagers with a complex optical system. These instruments rely on highly performing inertial navigation systems to achieve precise georeferencing of their line-based image data. Both aspects limit their use on mass and volume constrained platforms like compact unmanned aerial vehicles or small satellites. Furthermore image acquisition in narrow spectral bands on a moving platform implies an unavoidable trade-off between:

- high spatial resolution which avoids intermixing of spectral signatures of small scale features
- high signal to guarantee that the spectral signature can be effectively discriminated from background noise

In this paper, we describe a novel compact camera concept which we call a geospectral camera, which allows to generate geometrically precise hyperspectral image data combined with imagery with high spatial resolution.

The geospectral camera is a compact instrument which hosts 2 independently controllable 2-dimensional image sensors on a single image sensor chip behind one optical system. The first sensor captures the spectral information using a linear variable filter with narrow spectral bands. It focuses on acquiring high quality spectral data at low spatial resolution. The second sensor is a spectrally broadband frame sensor capturing the geometric information of the scene at high spatial resolution. The advantage of this camera concept is that geo-referencing the spectral line information from the first sensor can be performed by means of photogrammetric methods applied on the images taken with the second sensor relaxing the specifications for the inertial navigation system. In addition, both high spatial-low spectral and low spatial-hyperspectral image data are being acquired, which can be combined to fuse or spatially sharpen the spectral image product.

VITO has developed a prototype version of the geospectral camera. It makes use of the unique MEDUSA CMOS sensor containing two sensors of each 10000x1200 pixels on a single chip. High spatial information is acquired by means of a broadband colour sensor with a wide swath. Spectral information is acquired by means of a linearly variable-type optical filter in front of the second sensor allowing to capture more than 40 bands with FWHM of less than 15nm. In this paper the geospectral camera concept will be described in more detail as well as the demonstration of the new imaging method illustrated with the results from the prototype camera.

The geospectral camera concept is patented (WO 2011/073430 A1)

## **Exploiting the potential of hyperspectral filters on chip for compact earth observation instrumentation**

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**Keywords:** Hyperspectral imager, CMOS sensor, monolithic integration, optical filters, wedge filter

Hyperspectral imaging offers a very powerful technique for many remote sensing applications. It overcomes the limitations of conventional multispectral imaging by measuring many more, narrower spectral bands. This is essential, e.g. in environmental monitoring, where the presence of chemicals and the status of living organisms often reveals itself through small spectral differences. The general tendency in earth observation is to reduce cost and increase temporal frequency by employing ever smaller platforms, both in satellite missions and by using unmanned aerial systems (UAS). However, typically hyperspectral instruments consist of a large and complex optical design. Therefore there is a huge potential for smaller, compact and cost-effective hyperspectral imagers for use in remote sensing applications. The combination of linear variable optical filters (LVF) with 2D detector arrays offers a very promising technology to realize compact and lightweight hyperspectral imagers and support spaceborne hyperspectral imaging applications like limnology (study of inland waters), land cover classification, agriculture (crop classification, stress detection) and forestry (monitoring of biophysical variables, e.g. chlorophyll content). For local applications covered with UAS, this type of instrument could allow to perform for instance stress detection for precision farming, vegetation and water quality monitoring. Whereas the linear variable filter is traditionally deposited on a substrate and integrated and aligned in front of the image sensor. This method of production still involves assembly and alignment at component level, which leaves opportunities to improve on cost of production and also in performance.

Recent developments at imec have resulted into a novel hyperspectral line scanner based on a Fabry-Pérot interferometer, which is directly post-processed at the wafer level on top of the CMOS image sensor. The main challenge for this accomplishment was the production of the optical filters using tools and materials that are compatible with the standard CMOS process. Additionally, the materials' optical parameters have been improved for a better light transmission by tuning the process parameters of these tools. This approach provides several advantages compared to traditional LVF based instruments:

1. The implementation of the Fabry-Pérot interferometer operating at minimal cavity sizes to optimize for free spectral range and minimize stray light. The main challenge is the strict control of the processing tolerances in combination with a design correcting some of these tolerances.
2. A cross-component optimization of the optical filter and the CMOS image sensor, by eliminating parasitic glue layers or air gaps and taking the dielectric stack of the imager into account. This results in an optimized optical throughput.
3. A faster image acquisition by integrating multiple line scanners in parallel on the image sensor.

The design and development have focused on the use of production methods compatible with and available in semiconductor manufacturing, as used for image sensor production. Hence, this enables a cost-efficient mass-manufacturing of this hyperspectral sensor. Currently a prototype hyperspectral line scanner has been realized with a spectral range between 600 and 1000 nm, a spectral resolution better than 10 nm and a dynamic range of 10 bit. It contains 128 spectral bands, for each band a 2048 by 16 pixel block is acquired. This configuration has two advantages compared to traditional LVF instruments. Firstly it can capture a full spectrum in only 128 frames, which allows to relax the frame rate specification of the camera for a given aircraft speed. Secondly, it allows to perform pixel binning to increase SNR without reducing the spectral resolution of the image end product. This paper will describe in detail the novel hyperspectral camera and its potential for compact instrumentation for earth observation.

## **SYSIPHE, airborne hyperspectral system: Focus on the SIELETTERS thermal hyperspectral imaging instrument**

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**Keywords:** Remote sensing, infrared, multispectral, hyperspectral, airborne, Sysiphe, thermal infrared, anomaly detection, SIELETTERS, Odin

The SYSIPHE system is the state of the art airborne hyperspectral imaging system developed in European cooperation. With a unique wide spectral range and a fine spatial resolution, its aim is to validate and quantify the information potential of hyperspectral imaging in military, security and environment applications.

The first section of the paper recalls the architecture of the project. The second one describes the SIELETTERS sensors, their implementation onboard the platform and the data processing chain. The last section gives illustrations on the work in progress.



## **Full-spectrum VNIR and SWIR hyperspectral imager in a single instrument**

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**Keywords:** VNIR, SWIR, hyperspectral instrument

Currently, the best visible and NIR full spectrum solutions employ two separate push-broom hyperspectral cameras, VNIR and SWIR, in a platform where they are mechanically aligned to image the target with two parallel field of views (FOV). It results in a bulky construction which is prone to misalignment. The biggest issue with two separate FOVs is that pixel registration in the VNIR and SWIR image changes with varying distance to the target. It makes image processing challenging, especially for near real-time applications, like detection of IEDs and camouflaged objects, environmental monitoring, mineral mapping on open mine wall and ore processing lines.

This paper presents the first commercial full visible and NIR spectrum push-broom imager that resolves all the above problems. It images the target in 380-2500 nm spectral region with 650 bands through single front optics and single input slit, keeping all wavebands spatially co-registered independently of the distance to the target. The imager includes an innovative imaging spectrometer which, behind the single input slit, consists of two diffraction gratings and focal plane arrays (FPA), separately optimized for highest sensitivity and SNR (1000:1) in both VNIR and SWIR regions. Spot size matches the FPA pixel size and smile and keystone remain smaller than 20% of the pixel size. Besides, the imager is independent of polarization and high image rate (up to 130 Hz) enables excellent spatial resolution.

The imager is extremely compact and weighs only 15 kg. The temperature of the system is stabilized and its design meets MIL-specification for vibration and shock. It can be integrated to pan&tilt platforms, stabilized airborne turrets and UAVs.

## **Parallel Session 12: Mapping Earth and Planetary Surfaces**

### **Mapping feldspars with airborne hyperspectral SEBASS imagery**

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**Keywords:** TIR, SEBASS, hyperspectral, quantitative mineral mapping

Minerals of the feldspar group are the most common on earth. Their abundance and their variations in composition and mineral structure make them the most important tool in the classification of igneous rocks. To use feldspars for classifying rock compositions or metasomatic conditions during rock alteration events, we need analytical methods to identify and classify feldspars. Traditional laboratory methods, such as optical microscopy, X-ray diffraction (XRD), electron microprobe analysis (EMPA) or transmission infrared spectroscopy are time consuming, often costly and only applicable to a finite number of point observations on samples collected in the field. We cannot use these techniques for mapping variations of feldspar composition over a large area nor to highlight spatially continuous patterns.

The use of TIR imaging spectroscopy has the ability to overcome these shortcomings. It provides a synoptic view of an area and allows for mapping spatial distribution patterns of the rock-forming mineralogy. We present results from a study over the Yerington Batholith, Nevada. Hyperspectral TIR data acquired by the SEBASS sensor is combined with a partial least squares regression (PLSR) to quantitatively predict alkali feldspar, plagioclase and quartz modes, as well as plagioclase compositions from the airborne data.

## **Hyperspectral remote sensing detection of hydrothermal alteration at the Izok Lake base-metal deposit, Nunavut, Canada**

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**Keywords:** Volcanogenic massive sulfide deposits, base metals, hydrothermal alteration, alteration indices, hyperspectral, Archean, geochemical, airborne

Volcanogenic massive sulfide (VMS) deposits are a globally important source of Cu, Zn and other trace metals. Convective hydrothermal circulation of metalliferous fluids that forms these deposits through the host rocks alters their mineralogical and chemical compositions to form so-called “hydrothermal alteration zones” comprised of chlorite, white mica, and other minerals (e.g., quartz, carbonates). Hyperspectral remote sensing methods are potentially useful in delineating these hydrothermally altered rocks in high latitude regions with little or no vegetative cover and may be a potentially useful exploration vectoring tool. We have investigated the application of ground and airborne remote sensing methods to the detection of hydrothermal alteration associated with the Archean (2.5 Ga) Izok Lake Zn-Cu-Pb-Ag VMS deposit in Nunavut, northern Canada. Here, hydrothermally altered rocks contain muscovite and chlorite as alteration minerals, and there is a classic Na-depleted alteration halo that extends several kilometers around the deposit.

Airborne hyperspectral imagery was obtained for the deposit and surrounding area that is comprised of outcrops of felsic and mafic volcanic, volcanoclastic, and sedimentary rocks. These data were supplemented by field hyperspectral data collected in-situ from outcrops, drillcores from 8 drillholes comprising a cross-section through a mineralized zone, and hand specimens in the laboratory. The objective was to delineate the extent and intensity of hydrothermal alteration using the absorption band positions of AlOH and FeOH in micas and chlorite group minerals. These band positions shift as a result of hydrothermal alteration-induced mineral chemical changes. We developed a band position search algorithm for obtaining the continuum-removed AlOH and FeOH band positions of the phyllosilicate minerals. The algorithm was applied to our hyperspectral data sets, which range in scale from millimeters to kilometers. The resulting band position maps were compared with standard whole rock geochemical alteration indices (Ishikawa, chlorite-carbonate-pyrite, sericite and Spitz-Darling).

Our data indicate a shift to shorter wavelengths both in mica and chlorite group minerals with increasing alteration intensity. Based on AlOH band position results, mica group minerals display considerable compositional variability and range from paragonite to phengite. In order to optimize the predictive capability of the hyperspectral data, alteration indices were correlated with the spectral data. The correlation coefficients for the alteration indices and the AlOH band positions from the airborne data are weak. However, there is a statistically significant moderate correlation between the AlOH band positions of the ground data and the airborne data, thus validating the band position extraction process. The mineralogy and mineral chemistry of the 26 hand specimens as determined by the band position search algorithm, will be validated by petrographic microscopy and electron microprobe analysis. Spectral shifts in the samples will be compared to their chemical composition. After the spectral results have been validated, they will be used to construct a three-dimensional model of the hydrothermal alteration around the VMS deposit, hence gaining new insights into its geometry.

## **Spectroradiometry and Hyperion imagery for Satellite-based Geologic Cartography of Erupted Materials in the Central Andes**

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**Keywords:** Spectroradiometry, Hyperspectral, Remote Sensing, Hyperion, Geology, Vulcanism, Andes

We are improving the geologic cartography of erupted materials in the Central Andes by combining existing information, field and laboratory work and analysis of satellite imagery, with particular emphasis on Hyperion imagery. Based on previous knowledge of the area and on Principal Component Analysis of Landsat and Hyperion imagery, rock samples were collected at selected volcanic sites in the region of study from 10 km NE to 150 km SW of Antofagasta de la Sierra (NW Argentina) during our field campaign in September 2012. Samples, which included different types of ash, ignimbrite, rhyolite and andesitic basalt, were brought to the laboratory for analysis with a ASD FieldSpect 4 spectroradiometer in the VIS/NIR and SWIR regions. Resulting spectra indicate a high degree of discrimination and we are currently using these samples for the analysis of Hyperion imagery of the same area. This work is being performed within the framework of the Spanish-funded project QUECA (Ministry of Economy and Competitiveness, CGL2011-23307), which deals with the environmental impact of Quaternary eruptions of the central Andes.

## **Equinoctial activity over Titan dune fields revealed by the Visula and Infrared Mapping Spectrometer (VIMS) onboard Cassini**

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**Keywords:** remote sensing, infrared, climate, dunes, Titan

Titan, the largest satellite of Saturn, is the only satellite in the solar system with a dense atmosphere. The close and continuous observations of Titan by the Cassini spacecraft, in orbit around Saturn since July 2004, bring us evidences that Titan troposphere and low stratosphere experience an exotic, but complete meteorological cycle similar to the Earth hydrological cycle, with hydrocarbons evaporation, condensation in clouds, and rainfall. Cassini monitoring campaigns also demonstrate that Titan's cloud coverage and climate vary with latitude. Titan's tropics, with globally weak meteorological activity and widespread dune fields, seem to be slightly more arid than the poles, where extensive and numerous liquid reservoirs and sustained cloud activity were discovered. Only a few tropo-spheric clouds have been observed at Titan's tropics during the southern summer. As equinox was approaching (in August 2009), they occurred more frequently and appeared to grow in strength and size. We present here the obser-vation of intense brightening at Titan's tropics, very close to the equinox. These detections were conducted with the Visual and Infrared Mapping Spectrometer (VIMS) onboard Cassini. Figure 1 presents the VIMS color composite images of the three individual events detected so far, observed during the Titan's flybys T56 (22 May 2009), T65 (13 January 2010) and T70 (21 June 2010). T56, T65 and T70 observations show an intense and transient brighten-ing of large regions very close to the equator, right over the extensive dune fields of Senkyo, Belet and Sangria-La. They all appear spectrally and morphologically different from all transient surface features or atmospheric phenomena previously reported. Indeed, these events share in particular a strong brightening at wavelengths greater than 2  $\mu\text{m}$  (especially at 5  $\mu\text{m}$ ), making them spectrally distinct from the small tropical clouds observed before the equinox and the large storms observed near the equator in September and October 2010. In this paper, we will discuss the possibility that these singular events may have occurred very close to the surface, having a strong link with the underlying dune fields. Radiative transfer calculations indeed show that these singular brightenings are due to the transient appearance of an additional atmospheric layer, confined at very low altitudes and loaded with few but large particles. Gathering all the observational and modeling constraints, we conclude that the most probable explanation for these events is the local and transient occurrence of huge sand storms, directly originating from the underlying dune fields. We will also discuss the possible implications of the equinoctial occurrence of such events for Titan's tropical wind regimes and for the present-day activity of equatorial dunes.

## **Mapping the surface of Saturn's moon Titan through its thick atmosphere using the Cassini Visual and Infrared Mapping Spectrometer (VIMS) hyperspectral data - Mapping of the surface of Saturn's moon Titan using VIMS**

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**Keywords:** hyperspectral, Titan, image processing, atmospheric scattering, photometry

Saturn's largest moon, Titan, is the only moon of the Solar System that possesses a thick and active atmosphere, mainly composed of nitrogen (95 – 98 %) and methane (1 - 5 %) and producing a complex organic haze opaque in the visible. Since 2004, the Cassini spacecraft acquires imagery data during each flyby of Titan, in various viewing geometries, revealing familiar landforms such as lakes, seas and dunes, all composed of liquid or solid hydrocarbons.

The Visual and Infrared Mapping Spectrometer (VIMS) is the hyperspectral imaging spectrometer onboard Cassini. VIMS operates between 0.3 and 5.1  $\mu\text{m}$ , using 356 channels, and is able to reach spatial resolution of up to several hundred meters. Despite the wide range of wavelengths covered by VIMS and its spatial resolution, the vision of Titan's surface is often hampered by atmospheric (absorption, scattering) and photometric effects.

Indeed, due to the presence of methane in the atmosphere, VIMS sees Titan's surface at only few wavelengths in the infrared, called "atmospheric windows", centered at 1.08, 1.27, 1.59, 2.01, 2.7-2.8 and 5  $\mu\text{m}$ . Besides, the atmospheric windows located at wavelengths shorter than 2.8  $\mu\text{m}$  are strongly affected by an additive component to the signal recorded by VIMS, due to the aerosols scattering blurring effects. Finally, VIMS images in the atmospheric windows are also affected by the photometric properties of the surface, seen with a wide range of viewing angles.

We designed an empirical method to reduce the aerosols additive scattering component in VIMS images of Titan. This reduction is performed by (1) considering a single-scattering approximation, (2) using the images taken at wavelengths where Titan's surface cannot be seen in the wings of a given atmospheric window as proxies for pure atmospheric scattering by almost the whole atmospheric column of aerosols, and (3) neglecting atmospheric absorption at the center of atmospheric windows. The surface photometry is estimated by considering the images at 5  $\mu\text{m}$ , which are almost free of any atmospheric effects. We will show that our first order empirical atmospheric correction process improves significantly the quality of the surface maps. Once corrected, VIMS images can prove to be very useful for geological studies of Titan's extraterrestrial surface.

## **Parallel Session 13: Instrument Development (2)**

### **The “mixel” camera: A new camera concept that enables near perfect spatial co-registration in hyperspectral data**

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**Keywords:** hyperspectral imaging, co-registration, misregistration, camera design, mixel, imaging spectroscopy, restoring, keystone correction

Current hyperspectral camera designs aim for correcting co-registration errors in hardware, which severely limits specifications of these imaging instruments in terms of spatial resolution and ability to collect light. In this paper we present a new hyperspectral camera concept that enables near perfect spatial co-registration in the hyperspectral data without compromising the spatial resolution or light gathering capacity of the camera.

The proposed camera concept combines a new type of hardware component and a mathematical method. The hardware component modifies the image in such a way that it becomes possible to calculate the full resolution hyperspectral datacube with very high accuracy, even when large keystone and PSF variations are present in the optics. The concept requires very precise knowledge about the camera optics, such as keystone and PSF of the system. A method for precise calibration of the camera is suggested in the paper. National and international patents have been filed for this technology.

The “mixel” camera has been modeled, and its performance evaluated, using a Virtual Camera software that was developed specifically for this purpose. Geometric ray tracing was used to simulate the light propagation in the system. Keystone, PSF of the relay optics, and photon and readout noise were also included in the camera model. High-resolution hyperspectral images containing objects of various size and contrast were used as the input scenes for the simulations. The analyses showed that co-registration errors are extremely small and that this camera will be photon noise limited, even for very bright scenes. The “mixel” camera has also been compared to a simulated traditional hyperspectral camera that corrects keystone in hardware. These simulations showed that the new camera significantly outperforms the traditional cameras both with respect to co-registration errors and signal-to-noise ratio. A prototype version of the “mixel” camera has been built and is currently being tested.

The proposed camera has the potential to become the new standard for future hyperspectral camera designs.

## **The Bundle Adjustment of VNIR, SWIR and LWIR Airborne Hyperspectral Systems at Rothera Research Station, Antarctic Peninsula**

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**Keywords:** hyperspectral, airborne, VNIR, SWIR, LWIR, bundle adjustment, ground control points, mosaic

In February 2011, VNIR, SWIR and LWIR hyperspectral imaging systems (CASI-1500, SASI-600, and TASI-600 respectively) were installed in a Twin Otter, equipped with a large aerial survey port, at the Rothera Research Station, Antarctic Peninsula. The bundle adjustment parameters (positions and angular offsets between each system's entrance pupil and the IMU center and GPS antennae) were iteratively derived from data acquired during a bundle adjustment flight. The bundle adjustment flight consisted of fourteen north-south flight lines and nine east-west lines crisscrossing a nine square kilometer area surrounding the Research Station. Sixteen field-deployed and well-spaced targets made of Aluminized Mylar were used as GPS-surveyed ground control points (GCPs) within the bundle adjustment area. The Aluminized Mylar GCPs were clearly visible and easily detected in the data generated by all three instruments and facilitated the accurate derivation of the bundle adjustment parameters for the systems' installation. The GCPs also reflected the LWIR emissions of mesospheric ozone which were used to spectrally validate the LWIR hyperspectral data. The bundle adjustment parameters were subsequently used with in-situ IMU data, DGPS and DEM to ortho-rectify and mosaic the vast quantity of high-spatial resolution VNIR, SWIR and LWIR hyperspectral data collected during the following weeks.



## **Parallel Session 14: Mining environment and other applications**

### **Using Image Spectroscopy to Determine Surface Water Parameters in Mining Environment**

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**Keywords:** image spectroscopy, water pollution, linear spectral unmixing, dissolved Fe, suspension

Water has been traditionally monitored by in situ measurement, to take point samples at regular intervals. But point samples are not adequate to observe spatial and temporal variations in large areas or in polluted regions where the water quality can change dramatically and needs to be monitored at a regular basis. Image spectroscopy (hyperspectral remote sensing) provides a new way to obtain continuous information on water quality at regional scales. From an optical perspective, in addition to pure water itself, the optical properties of surface bodies of water are mainly influenced by three constituents: phytoplankton, suspended sediment, and colored dissolved organic matter (CDOM) that is also called yellow substance or gelbstoff. In our study we tested the feasibility of mapping properties of surface waters affected by long-term mining activities using airborne multi-flight-line HyMap hyperspectral (HS) datasets, which were corrected for the atmospheric effect and further processed to minimize strong cross-track illumination and bi-directional reflectance distribution function effects. The work was carried on the Sokolov lignite mines as they represent a site with extreme dynamics, material heterogeneity, high pH gradients and wide varieties of surface water pollution. For eight different water bodies physical and chemical properties were determined (e.g., suspended solids, dissolved Fe, pH, Eh, dissolved organic carbon (DOC), heavy metal content) and associated with the spectral properties of the corresponding image pixels. The unique spectral characteristics for the water gradients of dissolved Fe, mineral (inorganic) suspension and lignite (organic) suspension in relation to the DOC were defined. Furthermore, pure image endmembers for these fundamental physical components of the studied water bodies were extracted employing the minimum noise fraction transformation (MNF) and pixel purity index (PPI) procedure. To estimate the selected water parameters (dissolved Fe, inorganic and organic suspension content) a sub-pixel method was preferred rather than a hard classifier while taking into account the heterogeneity of the Sokolov surface waters. Therefore, the linear spectral unmixing (LSU) method was tested and, as sufficient accuracy was achieved, semi-quantitative maps of dissolved Fe, inorganic and organic suspension content were created.

#### **Acknowledgement**

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**Using Hyper- Multi- spectral Remote Sensing in the Thermal Region for classifying soil's mineralogy and assisting in monitoring the environmental impacts caused by mining activities**

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**Keywords:** Soil emissivity, LWIR hyperspectral remote sensing, LWIR multispectral remote sensing, Apparent thermal inertia

Recent technological developments of earth observation sensors placed Thermal InfraRed (TIR), alongside with VNIR-SWIR, hyper- multi- spectral remote sensing, as a promising tool in environmental studies. The use of TIR ground and airborne data provides an additional layer for improving our understanding of natural and human environmental impacts. The presented study was performed as part of the FP7 EO-MINERS project with the overall aim to apply new earth observation tools for monitoring the environmental impacts caused by mining activities. A Long Wavelength InfraRed (LWIR) spectral library of various soil samples, collected in Israel, the Czech Republic and the Republic of South Africa, were prepared using a hyperspectral SR-5000 SpectroRadiometer. The soil samples' emissivity was calculated from the emission spectra and the mineralogical content was deduced. Day and night coverage of the Sokolov test site in the Czech Republic was done by using the AHS (VNIR-SWIR-MIR-TIR) airborne sensor, operated by INTA in the framework of the EUFAR DeMinTIR project. Different atmospheric correction approaches have been applied to the airborne data cubes by DLR and TAU. The resulted temperature and emissivity were validated against ground acquired data obtained with ASD Field Spectrometer, SR-5000 and D&P  $\mu$ FTIR portable field spectrometers. The emissivity images were used to classify the soil coverage, focusing on clay and quartz content. Further analysis was performed on the day and night images to generate the Apparent Thermal Inertia (ATI) images. A threshold value to distinguish between high and low soil moisture content was derived from the data. It was concluded that the TIR (LWIR) region can provide additional information, alongside with VNIR-SWIR region, regarding environmental monitoring issue studied within the EO-MINERS project.

### **From hyperspectral pixel to archaeological information**

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**Keywords:** aerial archaeology, Carnuntum, distribution fitting, imaging spectroscopy, red-edge inflection point, vegetation stress

Aerial archaeology is the discipline that encompasses the study of all types of archaeological remains using data collected from an airborne platform: digital or film-based aerial photographs, airborne laser scanning, aerial imaging spectroscopy (AIS) etc. So far, AIS has occupied only a very small niche in the field of archaeological airborne remote sensing. Besides reasons of cost, the common archaeologically-insufficient ground-sampling distance of 1-3 m can be considered the main limiting factor. Moreover, the technical processing of these highly redundant data does typically not surpass the calculation of band ratios and a principal component analysis. As a result, the few practical applications of archaeological AIS have not been very convincing so far.

The aim of this contribution is to present the analysis of several archaeologically-relevant hyperspectral datasets acquired in different seasons above the Roman town of Carnuntum (Austria) and characterised by a ground-sampling distance of 40 cm or smaller. It will be shown how a specifically developed MATLAB toolbox was used to extract important archaeological information from these hyperspectral pixels. To this end, a variety of approaches that are not commonly applied in archaeological remote sensing research (such as the red edge inflection point and distribution fitting) are tested and validated. Finally, a comparison with simultaneously acquired oblique and vertical photographs will indicate the specific advantages of high-resolution AIS data.

## **The effect of canopy characteristics to reflectance of snow covered boreal forest based on airborne AISA spectrometer observations**

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**Keywords:** Reflectance, hyperspectral, Scene reflectance, NDSI, NDVI, Boreal forest, Crown coverage, Tree height, Snow, Airborne, AISA

In open areas with full snow cover, the error in the detection of snow from optical satellite data is usually very tolerable, but in forested areas the canopy prevents the visibility to the ground layer and the error is higher. To develop improved and accurate methods to describe satellite-based observations as a function of regionally varying scene (target) characteristics, i.e. forward modelling, requires extensive and reliable experimental datasets. In this investigation the high resolution airborne optical AisaDUAL (Airborne Imaging Spectrometer for Applications) measurements and LIDAR (Light Detection and Ranging) data-derived detailed forest canopy characteristics from the northern boreal region of Sodankylä were utilized in the examination of the effects of forest stand properties to the complex canopy-ground component. The airborne reflectances were acquired under homogeneous dry snow cover conditions which offer a beneficial opportunity to investigate solely the effects of canopy characteristics on the scene reflectance. According to the results, the change in canopy characteristics is related to the observed change in reflectance, as well as to changes in spectral indices. One notable finding was that the correlation between the forest characteristics and reflectance was nearly exponential, while with reflectance indices it was more linear. In future research, these results will be exploited in testing and further development of the scene reflectance models.

## POSTERS

### Airborne sensors

#### **Physical relations concerning a hyperspectral linescanner, modeling a multicopter sensor system**

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**Keywords:** UAV, sensor design, geometry, radiometry

Recent advances in avionics and sensor technology make it possible to deploy optical sensors onto unmanned multicopter vehicles. Remote sensing instruments can be assembled under an unmanned multicopter and observe areas in the range of several hectares. Mounting a line spectrograph onto a multicopter may result in spectral measurements with a high spatial resolution. However, such a sensor system has its physical limitations, rooted from the interplay between scene, platform and sensor. These limitations are dominated by the geometric and radiometric configuration and its payload. This study describes the physical relations and highlights the potential and limitations of hyperspectral multicopter acquisition. Understanding the physical relations of such a system is done through modeling the combination of natural phenomena and instrument specifications and settings.

The modeling involves the full remote sensing imaging chain. Starting with the physical properties of the sun's spectrum. Thereupon we used this information together with different spectral responses of surface phenomena, as a starting point for the analysis. The interplay of the geometric and radiometric relations in respect to system specifications is incorporated. The settings of the components are adjustable and we incorporated interplay of these settings resulting in different specifications of the hyperspectral imagery. Results from the modeling give insight into the system configuration and the achievable product. It enables the design of a system that optimally fits the needs for a certain application.

Furthermore, we obtained insight about camera settings and flight dynamics in relation to geometric and radiometric precision. The sensor system is modeled for a multicopter system, consequently it has different flight dynamics than, for example, an airplane. Therefore, we analyze the specific flightpath dynamics of a multicopter system. As the physical relations are modeled, error propagation is used to perform a sensitivity analysis of the output.

## **Introducing a novel miniaturized high performance spectrometer to measure vegetation using an octocopter - Calibration and validation of a new versatile airborne hyperspectral measurement approach**

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**Keywords:** Hyperspectral UAV calibration validation

Airborne and spaceborne hyperspectral imaging sensors rely heavily on good ground referencing. Measurements of targets at the ground are meanwhile time consuming and accompanied by huge efforts. Another problem arises from heterogeneous surfaces that are not easy to average by hand held devices due to their small field of view and the low altitude over ground. This becomes a huge challenge when inaccessible targets such as forest canopies or mud land are in the focus of interest.

To overcome these limitations we introduce a versatile hyperspectral measurement system based on an Asctec Falcon-8 octocopter UAV and the Ocean Optics STS microspectrometer. With this system highly reproducible measurements within a range of 150 m of altitude can be performed. The device is based on two interlinked hyperspectrometers. One unit on the ground measures the incoming irradiance at the same time the airborne unit measures upwelling radiance. Design, calibration and error estimation of the new system was conducted during laboratory and field measurements. Spectra can be recorded with 1024 bands between 350 and 800 nm and a FWHM better than 3 nm. Reference measurements against an ASD Field Spec 4 have shown good correlation ( $r^2 = 0.9957$ ). The measurements performed with the drone at 10 m altitude show a 10 times lower standard deviation than the measurements performed over the same agricultural target with the ASD Field Spec at the ground.

The highly automated drone spectrometer opens up opportunities for hyperspectral data collection over small to medium scale field experiments even if they are hard to access. Additionally the spectrometer allows investigation of spatio-temporal variations and the influence of atmospheric effects on hyperspectral measurements in altitudes between 1 and 150 m.

## **Two years of APEX operations: an overview of the research flights, APEX status and PAF**

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**Keywords:** APEX, operations, processing, archiving

Since its acceptance by ESA in 2010, several hundreds Gigabytes of airborne hyperspectral data have been acquired with the Airborne Imaging Spectrometer APEX (Airborne Prism Experiment).

APEX was operated over the last 2 years over test sites and research areas spread all over Europe. In 2011, data were acquired during two 'groupshoots' organized in June and September. In 2012, three flight campaigns were organized during respectively April, June and September.

Each campaign was organized around a main 'groupshoot' serving as mainframe for a major campaign. With those groupshoots as backbone other research groups were invited to join and take advantage of this opportunity. The first part of the presentation will thus give an overview of the data volumes gathered, research areas and research topics dealt with over the first 2 years of APEX operations.

The second part will highlight the latest status and known issues on the APEX instrument as well as the latest status of the APEX operational processing. The APEX Processing and Archiving Facility (PAF) is located at VITO and covers the data flow from customer flight requests to final product delivery. Specifically, the following aspects performed by the APEX PAF are treated:

- (a) processing of the acquired data from raw instrument data stream to physical units,
- (b) geometric and atmospheric correction for each scene, and
- (c) instrument calibration data management.

## **Development of a Lightweight Hyperspectral Mapping System for Unmanned Aerial Vehicles**

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**Keywords:** Unmanned aerial vehicle, Hyperspectral, Ortho-mosaic, Digital surface model

Unmanned Aerial Vehicles (UAV) are rapidly becoming an essential tool in small scale remote sensing. Nowadays, aerial RGB ortho-images and Digital Surface Models (DSM) are routinely produced using handy and economical small UAVs, capable of carrying 1–2 kg of payload. Currently, the optical sensors on such UAVs are mostly limited RGB or CIR cameras, as there are no commercial hyperspectral mapping systems available for this payload range. The most lightweight systems weigh closer to 3 kg, as they exploit rather heavy external flight computers and reflective grating spectrographs.

In this poster, we present a design of a miniaturized UAV hyperspectral mapping system and preliminary airborne data-sets related to habitat mapping and agricultural monitoring. Our system is based on a line-spectrometer built out of a transmissive grating spectrograph (Specim ImSpector V10, 400–1000 nm, 9 nm FWHM) and an industrial smart camera (Photonfocus SM2-D1312). The smart camera has a built-in Digital Signal Processor computer that we exploit in synchronizing acquisition and storing of data to an SD-card. To form a complete acquisition system, the spectrometer is connected with a GPS-Inertia Navigation System (GPS-INS, XSens MTi-G-700) and optionally, a photogrammetric camera (Panasonic GX1). The system weighs 1.4 kg with the minimum configuration and 1.8kg with the photogrammetric camera included.

In the processing phase, the GPS-INS positioned RGB images from the photogrammetric camera are used to calculate a DSM and true-orthomosaic. This process also outputs the photogrammetrically determined image positions with higher internal accuracy than is available in the original GPS-INS data. Thus the photogrammetric image positions are used to calibrate and stabilize the GPS-INS data ensuring high internal positioning accuracy. As the last processing step the empirical-line calibrated line-spectrometer data is projected over the DSM, producing the hyperspectral true-orthoimages of the target area.



## **Archeology**

### **Remote Sensing related characterisation of Pre-Columbian archaeological sites in the Dominican Republic**

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**Keywords:** Archaeology, spectroscopy, Caribbean, profiling, hyperspectral

Remote Sensing is predominantly used for characterisation of the current status or of the evolution of the landscape. Recently, the depletion of natural resources such as fresh water, fertile soils, living space, as well as threats to cultural resources and cultural heritage, coupled with the increasing population on earth, have generated more public and scientific interest in past cultures as a means to learn lessons for the future. Remote Sensing can assist in spatially delimiting areas of archaeological interest preceding in-situ investigation. Moreover, interpretations linked with remote sensing can contribute to a better and more regionally integrated understanding of past cultures. In this context, it is necessary to define, to measure and to spatially characterise local indicators detectable in airborne or spaceborne image acquisitions.

Ancient Caribbean cultures, including those of the Dominican Republic, have a 6000 year old history, contributing to worldwide research on colonization, cultural interaction, adaptation to and transformation of island environments, as well as encounters between the New and Old world. Currently the unique cultural heritage of the Caribbean is under threat due to natural disasters, large-scale development and difficulties of heritage protection. Ancient Taino Indian (AD 900-1550) settlements on the Dominican Republic have been excavated and interpreted using traditional archaeological approaches. To enable better spatial and physical characterisation of sites such as Playa Grande, near Río San Juan and Edilio Cruz and La Tierra Blanca near Imbert, in-situ spectroscopy, thermal imagery and 3D modelling based on multiangle digital image acquisitions were conducted. Additionally, field samples were biologically and geochemically analysed to validate indicator hypotheses. In consequence, a set of spatial and spectral indicators have been identified that can be used for spatial delineation of Pre-Columbian sites in the Caribbean by in-situ spectroscopic profiling, by spectral and spatial pattern matching with airborne or spaceborne multi- or hyperspectral image acquisitions.

### **CropMark – A Matlab toolbox for archaeological imaging spectroscopy**

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**Keywords:** airborne imaging spectroscopy, visualisation, information extraction, data mining, Whittaker smoother, red edge inflection point, edge detection, vegetation indices, data compression, data fusion

When using airborne imaging spectroscopy (AIS) data for archaeological research, at least two broad problems need to be solved (assuming that the georeferencing can be handled correctly). The first problem relates to the visualization of the huge amount of available data and the fact that imaging spectroscopy usually yields a large amount of redundant data. This makes data mining approaches necessary. The second problem relates to data quality. Indeed, as the upwelling electromagnetic radiation is recorded in small bands that are only about ten nanometres wide, the signal received by the sensor is quite low compared to sensor noise and possible atmospheric perturbations. In the same way, the necessary high spatial resolution (i.e. small ground sampling distance) further limits the useful signal stemming from the ground. For these reasons, radiometric filtering techniques are mandatory, as otherwise the noise component deteriorates the extracted information.

A user-friendly Matlab-based toolbox, called CropMark, was developed to enable the extraction of information out of the recorded hyperspectral data cube. As the main application of this toolbox is the field of archaeology, the aim was to visualize the data highlighting possibly occurring crop or soil marks. Powerful filters based on the Whittaker smoother (currently not available within commercial image processing software) were implemented. The user can visualize the sequence of individual bands in an animated way, or look at (the first few) principle components. Shape information such as the red edge inflection point is derived from spectrally smoothed and oversampled signatures giving new insights into crop vigour/crop stress. Additionally, various standard and optimized hyperspectral vegetation indices were implemented. Areas can be highlighted having a similar spectral signature compared to a user-selected pixel or region of interest. The user can further test the usefulness of a large set of edge detection algorithms. Import and export functions are available regarding a number of standard image formats.

## **Imaging spectroscopy as a tool for identifying areas of high archaeological potential**

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**Keywords:** imaging spectroscopy, archaeology

Advances in remote sensing over the past 30 years, and especially over the last decade, have provided new opportunities for geo-archaeological research, especially for identifying areas of high archaeological potential. Because of the relatively small size of archaeological sites and the variability of their shape and spectral properties, the spatial and spectral resolution of any remote sensing data must be extremely high to be really useful. In order to define these resolution requirements one first has to investigate the (post-depositional) processes producing remotely detectable geo-archaeological signatures as the way archaeological sites appear at the surface and thus can be identified as potential targets, is strongly dependent on the nature of the landscape they are buried in. Information on the interplay between site and soil characteristics thus is crucial for their potential detection, an aspect which is still lacking in present-day archaeological research. This currently limits the potential of airborne hyperspectral imaging as an archaeological prospection technique, because it cannot be targeted at sites and soils where it is most likely to be effective and because the reflectance spectral variations it records cannot be confidently interpreted unless they form clearly recognisable patterns. This is significant because airborne hyperspectral imaging is expensive and targeting it at sites where it can be most effective is essential if it is to be efficiently used. To complement research in this domain, this paper focuses on developing a methodology for investigating remote sensing signatures of archaeological remains using imaging spectroscopy techniques. It aims to clarify where and how imaging spectroscopy can identify buried remains as changes in the reflectance spectra of bare soil surfaces. The study is analysing the way in which the reflectance spectra of archaeological deposits form and change in the ground and how these spectral properties become detectable at the ground surface. This information will be used to define the requirements of future airborne hyperspectral sensors targeted to archaeological investigations.

## **Calibration – Validation**

### **Practical Example of the Supervised Vicarious Calibration (SVC) method - ValCalHyp Airborne Hyperspectral Campaign under EUFAR framework (3524)**

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**Keywords:** Supervised Vicarious Calibration, Radiometric Cross-Calibration, ValCalHyp, EUFAR, AISA-Dual, AHS, CASI

A novel reflectance-based approach for radiometric calibration and atmospheric correction of airborne hyperspectral (HRS) data, supervised vicarious calibration (SVC), was proposed by Brook and Ben-Dor in 2010. The present study aimed to validate the SVC method using simultaneously operated several different airborne HRS sensors that acquired data above several selected sites. The general goal of this study is thus to apply a cross-calibration approach to examine the capability and stability of the SVC method. The main assumption of the SVC method is that radiometric and spectral performances and stability of all HRS sensors are varying in time and space, therefore the periodical calibration information, such as laboratory calibration, might not be correct or suitable for a particular campaign. Therefore, a method to assess the overall accuracy of at-sensor radiance response and its stability alongside with correcting the possible radiance drifts are crucial, and suggested by the CVS method.

The basis of the SVC method relies on in-situ spectral measurements of a selected test site on the airplane's trajectory that is covered by artificial agricultural black polyethylene nets in various densities. These targets are set up on the ground close in time to the beginning of the airborne campaign, and are used to radiometrically recalibrate the HRS sensor, in case it is necessary. The different densities of the nets combined with any bright background afford full coverage of the HRS sensor's dynamic range.

In the current study three sensors were involved in an airborne campaign mission supported by EUFAR under a project entitled ValCalHyp. The AISA-Dual (operated by NERC), AHS and CASI (operated by INTA) were acquired data over several selected sites in the south of France (Salon de Provence, Marseille, Avignon and Montpellier) on October 28<sup>th</sup> 2010 between 13:00 and 16:00 UTC. The ground SVC site was set near Montpellier on the parking lot next to a coastline. This site provided a wide flat region mainly covered by a very bright sand. During the flight campaign two scenarios for cross-calibration were performed: the ideal scenario, when all sensors share the same geometry (in terms of flight heading) and the coincident acquisitions (sensing the same area with the same geometry), and the less ideal (more realistic) scenario, when the sensors do not share the same geometry but keep the coincident acquisitions, or when the sensors hold different geometry and different acquisitions.

This project studies cross-calibration results for all the above-mentioned scenarios and compared the results between AISA-Dual, AHS and CASI sensors. A brief overview of the sensors used for the cross-calibration is given and the SVC test site is discussed. The results of the SVC method were examined by comparing the ground-truth spectra of several selected validation targets with the imagery spectra corrected by the suggested method for the three HRS sensors.

The results of this study confirmed that the SVC approach performed identically well for the selected HRS sensors in both ideal and less ideal scenarios. In fact, the good agreement shown between the ground-truth validation spectra and the imagery spectra, suggests that the SVC approach is feasible for any of the selected HRS sensors and it is strongly recommended for the future utilization. The complete protocol on the practical execution of the SVC and cross-calibration is discussed together with the possible limitations of this method.

## **Coastal –Marine – Inland**

### **Study of water quality parameters of the Venice lagoon using hyperspectral data**

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**Keywords:** HICO, Venice Lagoon, chlorophyll, mapping

In the framework of the HICO Project (<http://hico.coas.oregonstate.edu/>), a number of radiance and reflectance images of the Venice Lagoon were used to evaluate the possibility of performing quick and reliable mapping of chlorophyll-a concentration in water.

Sponsored by the Office of Naval Research, the Hyperspectral Imager for the Coastal Ocean (HICO™) is the first spaceborne imaging spectrometer specifically designed to sample the coastal areas, with 128 spectral bands, a 90 m spatial resolution, full spectral coverage (380 to 960 nm sampled at 5.7 nm) and a very high signal-to-noise ratio to resolve the complexity of the coastal ocean.

Eutrophication is one of the major causes of water quality deterioration. Since contains the green pigment chlorophyll-a, the concentration of chlorophyll-a found in water can be used to trace the abundance of planktonic algae in rivers, lakes or lagoons. The Venice Lagoon, famous worldwide, represents one of the most fragile and vulnerable ecosystems, which is being constantly threatened by factors of stress, both human and natural, such as erosion, presence of urban and agricultural sources of pollution, stress from fishing, pollution produced by the industrial area of Porto Marghera and by the city of Venice itself, downwash of sediments from the hinterland and eutrophication.

Traditional methods of water quality estimation are often time consuming and involve periodical sampling and plenty of laboratory analyses. In this study the possibility of using imaging spectroscopy to rapidly obtain raster-based maps of chlorophyll concentration by comparing the results obtained through five different literature bio-optical models, which permit the retrieval of mathematical relations between the water's spectral properties and physicochemical parameters; pH, dissolved oxygen, turbidity and chlorophyll concentration. Evaluation of performances is accomplished by comparing the hyperspectral based maps with maps of kriged concentration values, provided by the Magistrato delle Acque di Venezia ([http://www.magisacque.it/sama/sama\\_monitoraggi1.htm](http://www.magisacque.it/sama/sama_monitoraggi1.htm)) and collected by the network of SAMANET sensors.

## **Tracing suspended sediment sources during flood events in a mesocale dryland catchment using hyperspectral VNIR-SWIR reflectance spectra**

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**Keywords:** soil erosion, spectroscopy, fingerprinting, suspended sediment, Spain

Knowledge on the origin of suspended sediment is important for improving our understanding of sediment fluxes and pathways and thereupon support of sustainable watershed management. An approach providing information on the origin of suspended sediments is a technique called fingerprinting. It is based on the assumption that potential sediment sources can be discriminated and that the contribution of these sources to the river sediment can be determined on the basis of distinctive characteristics (fingerprints). Recent studies indicate that VNIR-SWIR reflectance characteristics of soil may be a rapid, inexpensive alternative to traditional fingerprinting properties such as e.g. geochemical composition, radionuclides or mineral magnetism.

To further explore the applicability of hyperspectral data for sediment tracing purposes, soil and sediment samples were collected in the Isábena watershed, a 445 km<sup>2</sup> dryland catchment in the Central Spanish Pyrenees. In situ reflectance spectra using an ASD 3 field spectroradiometer and grab samples of the upper soil layer were collected from the main potential sediment sources. Suspended sediment samples were collected by automatic point samplers during flood events in the period 2011-2012. All soil and suspended sediment samples were dried, sieved and subsequently spectral readings were taken in the laboratory. The “traditional” procedure for fingerprint tracing of sediment sources (classically a Kruskal-Wallis test followed by a stepped discriminant function analysis for source discrimination and mixture modelling for source contribution) was applied to soil and sediment spectral features (colour, pca scores and physically based). In addition, machine learning algorithms were tested on spectral features as well as entire reflectance spectra and derivatives. The algorithms were trained on artificial soil sample mixtures of known proportions. Since the use of field spectra would be more straightforward, the procedures described above were applied to both, field and laboratory spectra of the soil sample set.

This study forms part of a multi-scale project on generation, transport and retention of water and suspended sediments in a large dryland catchment in NE Spain. Results of the spectral fingerprinting will be compared with sediment loads measured in the field and with fingerprinting results based on geochemistry and radionuclides in the future.

## Geology –Soils – Minerals

### **Vegetation patterns as a function of soil and soil water conditions using hyperspectral remote sensing**

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**Keywords:** soil moisture, vegetation pattern, AISA, electromagnetic induction, gamma ray

Quantifying and qualifying both the spatial and temporal patterns of soil properties and moisture patterns, still remains one of the central challenges in environmental monitoring. Information which describes the soil variability is an important input for ecological modeling, agriculture and soil management. Functional reactions in plants and vegetation are controlled and influenced by a combination of soil properties including characteristics such as texture, salinity, pH-level, chemical composition, soil moisture patterns and temperature. The functional relationship between soil properties and functions and vegetation patterns can clearly be recognised from simple aerial photography and satellite images.

The main hypothesis of our research is that biochemical-biophysical plant characteristics can be used to quantify changes in soil heterogeneity in the apparent electrical conductivity of soils. The current study investigates the feasibility of using reflectance spectra of the vegetation canopy to characterize, describe and predict the physical-chemical components and characteristics of the underlying soil.

The investigation area “Roßlauer Oberluch” used to be an ancient floodplain and is made up of various flood channels, floodplain forests and wet meadows. There is a high level of variation in the groundwater and soil water levels. Imaging hyperspectral data sets of the test site were carried out using the hyperspectral sensors AISA-EAGLE/HAWK with a ground resolution of 2 m and 491 spectral bands. Moisture patterns and soil characteristics were quantified based on electromagnetic induction EM (soil moisture measured with electrical conductivity) and Gamma-ray measurements (soil structure, lithology, type, water potential or hydraulic conductivity). Different imaging hyperspectral index types, single band reflectance and published spectral indices were used and related to the geophysical measurements using regression models.

The best models for predicting electrical conductivity based on spectral information were obtained for EM 38 V with an  $R^2=0.41$  with the spectral index CAI (cellulose absorption index) as well as for EM 38 H with an  $R^2=0.39$  with the spectral index PSRI (Plant senescence reflectance). For predicting soil characteristics measured with gamma ray methods the best model was obtained for Gamma K with an  $R^2=0.37$  with the spectral index TVI (triangular vegetation index). A considerable improvement to explain the variance of all EM measurement signals was obtained by including elevation in the predictive models. Based on multivariate regression modeling with the spectral index PSRI, a wavelength of 680 nm and elevation we obtained the best model fit with an  $R^2$  of 0.65 for EM 38 H.

By modeling soil characteristics based on Gamma ray techniques we achieved the model of best fit with an  $R^2$  of 0.55 for Gamma Th measurements. Our results show that the hyperspectral remote-sensing technique is a suitable tool for describing and analyzing biochemical vegetation characteristics as a reaction to underlying soil and moisture patterns. The electrical conductivity is highly influenced by the landform configuration of the investigation area and must therefore be integrated into the model.

We assume that the coherences between biochemical vegetation soil and soil water characteristics are nonlinear. Therefore, we intend to test other classification approaches such as SVM, PLSR and cluster algorithms for a better prediction of moisture patterns and soil characteristics.



## **Mixtures of alteration minerals observed with VIS/NIR spectroscopy: from detection to quantification using controlled weight mixtures of laboratory samples**

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**Keywords:** NIR, spectroscopy, mixtures, library

Hyperspectral imaging of planetary surfaces in the visible and near-infrared allows detection of absorption features related to electronic or vibrational processes in minerals such as oxides, olivines, pyroxenes, sulfates and phyllosilicates. Detections are validated by comparison of absorption patterns with that of library spectra. However, while natural materials usually consist of several minerals, libraries typically include spectra of only pure constituents.

Several methods exist to deconvolve spectra of mixtures of pure constituents. However, all have limitations, and while radiative transfer modeling gives quantitative results, it is impeded by the lack of optical constants relevant to most alteration minerals (eg. sulfates). We therefore approached the problem of mixtures from an empirical perspective, by creating spectral libraries of binary mixtures of constituents in controlled relative proportions.

We put together a collection of natural and synthetic samples relevant to the surface of Mars. We used an unaltered basalt sample from Iceland, the Mg-sulfates kieserite and hexahydrate, prepared from reaction grade epsomite dehydrated at controlled temperatures, dehydrated amorphous silica gel, and a natural nontronite sample. All samples were ground and passed through a 63  $\mu\text{m}$  sieve. Mixtures of basalt as the first endmember and each one of the later alteration minerals as the second were prepared using a precision balance at 10 %wt increments, with additional 5% and 1% mixtures. Spectra were acquired using a Nicolet 6700 FTIR in the 1-5  $\mu\text{m}$  wavelength range typical of hyperspectral imaging of planetary surfaces.

The first five spectral libraries prepared show a strong prevalence of alteration minerals over basalt even in very low proportion, eg. with Mg-sulfate completely hiding basalt signatures at 20% wt. Mixtures with low (<30%) ratio of alteration minerals best reproduce absorption band depth typical of alteration-minerals-bearing terrains on the surface of Mars.

Perspectives

We plan on expanding our libraries with more alteration minerals and different grain sizes, especially relative to the basaltic component, to investigate the possible blanketing effect of small particles on larger grains.

## **Estimation of soil texture using multidirectional hyperspectral laboratory measurements**

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**Keywords:** Soil anisotropy, Goniometer, Unmanned Airborne Vehicles

The spatial variation in soil texture is an important factor for erosion modelling and agricultural management. However, airborne hyperspectral data which meet the spatial and spectral resolution requirements to study soil texture are sparse. Unmanned airborne vehicles (UAV's) can potentially fill this data gap, when they are equipped with a hyperspectral mapping system. For quantitative estimates of the soil clay content usually the clay absorption feature in the shortwave infrared (SWIR) part of the spectrum is used, but measuring the reflectance in this wavelength range is hindered by technical limitations. A sensor sensitive in the SWIR would weigh more than the payload of most UAV's allows. Therefore, we want to investigate if multidirectional measurements in the visible and near-infrared wavelengths can be used for quantitative estimates of clay content and yield predictions which are comparable to nadir measurements including the SWIR.

We selected 59 samples from the North of Morocco, showing a large variation in texture and mineralogy. The reflectance of the samples was measured under 92 different angles using a robot-based goniometer system. On the robotic arm an ASD Fieldspec 3 was mounted, which measures the spectral reflectance in the range of 350-2500 nm. We will describe the differences in anisotropic behaviour of the different soil samples and relate this to differences in clay content and texture. Further, we will show the evaluation of the use of multidirectional measurements for the prediction of soil clay content and texture, compared to using nadir measurements only and we will evaluate how the outcome can be used to steer the development of hyperspectral soil sensing from UAV based platforms.

## **Shortwave infrared hyperspectral laboratory and airborne measurements as tool for local mapping of swelling soils, Loiret (France)**

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Swelling soils contain clay minerals that change volume with water content and cause extensive and expensive damage on infrastructures. Based on spatial distribution of infrastructure damages and existing geological maps, the Bureau de Recherches Géologiques et Minières (BRGM, the French Geological Survey) published in 2010 a 1:50 000 swelling hazard map of France. This map indexes the territory to low, intermediate, or high swell susceptibility, but does not display smallest and isolated clays lithologies. At local scale, identification of clay minerals and characterization of swell potential of soils using conventional soil analysis (DRX, chemical, and geotechnical analysis) are slow, expensive, and does not permit integrated measurements. Shortwave infrared (SWIR: 1100-2500 nm) spectral domains are characterized by significant spectral absorption bands that provide an underused tool for estimate the swell potential of soils. Reflectance spectroscopy, using an ASD Fieldspec Pro spectrometer, permits a rapid and less expensive measurement of soil reflectance spectra in the field and laboratory. In order to produce high precision map of expansive soils, the BRGM aims to optimize laboratory reflectance spectroscopy for mapping swelling soils. Geotechnical use of laboratory reflectance spectroscopy for local characterization of swell potential of soils could be assessable from an economical point of view. A new high resolution airborne hyperspectral survey (covering ca. 280 km<sup>2</sup>, 380 channels ranging from 400 to 2500 nm) located at the W of Orléans (Loiret, France) will also be combined with field and laboratory measurements to detect and map swelling soils.

Nina Boesche

## **Spectroscopy of Geological Materials and Alteration Zones, in Comparison to HYPERION and Simulated EnMAP Data, in Rodalquilar Southern Spain**

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**Keywords:** Alteration, Spectroscopy, EnMAP, HYPERION, EnGeoMAP

Image spectroscopy is widely used in the mineral exploration business today utilizing mainly data that have been acquired by airborne hyperspectral sensors, such as for example HYMAP and HYSPEX. While these airborne sensors have a superior SNR and GSD over any practical and hypothetical hyperspectral Satellite sensor, their available data coverage and recurrence time is limited to the data that are available from survey campaigns. The only spaceborne hyperspectral earth observing sensor continuously covering the visible, near infrared and the short wave infrared wavelength range flying today is NASAs HYPERION aboard EO1. This shows the necessity of a next generation hyperspectral earth observing satellite sensor, such as EnMAP for the earth science community.

This study shows field and laboratory spectroscopy data from Rodalquilar Spain to demonstrate the possibility of extracting characteristic mineral absorption features of hydrothermal alteration zones from a hydrothermal acid sulphate gold complex with spaceborne sensors, such as EnMAP or HYPERION. The geology of the area has been extensively studied by the USGS and its geology is well documented in the USGS report: (OF-89-326, by J. Rytuba and A. Arribas et al., 1989). Furthermore, HYPERION data is available together with simulated EnMAP data, from a 2004 HyMAP survey.

The documented hydrothermal alteration zones (silicic, advanced argillic and argillic) were identified and sampled in the field with a EnMAP and HyMAP sensor PSF adopted sampling scheme in mind. Preliminary results show similarities between the collected and gaussian weighted field spectra and the satellite data. Furthermore, HYSPEX laboratory results from field samples are shown in conjunction with preliminary EnGeoMAP analysis results.

**Mapping Minerals on a Painting Dating the French Revolution Using Hyperspectral Imagery**  
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Manuel Giraud, Erwan Le Menn, Caroline Leynia, Olivier Barbet

**Keywords:** hyperspectral, painting, art, infrared

Visible and infrared imaging spectroscopy is a very efficient non destructive remote sensing tool to characterize the composition and physical state of a surface. In support for our applications in the domain of planetary exploration and Earth remote sensing, we have set up a laboratory facility to characterize hyperspectral signatures of well controlled mineral, rocks, or man-made artifacts. This experimental facility is built upon three HySpex cameras from the NEO company, covering the 0.4-1.0  $\mu\text{m}$ , 0.9-1.7 $\mu\text{m}$  and 1.3-2.5  $\mu\text{m}$  wavelength ranges with a working distance of either 0.3 m or 1 m.

We have investigated the potential of visible and infrared hyperspectral imagery to characterize a painting dating from the French revolution : the "Club Breton" painting, belonging to the museum of Brittany in Rennes (France). Hyperspectral images of the painting have been acquired with the three cameras, using the painting mounted on a translation stage. Data have been calibrated in reflectance using a Spectralon as a reference. A series of Kremer pure pigments was also imaged with the cameras in order to provide a reference historical database.

The classification of the hyperspectral data set allowed the automated detection of restored areas, thanks to a different response of the surface varnish. The analysis provided information about the painter technic. In particular, images at increasingly long wavelengths, probing different depths into the painting, revealed the chronology of the drawings used by the artist. It shows that the two main characters of the drawing have been painted first, followed by the surrounding buildings. The classification using the Spectral Angle Mapper algorithm allowed the identification and the mapping of the distribution of the main pigments.

## **Mapping salt-affected soils using imaging spectroscopy technique with ASTER data in El-Tina plain, Egypt**

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**Keywords:** Salt-affected soils, ASTER data, Imaging spectroscopy, El-Tina plain

Development of salt-affected soils in the irrigated lands of arid and semi-arid region is a major cause of land degradation. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data were used in the present study for characterization and mapping of salt-affected soils in El-Tina plain area, Egypt. For this purpose, soil samples were collected carefully from 81 points to represent all spatial variability in soil salinity based on soil map and satellite image classification. A FieldSpec hand-held spectrometer (350-2500 nm) was used to measure the spectra of a range of salinized soils. Mixture Tuned Matched Filtering (MTMF) as imaging spectroscopy technique was used to map various categories of salt affected soils represented by spectral endmembers that were related to surface expression of various categories of salt-affected soils in the area, grouped into very slightly, slightly, moderately, strongly and very strongly salt-affected soils. The endmembers were selected by performing minimum noise fraction (MNF) transformation and pixel purity index (PPI) on ASTER surface reflectance data with reference to soil map and field data. Accuracy assessment was evaluated with the Receiver Operating Characteristic (ROC) plot technique. Training and validation saline and non-saline pixels were limited to areas with low vegetation coverage to avoid spectral interferences. The results showed that various classes of salt-affected soils could be reliably mapped using MTMF technique. The overall classification accuracies for very slightly, slightly, moderately, strongly and very strongly salt-affected soils were estimated of 74, 76, 80, 83 and 86% respectively. It may be concluded that the accuracy of the method could be increased by using hyperspectral data and spectral laboratory measurement.

## **Image Processing**

### **Hyperspectral data processing techniques applied to ASTER and WorldView-2 data**

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**Keywords:** hyperspectral, WorldView-2, processing

The field of remote sensing has benefited greatly in the last several years most notably due to the increase in spatial resolution of data from commercial satellites. In addition, sensors that have more channels than previous multispectral sensors have been developed. ASTER and WorldView-2 are examples of satellites with increased spectral capabilities. More channels sampling more wavelengths equals more information, so typically more materials can be mapped with data from these sensors. The spectral resolution of ASTER and WorldView-2 allows hyperspectral processing techniques to be used on data from these sensors. The work presented here compares the results of hyperspectral data processing with multispectral data processing using hyperspectral techniques. Results from partial unmixing, logical expressions, decorrelation stretches, and ENVI's Feature Extraction object-oriented classification algorithm are discussed. Additional work has focused on combining spatial and spectral data analysis techniques. Data sets from ASTER and WorldView-2 were analyzed in a two-step process. First, Feature Extraction was used to segment the data and classify the imagery based on shape. Then, selected features of interest were chosen for processing using tools that focus on spectral properties. These complementary techniques show promise in producing more precise and accurate information products derived from remote sensing imagery.

### **Import Vector Machines for sub-pixel mapping**

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**Keywords:** hyperspectral remote sensing, import vector machines, model parameterization, sub-pixel mapping

With the upcoming EnMAP and HySPIRI hyperspectral missions earth observation will take an important step forward in monitoring environmental processes at large spatial extent and on a timely and frequent basis. By observing the Earth's surface at a meso-scale (ground sampling distance of 30-60 meters), these data will contain a high number of mixed pixels, thus the need for quantitative approaches to map sub-pixel cover fractions, is particularly relevant for heterogeneous environments. Machine learning has been shown to be capable of modeling complex high dimensional feature spaces, especially in the field of image classification. However, research on the significance of class probabilities of kernel-based classification results for sub-pixel mapping is still rare. In our study we explore rule images derived from an IVM classifier as quantitative measure of class proportion. We have developed an alternative parameterization strategy to improve the usage of rule images for mapping class proportions, while maintaining the general capability of class separation. In this approach, we first synthetically mix pure training spectra at gradual proportions. During model parameterization, mean absolute error of class proportions, instead of overall accuracy of class assignment, is used as a performance measure in a cross-validation procedure. The best performing model is selected for later classification and analysis of sub-pixel cover fractions. The approach is tested on hyperspectral in-situ measurements collected during a field campaign in southern Portugal in 2011. IVM models generated with our parameter tuning strategy achieve similar or improved classification accuracies compared to IVM with standard parameterization. In addition, the respective rule images are characterized by values that correlate highly to class proportions derived from independent, synthetically mixed spectra. Model accuracies could be improved up to 5.1% in mean absolute error. We conclude that IVM probabilities are usable for quantitative sub-pixel mapping, particularly with adjusted parameterization. Thus, IVM showed not only to perform very well as a classifier, but also as a simple and effective tool for quantitative mapping of sub-pixel cover fractions.



## **Exploration of the correlation structure of the atmospheric condition parameters in support of the design of uncertainty propagation methods for hyperspectral image processing workflows**

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International initiatives like QA4EO (<http://www.qa4eo.org/>) and CEOS (<http://www.ceos.org/>) recommend to provide quality information with remote sensing products such as reflectance images in order to allow users to assess the fitness for use. Uncertainty quantification is one such method to quantitatively report the quality of the products. Often the development of remote sensing products involves complex processes like atmospheric correction, being the focus of this research. Atmospheric correction models aim to estimate the target reflectance from the total observed radiance originating from three main sources: 1) atmospheric path radiation 2) target radiance 3) background radiance. Under operational conditions, users of such models often utilise a set of predefined values for the atmospheric state parameters instead of locally measured values to save costs. Consequently, these parameters are uncertain, and the uncertainty propagates to the reflectance product. The uncertainty can further propagate when the reflectance product is used in turn to develop application level products like Chl-a maps. This study aims to quantify the uncertainty in reflectance product. Often atmospheric correction models use state-of-the-art radiative transfer models such as MODTRAN5 that require a number of correlated atmospheric parameters. In uncertainty quantification such a correlation is usually ignored, resulting in either overestimation or underestimation of the uncertainty. This is even more severe when uncertainty quantification is performed in a Monte Carlo Simulation (MCS), where multiple simulations are realised by randomly sampling from distributions of parameters. Correlation between parameters can then lead to unrealistic atmospheric scenarios if sampling was carried out from independent distributions. An example concerns high water vapour value: if this is sampled randomly from the water vapour distribution then visibility is possibly set to a high value, whereas in reality the two parameters are negatively correlated. This research focuses on exploring the importance of taking into account the dependence structure of the atmospheric parameters for uncertainty quantification. Experiments focused on four atmospheric correction parameters that were selected on the basis of expert opinion: aerosol model, relative humidity, meteorological range and background window size as determined by the MODTRAN5 radiative transfer model. Two experiments were carried out using the MCS framework: 1) correlation between the parameters is ignored 2) correlation between the parameters is taken into account. The experiments were performed by varying the four parameters to reflect different atmospheric conditions: highly absorptive and scattered atmosphere, clear atmosphere and moderate atmospheric conditions. These atmospheric conditions have been realised in five different cases that were depicted to reflect the different atmospheric conditions and tested on Airborne Hyperspectral Scanner (AHS160) images in the Scheldt river area of Antwerp, Belgium. Results of each case are summarised as probability density functions. Ignoring the correlation results into inconsistent measures of uncertainty, i.e. the uncertainty dispersion of a reflectance product is either too narrow or too wide for different simulations. Taking into account the dependency between the variables shows that the observed results are consistent in terms of width of uncertainty dispersion for different simulations. The study concludes that ignoring dependency structure within the parameters results into either overestimation or underestimation of uncertainty, whereas taking it into account results into consistent measures of uncertainty. Results of the experiments will be presented in the poster presentation.

## Simplifying Support Vector Regression Parameterisation by Heuristic Search for Optimal Epsilon-Loss

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**Keywords:** Support Vector Machine, Regression, Parameter Selection, Epsilon Loss

Over the last years, support vector machines (SVM) proved to be an accurate and robust tool for the classification and regression of hyperspectral data. While the use of SVM for classification has become standard, their use for regression approaches is still very limited. This can partly be explained by the more complex model parameterisation, where a third parameter, i.e.  $\epsilon$ , needs to be selected in addition to the kernel and regularization parameters. This  $\epsilon$  defines the trade off between model complexity (meaning sparsity) and desired accuracy. It is attempted to fit the flattest tube with radius  $\epsilon$  to the data.

For  $\epsilon$  selection the regularly applied two dimensional grid search for kernel and regularization parameters has to be extended by an additional dimension. This leads to a significant increase in processing times. We present an efficient search heuristic for  $\epsilon$  selection. The approach is based on the findings of Smola et al. [1998, Proc. 8th Intl. Conf. Artif. Neur. Netw.] who showed that the asymptotically optimal choice of  $\epsilon$  scales linearly with training data noise. Our methodology iteratively estimates the a priori unknown training data noise and uses this information for SVR training. The search initially starts with a high value for  $\epsilon$  (very sparse models) and converges towards an  $\epsilon$ -value that represents the training data noise. Results are shown for two hyperspectral data sets, i.e. HyMap data from Berlin, Germany, and simulated EnMAP data from Castro Verde, Portugal. Our tests show that the proposed approach constitutes an efficient search heuristic with fast and robust convergence under all conditions, including under- and overfitting parameterization. The resulting models are characterised by an efficient trade-off between generalisation and processing times and produce accurate quantitative maps. The approach is implemented in the imageSVM module for image classification and regression of hyperspectral data and this way freely available.

## **The EnMAP-Box – a toolbox and application programming interface for increased exchange of algorithms for imaging spectroscopy data**

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With the advent of EnMAP and with more abundant airborne imaging spectroscopy data remote sensing will soon enter a new era. For an optimized analysis of these new data most recent image processing approaches are needed in robust, standardized and user-friendly implementations. However, especially in the field of machine learning many recent developments often do not favor the use of common data formats and require complex work-arounds, which are rarely shared among the community. Regular remote sensing software packages, on the other hand, usually do not offer such state-of-the-art developments. To overcome these limitations the EnMAP-Box marks a corner stone in Germany's national EnMAP pre-launch program. The available algorithms in this toolbox will ensure powerful analyses for this new imaging spectroscopy data of high spatial and radiometric quality and frequent availability. The EnMAP-Box offers a freely available and platform independent software environment especially designed for the handling of EnMAP-like data. It is developed at Humboldt-Universität zu Berlin under a contract of the German Research Centre for Geosciences (GFZ) and includes applications such as support vector classification/regression, random forests classification/regression, partial least squares regression, as well as a flexible and advanced image calculator tool, which allows command line algebra with predefined spectral/spatial routines. To make the EnMAP-Box an evolving toolbox an application programming interface (API) – the so-called hubAPI - has been developed and can be downloaded with the box itself. It offers user-friendly pre-programmed code to make the implementation of new developments under standardized conditions as easy as possible (e.g. the design of wrapper approaches for arbitrary algorithms). Applications from the EnMAP-Box can be used in IDL/ENVI. EnMAP-Box and hubAPI have been used and successfully tested by different developers at various institutions and during events like EnMAP Summer Schools. They are available at [www.enmap.org](http://www.enmap.org). In our contribution we explain key aspects of the EnMAP-Box and hubAPI to allow an easy access to individual work with them.

## **Generating DEM from HRS data to improve reflectance retrieval over rough terrains areas**

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**Keywords:** Digital Elevation Model (DEM), Hyperspectral Remote Sensing (HRS), Reflectance

Digital elevation models (DEM) coupled with hyperspectral remote sensing (HRS) data is an important task to retrieve accurate reflectance values in general and over rough terrain in particular. DEM values can vary based on the production method used and on the spatial resolution obtained. Accurate georectification of the HRS data is strongly needed in order to effectively use the DEM information at hand. Georectification of rough terrain data may result in pixel's radiance resampling that can affect accurate retrieval of the exact pixel's reflectance value. We have developed in this study a method to generate DEM from the HRS data itself without the necessity to georectify the image prior the atmospheric correction stage. The method is based on modeling the absorption depth of several gas molecules in the atmosphere and correlate them to the surface altitude above sea level. Example to that end is given by two different sensors (AISA-DUAL and Carriage of Fire) over rough arid terrain area known as Makhtesh Ramon, Negev, Israel. Makhtesh Ramon is an erodic anticline that characterized by rough terrain with 500m elevation differences between the highest and lowest ground points. We generated the DEM by using the oxygen absorption peak at 760nm and the water vapor absorption at 724nm. The accuracy of each model was checked against DEM data that obtained by LIDAR sensor using statistical parameters such as R-square, maximum, minimum and average anomaly from the reference DEM. Finally, the generated DEMs were used as a parameter in the atmospheric correction process using ATCOR software and the reflectance obtained was compared to the ground reflectance and to the reflectance before and after applying the DEM-gas correction. It was concluded the suggested method is robust over the selected area as two different sensors that flew in different dates generated similar DEM results and were able to correct the radiance into accurate reflectance data.

## **Spaceborne missions**

### **HYPXIM Hyperspectral sensor: from science and societal applications to at-sensor radiance specifications**

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**Keywords:** hypxim, at-sensor radiance, optical sensor specifications

HYPXIM is a remote sensing mission in hyperspectral imaging spectroscopy currently in phase A, conducted by CNES. This paper deals with the technical requirements made by the so-called HYPXIM mission group, constituted of scientists and defense users experts in hyperspectral imagery, considering the following scientific applications: study of vegetation, coastal and inland waters geoscience, solid Earth science, urban environment, atmospheric sciences, security and defence. After a brief overview of the mission requirements in terms of spectral domain, spectral resolution, signal-to-noise ratio, spatial resolution, swath and revisit period, the paper will explain how the at-sensor radiances are specified, and establish the associated ground reflectances in the spectral range 0.4 to 2.5  $\mu\text{m}$ , taking into account the expected conditions of the observations. These conditions depend on the target observed (latitude of the target, atmospheric conditions), on the time and date of observation (seasonal variations in atmospheric conditions), and on the orbital parameters of the satellite (altitude, local time of ascending node). We will namely see that the solar zenithal angle (which depends on the latitude of the target, and on the season of observation) has a key impact on the ground reflectance that can be seen by the instrument. Absorption by the atmospheric gases (water vapor and carbon dioxide) also plays a major role in the signal computation for some spectral bands. In a second part, the simulations based on existing hyperspectral aerial data (HYMAP images) will be presented. The images have been converted into Top-Of-Atmosphere radiances. Different spatial resolutions (from 4 to 30 meters), different levels of MTF, signal-to-noise ratio and reference radiances have been tested. The limitations of the simulations performed, and the observed performances of the algorithms will also be discussed.

## **Terrestrial Ecosystems**

### **Bayesian object-based estimation of LAI and chlorophyll from a synthetic Sentinel-2 top-of-atmosphere radiance scene**

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**Keywords:** Top-of-atmosphere radiance, Sentinel-2, APEX, variable estimation, Bayesian optimization, object-based, coupled model, radiative transfer, SLC, MODTRAN4, Li-Ross, nadir-normalization

Leaf area index (LAI) and chlorophyll content (Cab) are important inputs in dynamic global vegetation models (DGVM) which can be monitored using remote sensing (RS). Physically-based approaches are more general and therefore better suited than empirically-based approaches for estimating LAI and Cab at global scales. These approaches, however, require inverting a radiative transfer (RT) model, which is an ill-posed problem. Four regularization methods have been proposed to allow finding stable solutions: 1) model coupling, 2) a priori information (e.g. Bayesian approaches), 3) spatial constraints (e.g. using objects), and 4) temporal constraints.

In an earlier study, we proposed using the maximum regularization set-up for mono-temporal data by inverting the SLC-MODTRAN4 coupled canopy-atmosphere RT model using a Bayesian object-based algorithm. The LAI estimates were more accurate than those obtained from a LUT approach with a Bayesian cost function. This study, however, heavily relied on expert knowledge about the objects and vegetation classes. Therefore, in this contribution, we investigated the applicability of the Bayesian object-based inversion of the SLC-MODTRAN4 model to a situation where no such knowledge was available.

A 16 x 22 km<sup>2</sup> synthetic top-of-atmosphere Sentinel-2 scene covering the area around Zurich was built. Seven APEX radiance images were nadir-normalized using the parametric Li-Ross model, spectrally and spatially resampled to the Sentinel-2 specifications, geometrically corrected, and mosaicked. The atmospheric effects between APEX flight height and top-of-atmosphere level were added based on two MODTRAN4 simulations. The objects were obtained by an image-based automatic multi-resolution segmentation, and the vegetation was classified in four levels of volume scattering (low, medium, high, and very high). The LAI and Cab maps obtained from the Bayesian object-based inversion of the SLC-MODTRAN4 model present realistic patterns. The impact of the parametric Li-Ross nadir-normalization was evaluated by comparing 1) the angular signatures of the SLC-MODTRAN4 and Li-Ross models, and 2) the LAI and Cab maps obtained from a nadir-normalized image, using nadir viewing geometry, and from the original image, using the original viewing geometry. The differences in angular signatures were small but systematic, and the differences between the LAI and Cab maps increased from the centre towards the edges of the across-track direction.

## **Comparison of narrow band vegetation indices and empirical models from hyperspectral remote sensing data for the assessment of wheat nitrogen content**

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**Keywords:** Nitrogen, Hyperspectral Data, Empirical Models, Vegetation Indices

The assessment and mapping of total canopy nitrogen (N) content of agricultural crops is very important to optimize nitrogen fertilizer management in agronomy. An efficient and precise use of N-fertilizer is helpful to improve yield, reduce costs and lower environmental pollution at the same time.

Spectral reflectance of plants in the visible (VIS) and near infrared (NIR) region of the electromagnetic spectrum is primarily affected by plant pigments (e.g. chlorophyll) and cellular structure of the leaves. Plants with N shortage will have a lower chlorophyll concentration which is an indicator for non-optimal photosynthesis. In this context, hyperspectral imagery data can provide important information about the N-concentration of plants because of the numerous spectral bands in the VIS and NIR spectral region. In this study the potential of narrow band indices and empirical regression methods derived from hyperspectral data is comparative investigated to gain detailed information about the spatial distribution of N-content from a wheat field.

During a field campaign in May 2011 the above-ground plant material of 37 plots (each with a size of 0.25 m<sup>2</sup>) of a field northwest of Koethen (Saxony-Anhalt, Germany) was harvested completely and the N-content of the samples was determined in laboratory afterwards. At the same time hyperspectral imagery of the test site was acquired by the airborne scanner AISA-DUAL (450-2500 nm).

For the assessment of the N-status, narrow band indices like the Red Edge Inflection Point (REIP), the Normalized Difference Red Edge Index (NDRE) and the Normalized Difference Nitrogen Index (NDNI) were calculated from the AISA-DUAL imagery. Additionally, empirical models based on support vector regression (SVR) and partial least squares regression (PLSR) were developed. Both the indices and the empirical models were built with extracted AISA-DUAL imagery spectra at the geographic location of the wheat plots and analytical laboratory results. Subsequently, the indices and the empirical models have been applied to AISA-DUAL image data of the field to assess the spatial distribution of N.

The N-concentrations estimated by SVR from AISA-DUAL data showed the best results ( $r^2_{cv}=0.75$ ). Predicted N-concentrations are consistent to laboratory chemical analysis and predicted N-values reflect the spatial distribution of the investigated field. Compared to SVR, PLSR ( $r^2_{cv}=0.70$ ) and narrow band indices ( $r^2_{cv}=0.69$ ) allowed lower prediction accuracies. The results clearly indicate the high potential of SVR for fast and reliable spatial N assessment from hyperspectral imagery.

The developed method based on SVR to estimate N-concentration of wheat has a high potential and is a suitable alternative to widely used vegetation indices which show lower prediction accuracies. Furthermore, increasing benefit is expected from the availability of new systems in precision agriculture which use hyperspectral sensors for real-time assessment of N-status to apply spatially adopted N-fertilization.

## **LAI assessing of wheat stands from AISA-DUAL imagery**

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**Keywords:** Leaf area index, hyperspectral, spectral resolution, PLSR, wheat

Biochemical properties like chlorophyll content, water content or mineral components influence the spectral reflectance of plants. In this context the leaf area index (LAI) allows to draw conclusions on the photosynthetic activity and hence the productivity of vegetation which makes it a state variable of crop growth models. The LAI is an important factor for the quality of yield estimates in agriculture since it is strongly influenced by yield reducing factors such as plant diseases and mismanagement.

In this study the spatial assessment of the LAI for a wheat plot in Saxony-Anhalt (Germany) from hyperspectral imagery (AISA-DUAL) will be presented. The AISA-DUAL imagery was collected in 367 spectral bands (400-2500nm) with 3m ground resolution on May 10, 2011. For atmospheric correction the software FLAASH was used. Additionally, an empirical line correction was performed. Geometric correction of the AISA-DUAL data was realized with the software CaliGeo while orthorectification was performed with ENVI. During overflight the LAI has been measured in the field using a Sunscan device. Prediction of LAI has been carried out by partial least squares regression (PLSR) with the PARLeS software using the LAI measurements taken in-situ and their corresponding spectra in the hyperspectral imagery. PLSR model results were cross-validated (cv) according to the 'leave-one-out-method'.

The LAI was predicted with a  $r^2_{cv}$  higher than 0.85. In order to assess the influence of the number of spectral bands on LAI prediction, AISA-DUAL spectra have been resampled by spectral binning to 50% (183 spectral bands) and 33% (122 spectral bands) of the original number of spectral bands, respectively. The hypothesis was that reduction of spectral bands may reduce data-inherent noise and consequently increase prediction accuracy. However, the resampled datasets achieve very similar results in LAI prediction. Furthermore, it was investigated whether standard normalization techniques have a positive effect and can improve the prediction. Subsequently, the developed PLS-model was transferred to the AISA-DUAL data. Predicted LAI obtained from hyperspectral imagery were well in line with in-situ LAI measurements and represented the spatial inner-field variations.

Results clearly highlight the potential of hyperspectral imagery for the spatial assessment of wheat LAI and provide a suitable alternative for the conventional, often inaccurate, methods to describe the LAI using physiological development approaches. At the same time results raise the question how many spectral bands are needed for robust parameter estimation.



## **Mapping Geochemical Parameters Derived from Fractional Abundances of Pioneer Vegetation Using Spectral Unmixing and Semi-Automated Endmember Extraction with HyMap Data**

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**Keywords:** post-mining landscapes, Acid Mine Drainage, pioneer vegetation, Fully Constraint Linear Spectral Unmixing, Lignite district Sokolov, endmember extraction

One of the general problems associated with open-pit mining is the total displacement of all geocomponents of the former landscape. The applied mining technology of overburden conveyor bridges leads to extreme profound and irreversible changes of the environment. The consequence of this exploitation is a completely new system – the so-called "post-mining landscapes" – characterized by extreme geochemical milieus, especially acidity, caused by weathering processes (Acid Mine Drainage). These extreme environments are often left to natural succession because of enormous costs and little success of reclamation. This study investigates the relationship between pioneer vegetation (e.g. Calamagrostis epigejos, Silver birch) and geochemical properties of heap material using hyperspectral HyMap data in the West Bohemian Lignite district Sokolov (Czech Republic). Thus, a Fully Constraint Linear Spectral Unmixing algorithm was applied to link geochemical parameters with fractional abundances. Due to the limitation of endmembers in the data set in such fragmented and mixed areas a three-stage semi-automated extraction was developed. The first stage includes a selection of pure surface types by using a decision tree with self-developed narrow band and normalized difference indices. The second stage extracts potential endmembers by using the Sequential Maximum Angle Convex Cone algorithm. The third stage identifies final endmembers and eliminates spectral outliers by comparing the extractions to field/laboratory spectral libraries. In comparison with field cover samples the unmixing results show a high accuracy ( $R\text{-sq} = 89.5\%$ ) and a low RMS-Error ( $< 2\%$ ). The spatial distribution and the density of several plant species show a relationship to the pH-value ( $R\text{-sq} = 73.6\%$ ) and other plant-available nutrients (Calcium, Potassium, Iron, etc.). The method demonstrates that Hyperspectral Remote Sensing data can be used for ecological medium- and long-term monitoring as well as spatial assessment in post-mining areas. In addition, the approach works with a minimum of geochemical measurements and a sparse availability of endmembers.

## **Prospect Inversions of Leaf Laboratory Imaging Spectroscopy – A Comparison of Spectral Range and Inversion Technique Influences**

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**Keywords:** Reflectance Modelling, Laboratory Spectroscopy

Within-leaf variation of chemical and structural leaf properties has not gained much attention in the remote sensing community yet. Laboratory imaging spectroscopy makes it possible to investigate leaf properties on much smaller scales than traditional laboratory spectroscopy.

Very high spatial resolution hyperspectral images of leaves were recorded using stationary pushbroom scanners and a translation stage. Images were recorded in the VNIR range (400–1000 nm) using a NEO HySpex VNIR-1600 camera and in the SWIR range (1000–2500 nm) with a HySpex SWIR 320m-e. VNIR images have a pixel size of about 62  $\mu\text{m}$  x 62  $\mu\text{m}$ , SWIR resolution is about 250  $\mu\text{m}$  x 250  $\mu\text{m}$ . VNIR and SWIR images were joined at SWIR spatial resolution. A white reference panel with known reflectance was recorded with the leaves so that reflectance could be calculated from recorded radiance. We inverted the leaf reflectance model PROSPECT-5b in two different ways, by numerical inversion and by a lookup table approach. Inversion results using only VNIR images and combined VNIR/SWIR images are compared. We found that the inversion technique has only minor influence on inversion results, but the spectral range of the input data is crucial for some variables: While results for the Prospect structure parameter N, chlorophyll content (Cab), carotenoid content (Car) and brown pigments (Cbrown) are similar for both input data sets, results for water content (Cw) and dry matter (Cm) are not correlated between VNIR inversion and SWIR inversion.

## Using 2009 and 2010 HyMap data to assess physiological status of macroscopically undamaged foliage on a regional scale

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**Keywords:** image spectroscopy, HyMap, Norway spruce (*Picea abies* L. Karst) health, non-specific stress markers, trace element, photosynthetic pigments

The transfer of chemical elements and compounds within the soil–plant chain is a part of the biochemical cycling and this complex system is controlled by diverse biotic and abiotic factors which determine the final mobility and availability of chemical variables. Heavy metal contamination and other negative physio-chemical changes in soil conditions such as low pH are stress factors that lead to changes in the contents of important foliage compounds (biochemical parameters) which can be used as non-specific indicators of plant stress. These biochemical parameters can be detected by the means of hyperspectral (HS) remote sensing.

In this study, Norway spruce forests in the Sokolov region, being a part of the „Black Triangle” exposed to heavy air pollution and long-term excessive lignite mining, were selected to assess geochemical and biochemical interactions in the natural soil/plant system. Factor analysis was used to link geochemical property of the forest soils with biochemical parameters (e.g., photosynthetic pigments, phenolic compounds and lignin) and to link these biochemical parameters with the needle spectral properties. Al and As were identified as toxic elements with high bio-availability for the spruce trees and both were taken up by trees and translocated to the foliage. The soluble phenolic compounds and total carotenoid to chlorophyll (Car/Cab) ratio, which both proved to be sensitive to the soil geochemical conditions, were suggested as non-specific stress markers for aluminium (Al) and arsenic (As) toxicity for Norway spruce.

Furthermore, the feasibility to assess the tree health was tested using airborne hyperspectral HyMap datasets acquired in summer 2009 and 2010. In addition to the atmospheric correction, both 2009 and 2010 HyMap data had to be further processed to minimize strong cross-track illumination and bi-directional reflectance distribution function effects. After proper pre-processing the 2009 HyMap data were used to develop a novel methods allowing objective assessment of forest health. The model attaining the greatest accuracy (D718/D704: RMSE = 0.2055 mg/g, R<sup>2</sup> = 0.9370) was selected to produce a map of foliar chlorophyll concentrations (Cab). The Cab values retrieved from the HS data were tested together with other nonquantitative vegetation indicators derived from the HyMap image reflectance to create a statistical method allowing assessment of the condition of Norway spruce. Based on these findings we integrated the following HyMap derived parameters (Cab, REP, and SIPI) to assess the subtle changes in physiological status of the forests on a regional scale. The HyMap 2010 data were used for further validation and change detection. The achieved results indicate that this method is potentially useful for general applicability.

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## **Tree species mapping using airborne and spaceborne Imaging Spectroscopy data: effects of scale and classifier**

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**Keywords:** HyMap, Hyperion, tree species, scale, classification, SV;. RandomForest

Knowledge of tree species distributions is important worldwide for sustainable forest management and resource evaluation. The accuracy and information content of species maps produced by using remote sensing images varies with scale, sensor and classification approach. This study aims to bridge the knowledge gap in understanding the scale effect in imaging spectroscopy going from 4m to 30m pixel size in a scenario of tree species mapping. Two airborne (HyMAP) and one spaceborne (Hyperion) imaging spectroscopy dataset with pixel sizes of 4m, 8m and 30 m respectively were selected to examine the effect of scale. Three different combinations of predictor variables (original spectral bands, selected components of a minimum noise fraction and vegetation indices) were explored at each scale. Supervised kernel based (support vector machine) and ensemble based (Random forest) machine learning algorithms were applied on the dataset to investigate the effect of classifier. 100 fold cross-validation combined with a bootstrapping approach was performed for classification model building and testing for all the trials.

For scale, analysis of overall classification accuracy and kappa values indicated that 8m spatial resolution serves best for the study area under investigation (reaching kappa values of over 0.83). 30m resolution Hyperion image produced sound results (kappa values of over 0.70), which in some areas of the test site were comparable with the smaller resolutions when qualitatively assessing the map outputs. For input predictors, MNF bands at 4m and 8m performed better than others. Optical bands were found to be best for 30m spatial resolution. Classification with MNF as input layers produced better visual appearance of tree species patches when compared with reference maps (supplied by Forest administration). However, in the examined cases there was no single best choice for classifier across spatial scales and predictors. It can be concluded that tree species mapping from imaging spectroscopy within forest sites comparable to the one under investigation is possible with reliable accuracies not only from airborne but also from spaceborne imaging spectroscopy datasets.

## **Comparing hyperspectral indices to assess nitrogen status in potato, maize and grassland - Up-scaling from plot to image level**

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**Keywords:** Imaging spectroscopy, agriculture, vegetation index, nitrogen status

To support efficient fertilization management strategies in arable farming insight in the crop's temporal and spatial requirements of nitrogen (N) is needed. Earlier studies have evaluated the use of remote sensing to assess canopy N concentrations in different arable crops. Based on the relation between N and chlorophyll in green leaves, results show that especially narrow-band indices including bands from the red-edge region provide good estimates. However, several factors are interfering this chlorophyll-N relation, e.g., growth-stage, crop type, fertilization management activities. The objective of this paper is to evaluate the accuracy and robustness of a selection of hyperspectral vegetation indices in estimating N status for different crops over varying management conditions over the growing season.

A detailed field experiment was conducted for a potato field in the South of the Netherlands in 2011. Within a parcel, 8 plots (30\*30 m) were prepared with four levels of nitrogen fertilization including two replicates. For all plots, detailed spectral measurements were made over the growing season on a weekly basis using the 16 band Cropscan field radiometer. The chlorophyll status of the crop was measured weekly using a Minolta Spad instrument and N concentrations were measured bi-weekly by sampling and wet-chemistry analysis. At the optimum point of the growing season on June 27, 2011, an APEX imaging spectroscopy dataset (228 bands in range 400-2500 nm) was acquired covering the experimental field and the surrounding fields. For a selection of crops (potato, maize and production grassland), canopy samples for chemical analysis of N were taken in the two days after the image acquisition: 5 samples in three fields for every crop type. Based on a previous sensitivity analysis using a radiative transfer model we made a selection of 12 vegetation indices to be assessed. We evaluated relationships ( $R^2$  and RMSE) between N and the vegetation indices using linear regression for potato over the growing season using the Cropscan data and for potato, maize and grassland using the APEX image. In addition, we tested if the plot-based relations could be scaled to the image level.

Good relations of nitrogen with vegetation indices were found for grassland and potato for several indices which included a band around the 740-750 nm region. For grassland the best relation was found for the Red-Edge Position ( $R^2=0.70$ ) and for potato with TCARI/OSAVI ( $R^2=0.54$ ) for the APEX based relations. Although relations between crops clearly differed, samples from different fields for the same crop clearly showed a consistent relation which means that the found relations can be used for different potato varieties and management schemes. Finally, the study will provide guidance on the transferability of the relations from field-based spectrometer measurements to airborne-based sensors like APEX as a basis to evaluate future opportunities of a sensor like Sentinel-2.

## **Tree species mapping within unmanaged closed forest reserves in Flanders (Belgium) using hyperspectral and LiDAR imagery to support forest management**

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**Keywords:** hyperspectral, LiDAR, crown delineation, classification, forests

In the context of sustainable forest management for multiple purposes, there is little doubt that the need for accurate resource information available at regular time intervals is still ongoing. In recent years, the efficiency with which such detailed forest information is collected steered remote sensing research towards the development of automated processes for fine-scale tree species mapping. The development of such automated routines is a typical example that is not only the area of interest to researchers but likewise to forest organisations and management agencies. In the framework of the monitoring programme of the Flemish forest reserves, since the year 2000 INBO (the Flemish Research Institute for Nature and Forest) is collecting individual tree information via costly and time-consuming field campaigns. In the absence of management, the forest reserves are characterized by growth stage diversity, high crown closure, multi-layering of the canopy and the non-existence of a pre-ordered spatial tree distribution. Given the associated high financial and human efforts INBO would greatly benefit from a more automated inventory process. As part of the larger research project HYPERFOREST we aim at developing optimized segmentation and classification algorithms using hyperspectral and LiDAR data to support sustainable forest management in these unmanaged forest reserves.

Fine-scale tree species mapping typically requires a tree crown delineation followed by classification. There are a number of different conceptual approaches to the problem of automated tree crown delineation. These approaches proved to be successful within relatively simple forests, including natural or plantation conifer forests and orchards, with small species diversity and tree crowns that are typically symmetrical and circular in shape with a single bright point near the centre. In these forests, individual tree crowns can be well delineated resulting in high classification accuracies at the tree-scale level. However, those approaches are less applicable in structurally complex and closed forests. Classification accuracies at the individual tree-scale often decrease beyond the acceptance level for forest organizations and management agencies. Therefore, we propose an optimized delineation methodology suitable for closed-canopy forests where the individual tree crowns can hardly be discriminated. Delineation is based on the synergy of LiDAR and hyperspectral data. First, the LiDAR-derived canopy height model is used to divide the forest into height strata based on a number of object-based decision rules. Afterwards, spectrally homogeneous units are segmented within these height strata based on a selection of hyperspectral bands. For the classification, several classifiers as support vector machines, random forest and artificial neural networks are compared. An in-depth analysis is also performed on the effectiveness of different LiDAR returns and channels (elevation and intensity) for increasing the accuracy of the classification obtained with hyperspectral images.

The research is carried out on two forest reserves in Flanders: Kersselaerspleyn and Wijnendale forest. Over these forests, full-waveform LiDAR data with the Riegl LMS Q560 full waveform laser scanner (point density > 10 points/m<sup>2</sup>, wavelength 1560 nm) and hyperspectral imagery with the APEX sensor (spatial resolution 1.5 m, 313 bands, wavelengths 370 – 2500 nm), were acquired during the summer of 2010 and 2011. Reference data on species composition were measured by INBO in the context of the monitoring program of the Flemish Forest Reserves.

## **The effect of leaf angle distribution on spectral reflectance in field crops**

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**Keywords:** Leaf angle distribution, Spectral reflectance, Field crop, AISA Eagle

Imaging spectroscopy can be used to determine crop canopy structural and biochemical variables for large areas. Leaf angle distribution (LAD) is one of important canopy structural parameters. Usually, LAD is assumed to be spherical as the actual LAD is difficult to quantify. This assumption will affect the retrieval of crop canopy variables, such as leaf area index (LAI), from hyperspectral image. To correct for this error, we measured LADs and spectral reflectance for six crop species in an agricultural test field in Helsinki, Finland.

Crops were photographed using a leveled digital camera from a distance of about 1m. Leaves oriented approximately perpendicular to the viewing direction were selected from the photographs. Leaf inclination angles of the selected leaves were measured using ImageJ software. This approach has been utilized to broadleaf tree species before, but it cannot be applied directly to the long, narrow and curved leaves of some crops. Therefore such leaves were divided into measurable segments and each segment was measured separately in the photograph. To calculate the relative area of each leaf segment, leaf shapes were measured with a portable document scanner. Additionally, LAI and mean tilt angles (MTA) were determined using the LAI-2000 plant canopy analyzer. Airborne hyperspectral images of the same crop species were acquired with AISA Eagle imaging spectrometer.

Measured LADs were fitted by beta distribution function. The reliability of the photographic LAD method was validated with LAI-2000 measurements. We analysed the correlation between LADs and AISA spectral data. The spectral data show strong correlation with MTAs and LADs especially in near-infrared bands. We conclude that the LADs measured from photographs can be used to improve the utility of AISA hyperspectral data in field crop research.

## **An approach for the phenological detection and classification of pioneer vegetation using laboratory spectrometric measurements**

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**Keywords:** phenology, spectrometry, pioneer vegetation, decision tree

Although remote sensing is increasingly used for mapping vegetation, typical image classification methods tend to suffer shortcomings due to nonnormality of spectral signatures, as well as overlapping and heterogeneity in reflectance of natural and semi natural vegetation. Spectral sampling of plant species and communities requires optimization and needs to be treated flexibly by time-, species- and environment dependent spectral properties.

This paper describes an investigation carried out for a first succession stage composed of typical pioneer plants (e.g. *Trifolium arvense*, *Hieracium pilosella*, *Rumex acetosella*) from oligotrophic and dry sites in Central Germany. The objectives of this study were to identify spectral variables of pioneer vegetation species derived from a green house experiment and to assess a phenological classification of this vegetation types. Every species had its own growing pot filled with original soil from test site. Watering and air conditioning were set and controlled by a computer aided remote system. Spectral measurements were taken in the laboratory in order to keep the proper temporal resolution. The field spectrometer (ASD FieldSpec FR Pro) was used with tripods to guarantee stability and constant viewing geometry. The data frequency (all 7 days) of the greenhouse pot experiment with makes a phenological approach possible defining spectral classes in terms of their timing, duration and spectral separability.

For the investigation, phenological metrics (plant cover, maximum photosynthesis, rate of green up, growing season length, time windows) have been calculated and incorporated within an adapted hierarchical decision tree to identify and separate phenological typical classes and furthermore, to extract the specific seasonal behaviour of each class. Decision trees have a strong intuitive appeal for Earth science applications because the classification structure is explicit. Due to their interpretability, a user can examine a decision tree and easily identify the important factors that distinguish classes from one another.

The set of variables which was used to produce a phenological classification of the vegetation consisted of the best explained endmember spectra of each species, time windows that identify and separate each vegetation type and methods such as vegetation indices (NDVI, CAI, Red-Edge) as well as feature extraction algorithms (continuum removal).

The results show that the pioneer vegetation can be clustered in three different spectral types. The spectra of vegetation species with the lowest spectral similarity (determined by the spectral feature fitting technique) can be separated and classified within the whole measurement duration due to a different phenological behavior. The main challenge is to analyse the separability of different species with a higher spectral similarity. Therefore, the identified time windows, occurring in the beginning of the growing phase (end of April and May) and in the maturity phase (end of August and September), could offer a spectral splitting. The species with a spectral similarity of 90 and more percent needs the implementation of vegetation indices and normalization of absorption bands in the range of the red light (around 674 nm), in the NIR shoulder area (around 785 nm) and in the areas affected by the biochemical components in the short wave infrared (around 2.150 nm).

The spectral approach described in this paper may provide possibility for detecting vegetation, especially pioneer vegetation in different environments effected by spatial, taxonomic, temporal, and biological conditions. It is supposed, that an optimized, multi-temporal, and multi-taxonomic reference library can supply valuable information on optimizing hyperspectral field-, airborne and spaceborne campaigns.



## **Estimating biophysical crop properties by a machine learning model inversion using hyperspectral imagery of different resolution**

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Surface reflectance images (400-2500 nm) of 1, 2 and 3 meter resolution were acquired by an airborne AISA sensor. All three resolutions were recorded at the same day while covering the same area. The measurements were taken to estimate leaf chlorophyll content and LAI from wheat and barley fields. For this, a radiative transfer model is inverted by combining a look-up table and a machine learning technique. With respect to the lower ground resolution of the upcoming EnMAP satellite sensor (30 meter) scaling effects, like the increase of subpixel heterogeneity, and their influence on the received signal and the inversion performance are studied.

PROSAIL [1, 2] - a 1D-turbid medium model - is used to build up a synthetic database of simulated vegetation reflectances. Based on this look-up table (LUT) a pixel-wise inversion is performed. To achieve reasonable inversion results each pixel should be radiatively independent from its surrounding pixels [3]. To account for this in the first place, image texture is used to calculate the second-order statistical variance between pixel pairs quantifying spatial heterogeneity utilizing the entire spectral space.

A support vector regression (SVR) [4] is applied for inversion of PROSAIL to estimate biophysical crop properties. Considering the different image resolutions the scale dependency of the parameters is studied. A new process chain is presented to improve and accelerate the inversion procedure. Firstly, the amount of simulated reflectances is reduced by selecting certain spectra from the LUT by means of the first two principle components [5, 6]. Secondly, the number of wavebands is reduced reasonably from the chosen spectra. In both cases the aim is pursued to find the best match between simulated and measured reflectances.

First results show that at all resolutions vegetated areas in the fields are representing a structurally homogeneous system. In contrary, forest areas (which are not further discussed in this study) and the tractor tracks within the crop field are identified as structurally heterogeneous. For these pixels any parameter estimation should be ranked highly uncertain. In line with this consideration the estimation of leaf chlorophyll exhibit notably high pixel values (above  $70 \mu\text{g cm}^{-2}$ ) along the tractor tracks.

Yet, the accuracy of parameter estimation cannot be definitively assessed. The reason for given inter-field (within the same resolution) and intra-field (across different resolutions) reflectance variability has to be investigated in more detail. Here it is to clarify if the reflectance differences emerge from possible scale effects, the phenological stage of the crop and/or potential inconsistencies during the atmospheric correction. Nevertheless we figured out in general that at 1 meter resolution chlorophyll predictions are lower (around  $25\text{-}30 \mu\text{g cm}^{-2}$ ) compared to predictions derived from 3 meter resolution images - whereas the latter are closer to the measurements taken during the field campaign (around  $45\text{-}50 \mu\text{g cm}^{-2}$  - leaf chlorophyll content was determined using the Konica Minolta SPAD-502 chlorophyll meter and LAI by using the LI-COR 2000 instrument).

The pixel-wise SVR parameter estimation led to a homogeneous chlorophyll distribution across the field. Using a common LUT inversion approach with the RMSE as a cost function, values of neighboring pixel were more likely of different magnitude resulting in a spatially less smooth pattern overall.

## **Hyppectral and Quazi-hyperspectral approach to vegetation type detection in the Ore Mountains, Czech republic**

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**Keywords:** hyperspectral, vegetation type, forest type, Hyperion, Aster, Landsat

The Ore Mountains are a long ridge located on north-western part of the Czech Republic. It is well known for its mining and processing of ore since the Middle Ages. This industry was very demanding on timber. During past centuries original mixed forests were copped down and fast growing spruce (*picea excelsa*) was planted to satisfy the need of the industry. These woods are weak in higher altitudes and susceptible to rough weather conditions. This is where the deforestation began. In 20th century brown coal basins were discovered in the area and became to be widely used as a fuel in local thermal power plants. The top of this economic activity came in late seventies. The growth of socialistic industry in Central Europe regardless state borders with no care about environment demanded more energy, fuel, steel and chemistry. Due to the need of power the output of thermal power plants increased which had major influence on the health of mountain forests. During following years the deforestation was very strong especially in summit areas. Solving this problem began a big topic among population after the revolution changes in 1989 and the improvement is significant. This paper deals with hyperspectral (Hyperion) and Quazi-hyperspectral (ASTER) data of specific area of the Ore Mountains to discover their possibilities in forest type detection and their comparison with multispectral (Landsat) data.

## ESTIMATING VEGETATION COVER FRACTION DYNAMICS BY LINEAR SPECTRAL UNMIXING FOR SOIL EROSION ASSESSMENT

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**Keywords:** Multiple Endmember Spectral Mixture Analysis, C-Factor, Airborne AISA imaging spectrometer, vegetation cover fraction, soil erosion assessment, mediterranean dryland

Mediterranean drylands often experience strong erosion in headwater catchments, resulting in reservoir siltation, which can lead to a significant reduction of water availability within a few decades. Fractional abundance of ground cover and bare soil is one of the most crucial factors in soil erosion assessment and modelling at the catchment scale. Hyperspectral imagery allows the discrimination of green and dry vegetation components that together protect the soil against rainfall and runoff impacts. In erosion models, the USLE/RUSLE C-Factor represents the effect of land cover and management on the soil erosion potential. The objective of this study is to derive C-Factor maps for two different seasons using a Multiple Endmember Spectral Mixture Analysis (MESMA) approach for input in erosion modelling.

The study area encompasses two sub-catchments (approx. 60 km<sup>2</sup>) of the Isábena River, a dryland river in the Spanish Pyrenees, that are characterised by high erosion rates. Airborne AISA imaging spectrometer data were acquired in April and August 2011 at a ground resolution of 4 m. In two concurrent field campaigns, fractional cover of photosynthetic-active vegetation (GV), photosynthetic non-active vegetation (NPV), bare soil, and rock were visually estimated for 67 (April) and 58 (August) transects of 20 m length each. The C-Factor was estimated from the field data for the land cover classes shrubland, arable land, and badland, which are suspected to contribute the largest proportion of sediments.

Derivation of C-Factor maps from image data was performed in a three steps procedure. First, MESMA was applied to the hyperspectral bi-temporal AISA imagery to estimate fractional cover for GV, NPV, soil and rock. MESMA is a Linear Spectral Mixture Analysis (SMA) approach in which image pixels are modelled as the linear sum of spectrally pure endmembers that vary on a per-pixel basis. For each target class, a subset of endmembers was selected from pure image endmember spectra and MESMA was applied using two-, three- and four-endmember models running in a partially constrained mode. The model with the lowest RMSE was selected on a per-pixel basis for final fractional cover mapping. Four-endmember models were found to be prevalent in the results. Validation of fractional cover of GV, NPV, bare soil and rock using fraction ground-truth data achieved good results. In a second step, a feature-based supervised land cover classification was performed using Support Vector Machine classification. Eight land cover classes were distinguished. Finally, fractional abundances and land cover information were linked to map spatially distributed C-Factors using three different approaches: a) assigning mean C-Factors estimated from ground-truth data to the land cover classes with highest erosion potential (arable land, shrubland, and badland) and literature C-Factors to the remaining five land cover classes, b) using the empirical relationship between fractional abundance of bare soil and vegetation cover found by Omasa and de Asis (2007) to define C-Factors on a pixel-by-pixel basis, whereas results were validated with the RUSLE C-Factors estimated from ground-truth data and c) using a regression between field estimated vegetation cover and image fractional vegetation cover, including GV and NPV, to calculate the C-Factor with the remaining variables of the RUSLE equation set as land cover dependent constants.

This work demonstrates the potential of high spectral resolution imagery to map and monitor quantitative vegetation cover fraction dynamics on a sub-pixel basis for soil erosion assessment and monitoring. It is expected that multi-temporal spatially-distributed C-Factor information can improve erosion model parameterization, which today still often builds on annually and spatially averaged empirical values.

## **Spectral discrimination of indigenous forest tree species based on airborne AISA Eagle VNIR data in the Taita Hills, Kenya**

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**Keywords:** Aisa Eagle, hyperspectral, tropical forest, tree species, Taita Hills

Tree species inventory and mapping are important for the management and conservation of the indigenous forest fragments of the Eastern Arc Mountains of Kenya. In the tropical forests, the field based inventories are very tedious and time consuming. Furthermore, the accuracy of the typical remote sensing methods is compromised because of the high tree species diversity. Therefore, the crown-level spectral data collected by the high spatial resolution airborne imaging spectroscopy provides promising possibilities for improving the accuracy and efficiency of the tree species inventory and mapping in the tropical forests. In this study, we examined the feasibility of AISA Eagle VNIR data for spectral discrimination of indigenous forest tree species in the Ngangao Forest (38°20'33"E, 3°21'55"S) in the Taita Hills in South-Eastern Kenya.

The Taita Hills are part of the Africa's Eastern Arc Mountains, which have been identified as one of the top ten biodiversity hotspots in the world because of the diverse flora and fauna, and high level of endemism. The Ngangao Forest covers approximately 120 ha and elevations range between 1700–1952 meters above sea level. Over 100 tree species are found in the Ngangao Forest, but about 20 species dominate the tree canopy. AISA Eagle data was acquired in January 2012 after the short rains, which occur from November to December. AISA Eagle VNIR sensor covers the spectral range of 400–1000 nm with 64 spectral bands that have bandwidth of approximately 9.3 nm. The data was georeferenced and radiometrically and atmospherically corrected. The spatial resolution of the final data is 0.5 m. The field data consist of 450 trees from 20 species that we were able to locate both in the field and from the AISA data. We also used aerial photos acquired simultaneously with AISA data for locating the trees. The tree crowns were delineated manually for the crowns and mean reflectance was calculated for each tree. Here, we present preliminary results of the statistical analysis. We studied, the spectral discrimination of the different species using analysis of variance (ANOVA) and covariance (ANCOVA), and used linear discriminant analysis for the species classification.

## **Spectral Variability Analysis for Crop Species Identification Using Hyperspectral Data – Case study of Taita Hills, Kenya**

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**Keywords:** Hyperspectral imaging, Spectral signature, Spectral variation, Crop identification, AISA Eagle

Recent advances in hyperspectral remote sensing techniques and technologies allow us more accurately identify larger range of crop species from airborne measurements. This study employs hyperspectral AISA Eagle imagery acquired with about 9 nm spectral and 0.6 nm spatial resolutions over a spectral range of 400nm to 1000nm. The case study area is located in Taita Hills, southern Kenya (03°20'S, 38°15'E) and elevation range of 600 to 2200 m. various crops are being cultivated. The most important crop species addressed here are majorly: maize (corn), bananas, sugarcane and some mango trees, nonetheless, there could be other crops to be discriminated in the same study.

Spectral signature of crops is known to vary in both within and between different crop species. The spectral reflectance of vegetation being affected by e.g. leaf optical properties, leaf angles and spatial distribution, signatures also vary in scale from leaf to canopy, ultimately depending on plant phenological state. Therefore, emphasis has to be given to the determination of spectral variation of crops in order to accurately identify species from each other. Contribution of scene components such as soil reflectance and shadows, have to also be taken into account, especially when attempting to find more general rules for crop identification from hyperspectral imagery.

One of the main questions in this study is what crop species can be distinguished from the cultivated population of local crop species, and what feature space discriminates most effectively the spectral signatures of different species. We have digitized field plots (With knowledge of land species distribution) which are the main training elements to retrieve spectral information of crops from AISA imagery.

Methodologies applied include the Principal Component Analysis (PCA) together with Dissimilarity concepts to statistically validate the results. Results will be presented in the conference paper.

## **Evaluation of sun-induced fluorescence maps as an indicator for plant functional properties**

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**Keywords:** sun-induced fluorescence, hyperspectral imaging, photosynthesis

Photosynthesis of plant canopies is governed by environmental constraints and varies with the physiological status and functional properties of different plants. One of the most used indicator for physiological status at leaf level is the active detection of fluorescence emitted by the chlorophyll. At canopy level, however, a different approach is needed to distinguish this weak signal from the sun light reflected from the vegetation. The estimation of sun-induced chlorophyll fluorescence ( $F_s$ ) by passive remote sensing systems requires a spectrometer with a very high spectral resolution to exploit the oxygen atmospheric absorption bands in which irradiance is strongly reduced. Several studies indicated that  $F_s$  can be used to investigate plant functional properties.

In this communication we present the first results obtained by the novel high performance airborne imaging spectrometer HyPlant characterized by a full width at half maximum (FWHM) of 0.26 nm in the oxygen atmospheric absorption bands. The sensor was used to obtain  $F_s$  maps from hyperspectral data acquired over a mainly agricultural dominated region within the Rur catchment (NRW, Germany) during summer 2012. Several flight lines with 1 meter resolution were designed and planned at different times of the day with the intention to evaluate spatio-temporal variations of the  $F_s$  signal among the different crops. Ground measurements of  $F_s$  were acquired with high spectral resolution spectroradiometers (FWHM of 0.13 nm) during the overpasses in order to validate the signal obtained with the airborne sensor. Additionally, a complete characterization of plant structural and functional properties was performed in selected sugar beet fields. The combination of  $F_s$  maps obtained by HyPlant and the measured ground reference data would provide new insights in the capability of  $F_s$  signal to be used as an indicator for plant functional properties at large scales.

## **Airborne Hyperspectral and LiDAR Data in Assessment of Forest Regeneration Processes**

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**Keywords:** object oriented classification, HS and LiDAR data fusion

A large complex of Norway spruce forests situated in the central European mountain have been facing to frequent bark beetle (*Ips typographus* (L.)) outbreaks since 1990's. Extensive spruce dieback has resulted from the bark beetle activities. Some of the dying spruce forests have been left to natural regeneration/recovery processes, while the other forests have undergone traditional forestry approach to combat bark beetle mainly by salvage logging followed by plantation.

The study aims to analyze forest regeneration processes in managed and non-managed areas using airborne hyperspectral, LiDAR, and ancillary data.

We parameterized actual forest regeneration phase by a number of young trees and their crown projected area per square unit of the managed and non-managed areas resp. Two more parameters derived from DEM and representing stand conditions for regeneration were used as covariates: slope and aspect of the terrain. A general linear model (GLM) was used to estimate the contribution of each factor to the regeneration.

We used hyperspectral data (HS) AISA Eagle, spatial resolution 0.4 m, spectral resolution 10 nm, spectral range from 400 to 1000 nm. The LiDAR (TopEye Mk II 1064 nm) has point spacing 1 m. The field data includes field spectral measurements of different species (ASD Field Spec) and GPS measurements.

The HS data were postprocessed for radiometric correction (CaliGeo), atmospheric correction (ATCOR-4), and geometric correction (PARGE). The LiDAR clouds were split into two groups by using OPALS software: surface points and terrain points. The former point clouds enabled to interpolate the digital surface model (DSM) and the latter one to calculate the digital elevation model (DEM). The difference between the DSM and the DEM represents the heights of the pixels in the area of interest.

Object oriented classification (eCognition) was applied to HS data and to pixel heights band to distinguish between objects/cover formed by herbal cover, living spruce trees, dead trees and shadows.

We did not find statistically significant (GLM) difference in the number of leaving young trees per unit area between managed and non-managed sites. There is statistically significant ( $\alpha = 0,0003$ ) difference between the two types of sites with respect to projected areas of crowns of leaving young trees per unit area. The slope of the sites has been recognized as a statistically significant factor ( $\alpha = 0,003$ ) of tree regeneration after the bark beetle calamities while aspect is not statistically significant.

## Urban Environment

### **Very high resolution land cover extraction in urban areas**

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**Keywords:** classification, land cover, urban areas, material classification, airborne imagery, camera design

During last decade, needs for high resolution land cover data have been growing. Such knowledge is namely often required in environment monitoring studies. Thus, to answer these needs, national mapping or environment agencies, in many countries, have undertaken the production of such large scale national land cover database. Nevertheless, these databases provide a general classification and may not suit some specific (often new) applications requiring a semantic or geometric finer level of detail. That is to say that, on one hand, additional land cover classes should sometimes be specified, whereas, on the other hand, some existing classes should be delineated at a finer level.

More particularly, in urban areas, knowledge concerning very high resolution land cover and especially material classification are necessary for several city modelling applications. Most of these applications are still experimental scientific ones in various fields such as micro-meteorology, hydrology, pollutants flow monitoring and ground perviousness monitoring. Thus, knowledge concerning the roofing materials or the different kinds of ground areas (pervious, vegetated, impervious...) are required. As no map containing such information already exists, airborne remote sensing techniques appear to be convenient for obtaining it at a large scale. However, remote sensing imagery of urban environments from airborne acquisitions namely still remains a major scientific issue, since on one hand, urban areas are characterized by a high variety of materials, and on the other hand, results provided by most of the traditional processing methods based on usual red-green-blue-near infrared multispectral images remain limited for such applications. A possible way to improve classification results is to enhance the imagery spectral resolution using superspectral or hyperspectral imagery.

Thus, the present experiments are part of a work aiming at designing a future superspectral camera system dedicated to high resolution urban land cover classification applications, and especially material mapping. The choice of optimal band sets is processed here from a set of airborne hyperspectral data.

A data acquisition campaign named UMBRA has recently been carried out thanks to the French collaboration of IGN and ONERA. Data have been captured over two French cities chosen for their difference in building architecture, urbanization planning and their variety in urban material. Airborne images have been acquired simultaneously by multispectral and hyperspectral cameras with a ground sampling distance ranging from 0.15m for multispectral to 1.6m for hyperspectral in the SWIR channels. The images were radiometrically and geometrically calibrated and have a noticeable low signal-to-noise ratio.

The first urban land cover / material classification results obtained from this new reference data set will be presented in this paper.



## **Laboratory spectral measurements**

### **SpecTour – New results from the international round robin test for the comparison of spectroscopic laboratory measurements**

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**Keywords:** SpecTour, reflectance spectroscopy, chlorite, spectral libraries

The increasing number of users in the field of hyperspectral remote sensing as well as the growing market of field and laboratory spectrometers and other measuring equipment lead to a increasing variety of laboratory equipment and user specific spectral libraries. The simultaneous lack of standards concerning experimental set-ups and measurement protocols further increases possible variations and raises the question of the comparability of results from different institutions.

Against this background, in 2009 the SpecTour project was launched with the purpose of giving an overview of the current test patterns in the hyperspectral research community and analysing the comparability of the individual measurement results ([www.spectour.org](http://www.spectour.org)). The project is funded by the German Society for Photogrammetry, Remote Sensing and Geoinformation (DGPF) and the Martin Luther University Halle (Germany). The experimental framework of the SpecTour includes a box with 4 reference panels as well as a chlorite rock sample that is sent to each participant in a collaborative study. The philosophy behind SpecTour is "just measure as you always do". Comprehensive guidelines regarding the lighting parameters of the measurement setup and measurement procedure were therefore excluded. However, the measuring equipment and the applied measuring parameters are documented in a protocol by the participants. At the present date (November 2012) 28 institutions from 6 countries with over 40 different test arrangements participated on the national and international level. The first analyses have already shown significant variations in the results of the reference panels. Their causes can be attributed in particular to the used background materials and the illumination sources. Distinctive errors, for example, were sinusoidal spectral curves caused by power signals without an AC/DC converter, disruptive influences of background materials consisting of of herbal materials with specific spectral signatures and influences of fluorescent lamps with strong mercury emission peaks (Jung et al. 2012)\*.

The focus of this study lies on the evaluation of the results from the chlorite measurements. Chlorite has characteristic absorption features in the shortwave infrared (SWIR, 1300 – 2500 nm) that can be used for the spectral identification of the mineral. Therefore, the precise determination of band positions and shapes is important. The absorption features at about 1400, 2250 and 2345 nm of the chlorite spectra were parameterized (positions of the absorption minima and shoulders, absorption depths, ), statistically analyzed and afterwards correlated with measurement parameters (spectrometer type, last calibration, lighting source, measurement distance, etc.).

The comparison of the results between the different participating institutions as well as the measurement series of the same participants show that the majority of the measured spectra allow the spectral identification of the mineral. Nevertheless, the spectra from some

measurement set ups showed impairments of the qualitative information which is mainly due to influences of the background material, the light sources and sensor noise. For instance, while the positions of the absorption feature at about 1400 nm show little deviations (mean 0.37, max 1.3), they are significantly increasing towards the longer wavelengths. In particular, the absorption minimum at the 2345 nm absorption feature reaches mean deviations of 3.4 nm (12.25 nm max) and the shoulder positions at 2440 nm vary up to even 30 nm (10 nm on average).

In addition, we also observed variations of spectral parameters between the apparently error-free measurements of different institutions which raise questions about the transferability of quantitative statements. For example, the relative absorption depth of the 1400 nm feature is 9 on average, but ranges between 2 and 11.

This study clarifies the need for standards in the field of spectroscopic measurements. On this account, "good practice" advices and recommendations to reduce or prevent major errors are to be derived within the SpecTour project to contribute to an increase of data quality and the comparability of results from hyperspectral measurements.

\*Jung, A.; Götze, C.; Gläßer, C. (2012): Overview of Experimental Setups in Spectroscopic Laboratory Measurements – the SpecTour Project. In: PFG, 4, pp. 433-442 (DOI: 10.1127/1432-8364/20/0129).