HYPER-SWISS-NET: FOSTERING THE SWISS RESEARCH COMMUNITY IN THE FIELD OF IMAGING SPECTROSCOPY

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ABSTRACT:

The field of imaging spectroscopy has reached in terms of knowhow and technology a high level of maturity, which makes its observations accessible and useful for a larger research and user community. The Hyper-Swiss-Net will develop a range of Earth observation (EO) applications drawing from the scientific expertise of the project consortium as well as considering the requirements of the respective user community. The implementation of the different EO products will be based on dedicated flight experiments with the airborne imaging spectrometer APEX and will directly build on the operational capabilities of the APEX processing and archiving facility (PAF).

1. INTRODCUTION

The Hyper-Swiss-Net project aims at developing and supporting the scientific expertise and infrastructure in Switzerland for the exploitation of imaging spectrometry for different Earth observation applications. The development of imaging spectrometers, the availability of Earth observations from air- and spaceborne platforms in high spectral resolution as well as the facility of their processing has remarkably evolved over the last decade (Jacquemoud et al. 2006; Schaepman et al. 2006). This trend leads to a level of maturity, which makes imaging spectrometry accessible and useful for a larger research and user community. Against this background Hyper-Swiss-Net will develop a range of prototype application products drawing from the diverse expertise present in the project consortium and the respective user community. The following products will be covered within the project, prototyping the use of imaging spectrometry to fulfil the requirements for environmental monitoring in different fields: Vegetation (RSL) and land use dynamics (WSL), atmospheric trace gases (Empa), urban climatology (University of Basel), snow properties (University of Bern) as well as a synergy study of imaging spectrometry and SAR for bio/geophysical parameters retrieval (EPFL). Development and implementation of the different products will be based on dedicated flight experiments with the airborne ESA imaging spectrometer APEX (Itten et al. 2008) and will directly build on and link into the operational capabilities of the APEX processing and archiving facility (PAF) (Hueni et al. 2009).

The scientific expertise gathered during the project will be further disseminated within the Swiss research community by integrating the developed capabilities into specific teaching modules.

1.1 Project structure and work plan

The consortium of the project consist of six Swiss research institutes covering different scientific fields. The Hyper-Swiss-Net project is organized in six experimental (E1-6) and educational (V1-6) work packages and one coordination work package (P1, G1-3) for horizontal tasks (Fig. 1). Each of the six partners is responsible for one of the experimental and educational work packages according to his specific scientific field and expert knowledge. The project coordination and horizontal tasks are carried out by RSL.
The work plan of Hyper-Swiss-Net spanning a total time period of 3.5 years is split into four phases with dedicated tasks, which will each result in explicit deliverables. The Design Phase was already concluded in 2008 with the scientific design of the experiments and the implementation of a basic education module on imaging spectroscopy. In the preparation and development phase the data acquisition, including field campaigns and flight experiments, as well as the algorithm development are foreseen. Final products as well as the educational modules will be provided during the implementation phase to be concluded by December 2011.

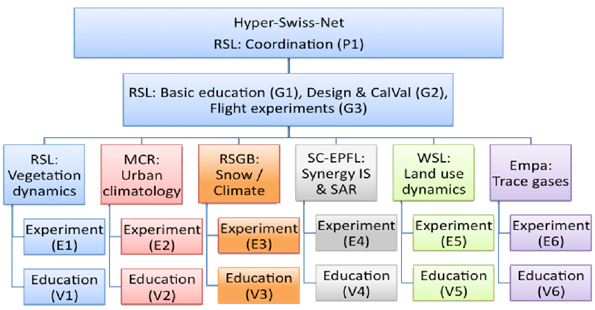

Figure 1. Work breakdown of the Hyper-Swiss-Net project

2. SCIENTIFIC OBJECTIVES AND EARTH OBSERVATION PRODUCTS

The goal of the Hyper-Swiss-Net is to develop six scientific clusters in imaging spectroscopy addressing atmospheric to ecological research questions. The development of appropriate EO products fulfilling the requirements of the research question at hand requires the combination of scientific expertise and user needs in the respective field together with reliable observations of high performance. Within the Hyper-Swiss-Net each research partner can rely on the high data quality of the APEX instrument and can also build on the operational products of the APEX processing and archiving facility (PAF). Such an environment will allow an integral algorithm development to provide EO products of unprecedented quality and detail dedicated for specific research questions. After successful testing and validation the EO products will be integrated in the APEX PAF in order to increase the range of added value APEX level 3 products. The final objective of Hyper-Swiss-Net is to advance the availability of reliable EO products for the environmental monitoring requirements within different scientific user communities.
The specific objectives of each partner in their respective fields of scientific expertise are outlined in the following chapters.

2.1 Urban Climatology

The architecture of urban areas reflects an extremely specific man-made structure introducing complex phenomena and influencing ecological, climatic and energetic conditions of the urban climate. Energy and radiation fluxes are the main drivers of urban climate, which significantly deviates from the climate of the rural surroundings.
Together with "traditional" techniques using thermal bands of low resolution spaceborne sensors, micrometeorological *in situ* measurements and numerical modelling, remote sensing data from the imaging spectrometer APEX open new opportunities

for the assessment of the complete radiation and energy balance of a city. The Urban Climatology Module in the frame of the HyperSwissNet project will further develop and refine existing urban specific methods in imaging spectrometry towards the assessment of specific fluxes in the radiation and energy balance of urban surfaces.

A main topic of urban climatology is the understanding of climatic stress factors acting on urban populations, like air pollution and thermal stress, due to the modification of the radiation and energy balance by urban areas. However, the difficulty of making remote sensing observations in urban areas, associated with the height of the roughness elements and the complexity of the surface, has resulted in a lag in progress relative to studies of vegetated areas. Probably the best known phenomenon for the modification of the climate by urban environments is the Urban Heat Island UHI (Oke 1982), a topic which has been widely analyzed using remote sensing data mainly from thermal bands and meteorological *in situ* measurements. The analysis of the UHI is an excellent example that a comprehensive assessment of energy and radiation fluxes is best achieved by combining remote sensing techniques, micrometeorological *in situ* measurements and numerical simulations. The Institute of Meteorology, Climatology and Remote Sensing of the University of Basel (MCR Lab) is following this combined approach since many years (e.g.(Frey et al. 2007; Rigo and Parlow 2007)). Including high resolution imaging spectrometer data and the related processing chains is a unique opportunity to enhance this approach towards higher accuracy of specific terms in the radiation and energy balance of cities. In particular, using the specific APEX data set, we will focus on

- how the short wave radiation fluxes and the spectral surface albedo are modified by the 3-D nature of the urban topography
- identification of urban surface materials to deduce their properties of heat conductance and heat capacity for an accurate estimation of the heat storage term
- the conditions (e.g. water stress) of the vegetation of urban parks, greens, trees and green roofs and its impact on the latent heat flux
- urban air pollution over a transect of different urban specific land covers.

2.2 Snow and Climate

In alpine regions such as the European Alps, snow is a predominant environmental factor. High accurate snow monitoring in the Alpine Region is of great importance as temporal and spatial variations in snow coverage have far-reaching consequences on the natural and the socio-economic systems. An accurate snow cover observation is required for various purposes such as meteorological modelling, climate studies, snow mapping, estimation of stored water equivalent or snowmelt runoff prediction.

Since many years the RSGB uses satellite data (NOAA-AVHRR, Terra-MODIS, Terra-ASTER, Landsat-TM) to monitor the snow cover of the European Alps. Depending on sensor’s temporal and spatial resolution the area of investigation covers small catchments or the whole Alpine region. Due to the fact we always observe mixed pixels a detailed (high spectral and spatial resolution) mapping could improve regional monitoring. Not only grain size, snow pollution caused by different sources, liquid water on the surface affects the spectral behaviour but also the spectral composition of the pixel. Homogeneity of the landscape and the spatial resolution of a sensor has to be addressed to make the APEX related research sustainable in complex topography.

Within the frame of the project outline an optimization of snow detection in the Alpine Region is intended, since snow parameters (snow grain size, impurities) are highly sensitive to variations of climate variables and also themselves influence climatic variables (snow albedo). The availability of imaging spectrometer data gained from an individually

designed flight experiment with the APEX instrument along nadir and simultaneous to selected spaceborne sensors overpass offers a valuable source of information. This data set with a high spatial and spectral resolution will be evaluated in terms of different snow parameters such as grain size and snow impurities as well as in different illumination conditions.
Based on this, the accuracy of snow cover detection from medium resolution satellite sensors (i.e. Terra-MODIS, NOAA AVHRR) data can be estimated and the trade-off of a decreased spatial and spectral resolution in larger catchment areas can be assessed

2.3 Vegetation dynamics

The biophysical description of terrestrial ecosystem structure and composition is essential to understand and assess the ecological functions and subsequently the services an ecosystem can provide to the environment and humans (Balmford et al. 2005). Anthropogenic pressure and climate change emphasize the need for monitoring the status and extent of ecosystems over time and space. Earth observation technology, such as imaging spectroscopy, is predestined to monitor ecosystems in a systematic, robust and repeatable manner. The Vegetation dynamics module of the Hyper-Swiss-Net will thus develop and implement physically-based algorithms required by a monitoring system for trends in status and extent of terrestrial ecosystems based on the imaging spectrometer APEX.
Imaging spectrometry provides a signature of unprecedented high spectral resolution resolving the ecosystem composition and structure in terms of its biophysical properties as well as of prevailing plant functional types (Ustin et al. 2004). APEX as an airborne instrument gives access to local and regional distribution of ecosystem pattern, which are most compatible to match the scale of existing and indispensable field studies. Further, existing and upcoming space-borne imaging spectrometers will allow to up-scale the approach to continental and global scales.
Two major steps shall develop the knowhow and capacity to serve user communities within the fields of ecology and biological conservation with detailed information on spatial distribution of the state and change of ecosystem properties. The developed user service shall be focused on supporting monitoring requirements as requested by international and national environmental policies.
Step 1: Development and implementation of algorithms to derive biophysical properties as well as plant functional types of terrestrial ecosystems based on imaging spectrometry. Existing radiative transfer models (RTM) will be improved and adapted to the needs of a systematic operation based on data sets provided by APEX. The leaf model PROSPECT will be combined on canopy level with two RTM SAIL for homogenous and GeoSAIL for heterogeneous canopies. The developed algorithms shall be implemented in software modules as integral part of the APEX Processing and Archiving Facility (PAF). For heterogeneous canopies such as forests the synergy with LiDAR derived products and their integration to the retrieval algorithms shall be investigated (Koetz et al. 2007). Classification algorithms specifically adapted to the high dimensionality of the imaging spectrometer data will be selected and adapted to the APEX PAF environment for mapping the spatial extent of different plant functional types (Koetz et al. 2008).
Step 2: Mapping of selected ecosystems based on the systematic and repeatable application of the developed software modules shall demonstrate their monitoring capabilities. The derived biophysical properties shall support the physiological characterization of ecosystems and habitats as well as assess their spatial extent and fragmentation. The developed algorithms shall be tested and validated over test sites selected for their ecological relevance and in collaboration with interested users in the field of biodiversity

(e.g. invasive species mapping) and ecology (e.g. habitat mapping, carbon flux cycle).

2.4 Atmospheric trace gases

Imaging spectrometer data provided by APEX will be used by Empa to study the distribution of key air pollutants and to obtain detailed information on individual emission sources. Empa will primarily focus on nitrogen dioxide (NO_2) since satellite observations have demonstrated that NO_2 vertical columns can be obtained in good quality from nadir-looking instruments in the UV/VIS range covered by APEX. The focus on NO_2 is also motivated by the fact that it is one of the most relevant air pollutants with concentrations frequently exceeding the air quality thresholds in Europe and elsewhere, and that it is an important precursor for the formation of ozone and aerosols. APEX offers a unique opportunity to measure air pollutants over extended areas at a spatial resolution exceeding the resolution of current satellite sensors by several orders of magnitude (approx. 10^5 in area!). The preparatory studies by (Kaiser et al. 2005) have demonstrated that NO_2 retrievals should principally be feasible given the specifications of the APEX instrument.

A first objective is to develop the tools needed to retrieve NO_2 vertical columns between the surface and the aircraft cruise altitude from the spectral radiance information provided by APEX. This will involve selecting appropriate spectral windows, adapting existing Differential Optical Absorption Spectroscopy (DOAS) to the APEX data, developing an optimal strategy for the subtraction of the stratospheric background signal, and implementing a radiative transfer code for the computation of air mass factors to convert between slant (depending on viewing geometry) and vertical (independent of the geometry) columns.

The second objective is to characterize the NO_2 distribution above Switzerland and in particular its spatial and seasonal variability. Large NO_2 gradients are expected for instance between polluted (cities, industrial regions, motorways) and rural locations. However, relatively little is known about the spatial scales of this variability which depends on the lifetime of NO_x as well as on meteorological factors that determine the transport and dispersion of any pollutant emitted to the atmosphere.

The third objective is to derive emission estimates by combining the observations with suitable models. Emissions may be estimated for individual point sources such as power plants or waste incinerators, or for the combined effect of multiple sources such as traffic on a motorway or an entire city. Model approaches may vary from simple conceptual models to complex atmospheric dispersion and chemistry-transport models available at Empa.

2.5 Synergy between imaging spectrometry and SAR

Due to its expertise in the domain of the exploitation of images acquired by satellites sensors, the main objective of the Space Center EPFL in this project will be to investigate retrieval algorithms to derive bio- and geo-physical parameters from remote sensing data for land applications. A special emphasis will be put on the study of the synergy of imaging spectrometer data acquired by the APEX airborne sensor and SAR (Synthetic Aperture Radar) satellite data over vegetated (forestry, agricultural areas) and bare soil areas.

The synergy of optical and microwave remote sensing data for land applications has been and is still being studied but the scientific community is rather split between these two types of data. Furthermore, owing to the wavelength used (400-2500 nm for optical systems and 3-30 cm for radars), the targets imaged will interact differently to the two types of electromagnetic radiation. However, these two types of data are extremely complementary and a clever combined use could yield significant better results than the use of a single type of remote sensing data. Such a joint analysis of these data could be employed for instance to improve the temporal coverage, the spatial resolution, or increase the accuracy of classification algorithms. However, to make a scientific sound use of these two types of data, models need to be developed that carefully describe and represent how electromagnetic waves interact with the media of interest. Not only these models are required but also a careful description of the surface being imaged (e.g. vegetation, rough terrains) so that the scattering of the electromagnetic signals can be properly taken into account. Once these "direct" models have been developed (they predict the variables that the satellite can measure such as reflectance or backscattering coefficients), "inverse" algorithms can then be studied in order to retrieve bio- and geo-physical parameters from the data acquired by the satellites.

The proposed research focuses on the development of models and retrieval algorithms using spaceborne or airborne remote sensing data for land applications. In particular, the synergy of optical (VIS+NIR) and microwave (SAR) data might yield improvement in order to obtain bio- and geo-physical parameters for vegetated (forestry, agricultural) areas and bare soil surfaces. The research will involve a thorough and realistic description of the target being observed from the remote sensing sensor at both optical and microwave frequencies and the development of directs models to simulate the electromagnetic wave interactions with the area of interest. Based on these models developed to predict reflectance and backscattering coefficients, then inversion algorithms can be inferred based on a physical description and the knowledge obtained with the direct models. Special attention will be given to vegetation models enabling to proper represent the structure of the target since microwaves, but also scattering at optical frequency to a lesser extent, are very sensitive to this parameter.

Among the parameters to be studied and hopefully retrieved, top soil moisture, vegetation biomass, vegetation stress, vegetation and forest types, leaf area index, are the most likely candidates but others might be considered depending on the successful development of models and their validation.

2.6 Land use dynamic

Within Hyper-Swiss-Net WSL aims at advancing the state of science in remote sensing and its applications in the following fields: (1) calibration of canopy biochemistry for different habitat types using (APEX); (2) scaling canopy biochemistry from high resolution imaging spectrometer data (APEX) to space-borne optical sensors; (3) run larger scale modelling experiments in order to explore the effect using spatially distributed input of canopy chemistry data into biogeochemistry models (e.g. BIOME-BGC) compared to using ecosystem averages; (4) explore methods to map individual tree species in forest communities using APEX data; (5) explore methods of generating vegetation maps using APEX data; and (6) compare the results with traditional (LANDSAT-based) approaches.

Preliminary results have already shown that (a) canopy biochemical properties can be retrieved with high accuracy at a regional level (Huber et al. 2009 (in review); Huber et al. 2008; Psomas et al. in preparation), and that spatially distributed input of canopy biochemistry (specifically C:N ratios) are required in order to simulate biogeochemical processes accurately (Psomas et al. in preparation). However, the above studies have only demonstrated that the accurate retrieval works well at regional scales using air-borne sensors. Methods to a) improve the inter-/ and extrapolation to larger spatial scales and to b) up-scale air-borne regional models to retrieve vegetation canopy biochemistry are still to be developed. First results have shown that the selection of bands needs to be well calibrated in the lab for better between-region calibration (Huber et al. 2008), and that specifically designed vegetation indices have a better capacity for scaling to other sensors than do the individual bands alone (Psomas et al. in preparation b). Additionally, it was demonstrated, that the retrieval of biochemical canopy properties can be enhanced if the functional type of the species involved is known (Huber et al. 2008).

3. OUTLOOK

Hyper-Swiss-Net is an open network, which intends to include further users and most importantly to link into the European community and their expertise represented within the running Hyper-I-Net project.

First flight experiments supporting the development of the foreseen EO products are planed for June 2009.

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