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16. Earth System Science related Earth Observation

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16. Earth System Science related Earth Observation

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Swiss Commission for Remote Sensing,
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16.1

Investigating variations of gross primary productivity (GPP) over several ecotypes in Switzerland using the APEX chlorophyll fluorescence product

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Approximately 60 Gt of carbon are annually absorbed through plant photosynthesis. Slight alterations within terrestrial ecosystems may have significant changes on atmospheric carbon concentrations. Reliable monitoring systems are required to increase the knowledge on spatio-temporal dynamics of plant photosynthesis and related carbon fixation rates. Direct measurements of CO2 uptake by plant canopies are well established using ground operated gas analyzer (eddy flux tower) (Baldocchi et al. 2001). Such systems are, however, limited as observations are only representative for local footprints of the underlying ecosystem. Remote sensing (RS) offers a unique possibility to spatially investigate carbon uptake by plant photosynthesis, which is commonly referred to as terrestrial gross primary production (GPP).

Remote sensing approaches used to quantify GPP are based on the light use efficiency (LUE) concept from Monteith (Monteith 1972, 1977), which relates GPP to the Absorbed Photosynthetic Active Radiation (APAR) and the efficiency of plants to utilize the absorbed radiation for photosynthesis, the LUE. There is evidence that APAR can be reliably derived from optical measurements. The estimation of the highly variable LUE, however, is challenging. A first generation of RS-GPP approaches relate optical vegetation indices to APAR and assume LUE either as constant or as a function of actual meteorological conditions. Research has currently focused on estimating both APAR and LUE directly from RS data because these approaches are expected to provide more realistic GPP estimates. In this context, the emitted chlorophyll fluorescence (Fs) provides a new powerful tool for assessing actual plant LUE and, consequently, for mapping GPP. FS is emitted by the core of the photosynthetic machinery and can be considered as direct indicator for the functional status of plant photosynthesis. Several studies proved the capability of this remote sensing parameter to predict GPP at leaf and canopy level (Damm et al. 2010; Meroni et al. 2008; Rascher et al. 2009).

The proposed contribution provides one of the first spatial explicit investigations of GPP at local/regional scale. Data of the new imaging spectrometer APEX (Airborne Prism EXperiment) were used to derive all relevant parameters needed to estimate GPP. Differences in spatial distribution of GPP are investigated for different ecosystems in Switzerland including an agricultural test site, a semi-natural grassland site, a mixed forest, and an alpine pine forest.

Results of this contribution are considered as important information, e.g. for the development of ESA's (European Space Agency) FLEX (FLuorescence Explorer), for the improvement of knowledge on ecosystem responses to environmental properties, or for evaluating common ecosystem monitoring approaches (eddy flux tower).

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16.2

Satellite-based climate products for alpine studies within GCOS Switzerland

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The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations necessary to address climate-related issues are defined, obtained and made available to all potential users. Primarily, the GCOS observations should assist Parties in meeting their responsibilities under the UN Framework Convention on Climate Change (UNFCCC), as well as provide the systematic observations needed by the World Climate Research Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC).

The Swiss GCOS Office at the Federal Office of Meteorology and Climatology MeteoSwiss has the task of coordinating all climate relevant measurements in Switzerland. These include measurements in both the atmospheric and terrestrial domains made by a variety of measurement systems, including satellite-based sensors. Latter have become increasingly important in recent years due to significant advances in space technology, and “a detailed global climate record for the future critically depends upon an observing system involving a major satellite component”, as stated in the satellite supplement to the GCOS Implementation Plan.

An important task of the Swiss GCOS Office is to foster the use of satellite-based data for alpine studies in Switzerland, to complement the long-term in situ observations. We will present an overview of the activities of the Swiss GCOS Office. In particular, the results of climatological studies of atmospheric and terrestrial Essential Climate Variables (ECVs) will be presented as a contribution to the National Climate Observing System (GCOS Switzerland).

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16.3

Retrieval of the ECV „snow spatial extent“ from 25 years of AVHRR data over the European Alps for climate research

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Satellite time series can provide spatially and temporally consistent measurements of the Earth surface processes. In recent years, an increasing need for full resolution, multi-temporal satellite data sets has been identified to serve the purpose of climate change monitoring. Solely AVHRR offers the opportunity to analyze more than 25 years of medium resolution satellite imagery on a daily basis. Thereby it holds a great potential to detect, map and quantify long-term environmental changes, as this is the first satellite record approaching the length of statistical significance.

The University of Bern receives and archives daily full resolution (1.1 km) AVHRR data over Europe since 1984. This unique data set is used to generate a number of geophysical data records such as snow spatial extent, which has been declared an ECV. However, to compile a homogeneous data set for the use in climate studies, some inaccuracies, especially in the beginning stages of remote sensing techniques, have to be adequately corrected for. Therefore, a careful validation of the data is of major importance. In this study, we present an extended accuracy assessment of a modified snow cover retrieval from historical 1-km AVHRR data using a stable snow detection algorithm, which allows consistent snow sampling across the different AVHRR sensor generations. The spatial and seasonal validation includes a comparison to the quality assessed MOD10A1 snow cover product and a new approach of ground-truth validation using webcam imagery. The accuracy of the binary snow mask is found to be close to 90% (when compared to ground measurements) and correlations with MODIS snow masks exceed 0.9. In regard to time series compilation, assimilated station data were particularly valuable as a temporally stable reference to ensure sensor-to-sensor consistency. We will discuss snow product validation and present first time series results but also address the remaining challenges of a 25 year snow cover time series from space.

Given the importance of mountain regions for climate change assessment, the final objective is to provide a consistent database of snow extent that comes along with distinct accuracy parameters. This bears the potential to serve as a reference for climate models as well as supplement information for the assessment of trends over the last 25 years.

16.4
Estimation of forest variables from multiangular radiance data using a coupled canopy-atmosphere model

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Many land targets have directional reflectance properties, including vegetation, and forests in particular. Since the launch of satellite platforms with angular sampling capabilities, the higher potential of multi-angular data for estimating vegetation structural and biochemical variables has been recognized. Many studies successfully estimated forest variables from atmospherically corrected multiangular data, but the use of physically based radiative transfer (RT) models is still limited. Because the atmosphere also has directional properties, it is important to understand the directional behaviour of the coupled canopy-atmosphere system in order to understand the multiangular radiance signal measured by the sensor at the top of the atmosphere (TOA). Coupling canopy and atmosphere RT models allows linking the vegetation and atmosphere variables directly to the TOA radiance. Such a coupled model is therefore a very interesting tool for estimating the forest variables directly from the multi-angular TOA radiance.

This case study investigated the potential of multi-angular radiance data as measured by CHRIS/PROBA for estimating structural and biochemical variables of three Norway spruce stands located at the Bily Kriz experimental site in Czech Republic. The soil-leaf-canopy RT model SLC and the atmospheric model MODTRAN4 were coupled using a method allowing to make full use of the four canopy angular reflectance components provided by SLC (Laurent et al. 2011a).

The coupled model provided good simulations of the measured spectral and angular signatures. The dimensionality of the data was investigated by performing singular value decompositions of the Jacobian matrices. The analysis showed that the dimensionality increased from 3 to 6 when increasing the number of angles from 1 to 4 (Table 1). Two cases were investigated for the estimation of the forest variables: 4 and 7 variables. The estimation was conducted by inverting the coupled model using look-up tables (LUT). The most influential variables were chosen for building the LUTs: vertical crown cover (Cv), fraction of bark material (fB), needle chlorophyll content (needleCab), needle dry matter content (needleCdm) for the 4-variable case, and additionally, tree shape factor (Zeta), dissociation factor (D), and needle brown pigments content (needleCs) in the 7-variable case. All angular combinations were tested, and the best estimates were obtained with combinations using two or three angles, depending on the number of variables and on the stand used. Overall, this case study showed that, although making use of its full potential is still a challenge, TOA multi-angular radiance data do have a higher potential for variable estimation than mono-angular data (Laurent et al. 2011b).

Table 1. Dimensionality based on the singular value decomposition for all possible angular combinations.

Θ	YOUNG	OLD1	OLD2
{m36}	3	3	3
{nadir}	3	3	3
{p36}	3	3	3
{p55}	4	4	4
{nadir, m36}	4	4	4
{nadir, p36}	4	5	5
{nadir, p55}	5	5	5
{m36, p36}	4	4	4
{m36, p55}	4	5	5
{p36, p55}	5	5	5
{nadir, m36, p36}	5	5	5
{nadir, m36, p55}	5	6	6
{nadir, p36, p55}	5	6	6
{m36, p36, p55}	5	6	6
{nadir, m36, p36, p55}	5	6	6

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16.5

Fusion of Digital Elevation Models Using Sparse Representations

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Digital Elevations Models (DEMs) are one of the most important types of geodata. They are needed in a large number of applications, ranging from virtual globes and visualization to engineering and environmental planning. DEMs of larger areas are usually generated either by photogrammetric processing of aerial and satellite images, SAR (Synthetic Aperture Radar) interferometry, or laser scanning (mainly from airborne platforms). Each sensing technology has its own strengths and weaknesses, and even within one technology the variations in DEM quality are large. DEMs are available at different scales from tailor-made local models to national and even global coverage. We are primarily interested in large-scale national and global products, whose resolution, accuracy, error characteristics, and homogeneity vary a lot. In most cases, the DEM producers provide users with information only on production technology, date of acquisition, and resolution, but only with coarse accuracy measures that fail to capture the local variations in data quality – sometimes only a single global number.

In an ideal world, one would of course obtain the raw measurements and sensor models from all sensors, and merge them by fitting a single DEM to the entire set of heterogeneous observations, along the way computing quality measures for every single height value. Unfortunately, this is usually not feasible in practice. Thus, one resorts to the next best solution, namely to fuse DEMs from different providers into a higher-quality product, and estimate its quality in the process from the available redundancy.

DEM fusion – and its necessary prerequisite, fine-grained quality characterization of the inputs – has several benefits: improved accuracy, homogeneity and completeness, as well as fine-grained quality information for the final product. We deal only with 2-D surfaces in regular grid format, which constitute the vast majority of large-scale DEMs (although our framework could in principle be extended to TINs).

In this work we make two contributions: we develop a computationally efficient and flexible mathematical method for robust fusion of 2-D surface models. The formulation is generic and can be applied with any two input DEMs, independent of the sensor technology and processing with which they were created, making it useful for practical applications; it takes into account both prior information about plausible terrain shapes (in the form of a dictionary), and the local accuracy of the inputs, controlled by interpretable weights; and it poses the complete fusion as a clean, convex mathematical optimisation problem that can be solved to global optimality, and in which the influence of the input DEMs is controlled by an interpretable set of local fusion weights.

We propose a data-driven method, which allows one to derive local measures of DEM quality (and thus also fusion weights) for each point or segment of a DEM, if no such information is available. To this end we use as input geomorphological characteristics of the terrain (slope, aspect, roughness) which are derived directly from the DEMs, as well as optionally semantic information such as land-cover maps. Using existing high-quality ground-truth DEMs as reference, we learn regression functions relating the available geomorphological characteristics to the DEM quality, which then allow one to estimate the local quality of a new DEM.

The proposed method is evaluated in detail with three different satellite datasets, and shows a significant improvement in DEM quality, consistently over all combinations of inputs.

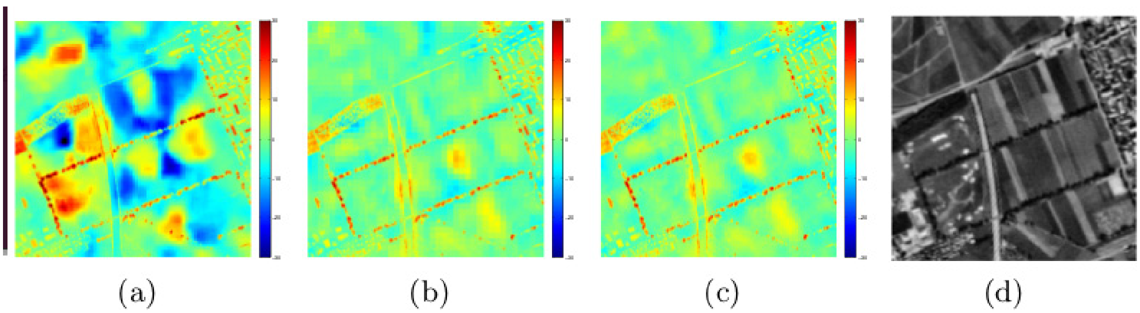

Figure 1. ALOS-SPOT fusion example. (a) Residuals between the L and A DEM, (b) Residuals between the L and S DEM, (c) Residuals between the L and F1 DEM. (d) SPOT orthoimage. The colored Z residuals are mapped in the interval [-30,30]. The bar unit is meters.

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16.6

Methods and sensors for monitoring land subsidence phenomena based on satellite SAR interferometric stacking

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Interferometric stacking techniques emerged in the last decade as methods to obtain very precise measurements of terrain displacements, and in particular subsidence phenomena. In particular, the so-called Persistent Scatterers (Ferretti et al. 2001) and Small BASeline (Berardino et al. 2002) methods can be considered as the two most representative stacking approaches.

In both cases, the exploitation of 20 or more satellite Synthetic Aperture Radar (SAR) acquisitions obtained from the same satellite sensor with similar geometries on the interest area allows to measure displacements with an accuracy in the order of few mm / year, and to derive the full location history of "good" pixels with an accuracy of 1cm or better for every available date. A main difference between the two approaches is the type of objects and land cover that are favoured in the analysis: the PS technique focuses on so-called Point Targets, i.e. objects possibly of small size and with a very well characterized geometry like corner reflectors (e.g. buildings, rocks) and with a high temporal stability of the backscattered signal; the SBAS technique vice-versa is concentrating the analysis on so-called distributed targets, like open fields and not very geometrically characterized objects. The PS approach is then not making any assumption on spatial correlation of the displacement to be measured, but more on its linearity; the SBAS approach vice-versa is more robust in case of spatially correlated displacements, and allows in this case to monitor larger displacement rates.

This paper is performing an extensive analysis and comparison of the results that have been obtained with the two approaches in a same geographical area in Japan, characterized by subsidence due to water and natural gas extraction. The analysis is based on data acquired from the ALOS PALSAR (L-band), ENVISAT ASAR (C-band) and COSMO-Skymed (X-band) satellite instruments, and the validation of the results is based on GPS and leveling measurement.

The analysis allows to draw conclusions on the best approach and sensor to be selected for deriving the displacement measures for monitoring subsidence phenomena; the feasibility of exploiting the same approach in different geographical areas like Switzerland is also discussed.

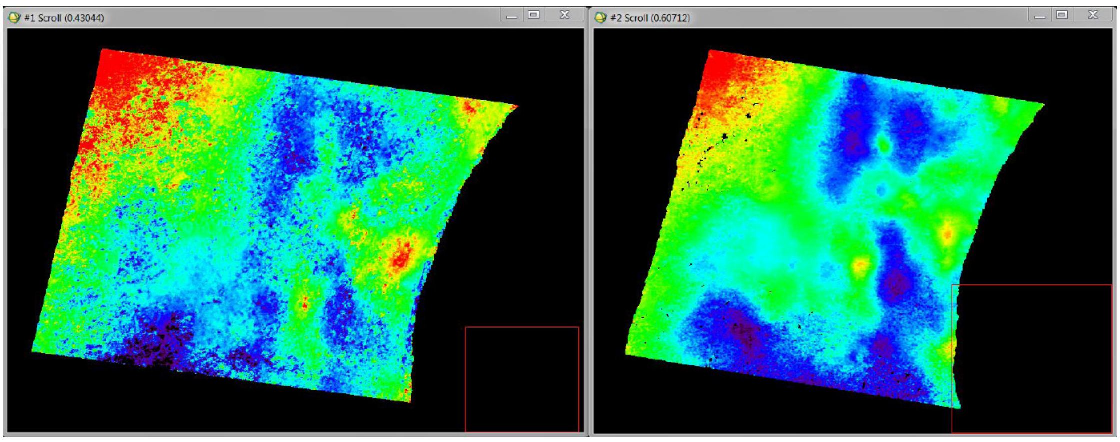

Figure 1. Comparison of average displacement rates (color scale between -25 mm/year in blue and +25mm/year in red) as derived from ALOS PALSAR (on the left) and ENVISAT ASAR (on the right) data.

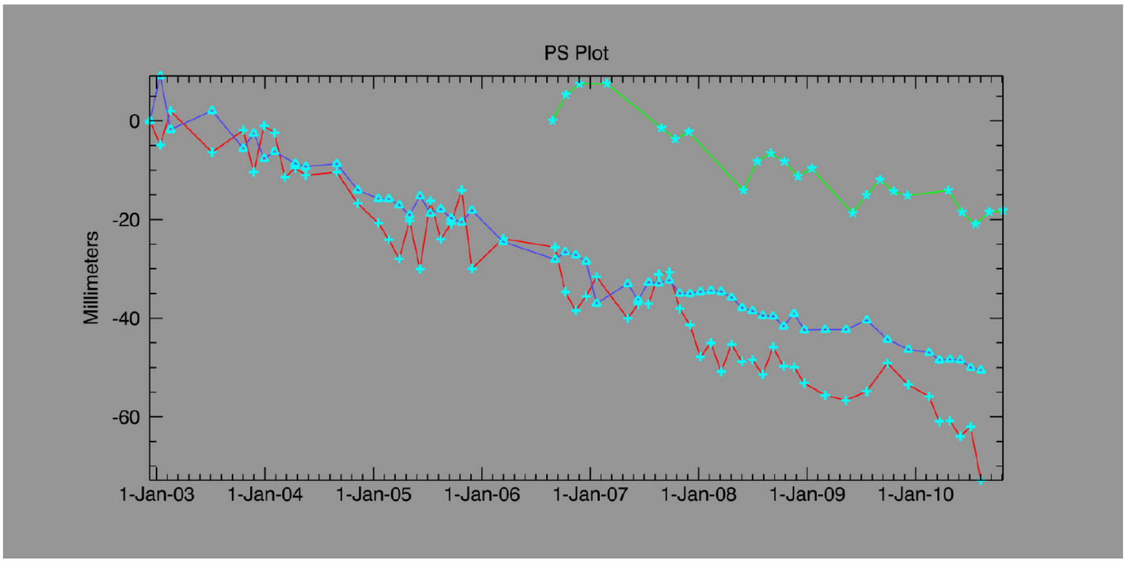

Figure 2. Comparison of displacement time series as derived from ALOS PALSAR + SBAS (star), ENVISAT ASAR + SBAS (triangle) and ENVISAT ASAR PS (plus).

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16.7

High spatial resolution mapping of NO_2 from APEX imaging spectrometer data

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The investigation of small scale nitrogen dioxide (NO_2) distribution and concentration is of particular interest for local and regional air pollution assessment, for the identification and quantification of emission sources, or to assess the impact of small-scale variability on the comparison between coarse resolution satellite observations (e.g. from SCIAMACHY, OMI, GOME) and in-situ (point) observations. In this contribution, we present a methodological framework for NO_2 retrieval and first results using data of the Airborne Prism EXperiment (APEX) imaging spectrometer. APEX is a dispersive pushbroom imaging spectrometer for environmental monitoring covering the wavelength region between 380 nm and 2500 nm with a sampling interval between 0.4 nm and 10 nm. The radiometric and spectral performance of APEX allows mapping air pollution gradients and even individual strong NO_2 sources at an unprecedented resolution of about 50 m. Data used in this study were acquired during test flights on a Saturday in June 2010 over Zurich, Switzerland. NO_2 columns over Zurich were derived following a well-established two-step approach. First, the differential optical absorption spectroscopy (DOAS) technique is applied to raw APEX spectra in order to retrieve differential slant column densities (dSCD) using spectra obtained over pollution-free scenes as reference. Second, dSCD are converted to differential vertical column densities (dVCD) by computing air mass factors with a radiative transfer code. First results reveal very plausible spatial distributions of NO_2 over the greater Zurich area, e.g. peak concentrations in a shopping area as well as high concentrations along the major traffic pathways. APEX NO_2 maps are also evaluated by comparison with ground-based air quality measurements from the NABEL (National Air Pollution Network) and the inter-cantonal network Ostluft. Finally, we identify critical aspects for NO_2 retrieval from airborne imaging spectrometry data including sensor calibration. Further we outline requirements necessary to identify not only strong pollution sources but also to distinguish between background and moderately polluted regions.

P 16.1

Ecosystem parameter mapping of Alpine regions using continuous fields derived from imaging spectrometer data

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Understanding and quantifying ecological processes and their spatio-temporal dynamics are crucial for monitoring and modeling ecosystems. Over the past two decades, remotely sensed data from imaging spectrometers have been used to accurately derive biogeochemical and biophysical ecosystem properties related to key ecological processes. The approach of Multiple Combined Continuous Fields (MCCF) is a promising alternative in representing the spatial and temporal distribution of ecosystem properties and offer advantages compared to traditional discrete classification approaches. In this contribution, the concept of continuous fields and a dedicated methodological framework for deriving continuous fields of ecosystem properties of Alpine regions is presented. The method includes abundance mapping of predominant land surface types and related quantitative maps of ecosystem parameters derived with empirical models from APEX (Airborne Prism Experiment) imaging spectrometer data.

P 16.2

Modeling the complexity of the dynamic rupture process of the 2011 Mw 9 Tohoku earthquake.

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On March 11th 2011, a violent Mw=9 earthquake stroke Japan causing 28000 victims, including casualties and missing. This earthquake triggered a devastating tsunami causing severe damage in cities and nuclear facilities along the Japanese coast. The amount of data recorded from this earthquake is exceptional, with thousands of broadband, strong motion and continuous GPS sensors located all over Japan. This provides a great opportunity for seismologist and engineers to deeply investigate the rupture process in order to better understand the physics of this type of earthquakes and their associated effects like tsunamis.

Kinematic source inversion of strong ground motion, teleseismic, geodetic and tsunami data and source imaging by back-projection of body waves recorded by teleseismic arrays (e.g, Simons et al, Science 2011, Meng et al, GRL 2011) suggest that the earthquake featured a diversity of rupture styles, comprising distinct stages of fast and slow rupture intermingled with high-frequency radiation. Those results also revealed a clear spatial complementarity between the regions of low and high frequency radiation: the regions of large slip had long rise time dominating the low frequency radiation and the strongest high frequencies is originated along the bottom rim of the main slip areas, near the deep limit of interplate seismicity. A plausible interpretation of this high/low frequency complementarity, consistent with the presence of repeating earthquakes in the area, is that high frequency radiation arises from failure of brittle asperities embedded in the frictionally stable fault regions at the bottom of the seismogenic zone.

Here we investigate the proposed mechanism of this key feature of the rupture process of this event by means of dynamic rupture simulations. We employ the 3D spectral element code SPECFEM3D-SESAME, in which we recently implemented the capability of solving for dynamic fault rupture. Through the usage of an unstructured mesh, our model incorporates the non-planar geometry of the megathrust interface. We assume that the fault rupture is governed by slip weakening friction. Our first set of simulations is aimed at testing if the diversity of rupture phenomena during this earthquake can be overall reproduced by assuming the most basic friction law, linear slip-weakening friction, but prescribing a spatially heterogeneous distribution of the critical slip weakening distance Dc and initial fault stresses. Our initial model is composed of overlapping patches of a range of sizes which Dc correlates with the patch size. By trial-and-error we determine a range of asperity properties that are compatible with the main features of the Tohoku earthquake. In particular, we distribute a collection of small patches near the deeper transition zone of the fault, to account for the strong high frequency radiation in that region.

P 16.3

Consistent Trends in Water Vapour, Downwelling Radiation, and Temperature

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The motivation of the presentation is the challenging question: „Do we observe the rising greenhouse effect in time series of water vapour, downwelling long-wave radiation, and temperature measured by a Swiss ground station network?"

Observation data of the time interval 1994 to 2007 comes from pyrgeometers and thermometers at Davos, Payerne, Jungfraujoch, and Locarno-Monti (Alpine Surface Radiation Budget Network ASRB) and from the ground-based microwave radiometer TROWARA at Bern.

We performed a Mann-Kendall trend analysis and found consistent trends in integrated water vapour, downwelling long-wave radiation, and surface air temperature. Generally the seasonal trends were positive during summer with exception of August where all parameters showed a dip in the trend. Negative trends were present during winter in all parameters. These results are in a qualitative agreement with the consideration that the rising temperature due to man-made CO_2 emissions causes higher evaporation rates of water vapour. In turn, higher concentrations of tropospheric CO_2 and H_2O lead to an increase of downwelling long-wave radiation which was measured by means of the Alpine Surface Radiation Budget Network. This observation result is not trivial since it requires long-term stability of all measurement instruments.

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P 16.4

Estimation of plant functional biochemical traits of subalpine and alpine grasslands from airborne images of high spatial and spectral resolution

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Plant functional traits (PFT) are any measureable feature that determines plants' responses to environmental factors and their effects on ecosystem processes. PFT are increasingly used to classify plants with similar function in an ecosystem, to quantify functional diversity of communities, or to parameterize e.g. dynamic global vegetation models. Even though field measurement protocols of many PFT are well established, they are time consuming and limited to discrete sampling points usually at local scale. Spatially continuous and non-destructive mapping of plant functional traits at larger areas using remote sensing methods is of interest to the plant ecology community.

Our research objective is to retrieve leaf biochemical traits, namely total chlorophylls (C_{ab}), water (C_w) content, and specific leaf area (SLA) of subalpine and alpine grasslands from high spatial and spectral resolution airborne imaging spectroscopy data. Further we are interested in interpretation of the spatial gradients of functional traits and their use for mapping of plant functional groups within the study area.

The airborne images, acquired with AISA Dual system (Specim, Ltd., Finland) during the vegetation season 2008 over subalpine and alpine grasslands in French Alps, were the main input into the physically based retrieval of functional traits.

The retrievals were based on look-up table inversion of integrated soil-leaf-canopy (SLC) radiative transfer model (Verhoef & Bach 2007). The model input parameters were adjusted to the local case study using field measurements to specify ranges and distributions of the model inputs. The ill-posed nature of the look-up table inversion, i.e. situations when different combinations of model inputs yield the same simulated top-of-canopy reflectance, was alleviated by retrieving individual traits from specific parts of the electromagnetic spectra.

Statistical analysis of field-measured leaf trait data revealed that trait variability is strongly driven by species (40-75%) and less by environmental gradients such as altitude (only less than 5% of the overall traits' variability could be explained by the altitude). Principal component analysis identified a triplet of leaf traits (Cab, Cw, and SLA) having high potential to distinguish functionally different plant groups, which is expected to be spatially revealed also at the canopy level from airborne spectral images.

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P 16.5

Time series of radar backscatter: Moving towards simultaneous high temporal & spatial resolution observations of Alpine snow melting

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Although snow provides a familiar strong signature at optical wavelengths, monitoring its presence and melting state is severely impaired by cloud cover and long wintry nights (and daytime shallow illumination) that often render meaningful observations by visible or infra-red sensors impossible. Radar sensors provide their own illumination source, penetrating through clouds to deliver backscatter observations day or night in all kinds of weather. Wet snow is characterised by very weak response to radars, observed as dark areas in the resulting imagery (Nagler & Rott, 2000).

Synthetic Aperture Radar (SAR) imagery is subject to both *geometric* and *radiometric* distortions caused by variations in the topography within an image. Corrections for the geometric properties of the images (topography and atmosphere) are being utilised to an increasing extent as SAR sensor positional accuracies also improve (Schubert et al., 2010).

High *geometric* accuracy is a pre-requisite for a well-defined local *radiometric* calibration throughout radar imagery. Correcting for the radiometric distortions induced by terrain has improved with a new technique recently developed within our group and demonstrated using data from ENVISAT ASAR, ALOS PALSAR, Radarsat-2, and TerraSAR-X. It is applicable to radar backscatter data available from any of over 10 satellites observing the Earth at a variety of microwave wavelengths (Small, 2011). A sample image acquired with the Canadian Radarsat-2 satellite in 2010 is shown in Figure 1. Open water and wet snow appears dark, fields dark grey, and forests intermediate grey. Cities and dry snow (above the freezing level) appear bright.

The technique is first demonstrated on a single image product, and then applied to a time-series of hundreds of radar images covering Switzerland. Improvements to multi-track inter-comparisons are shown. Wet snow observations in the springtime melting period are highlighted.

Given the upcoming European Sentinel-1 satellites due for launch in 2013, the potential of the technique to offer near daily high-resolution observations of wet snow throughout Switzerland and the Alpine chain is discussed.

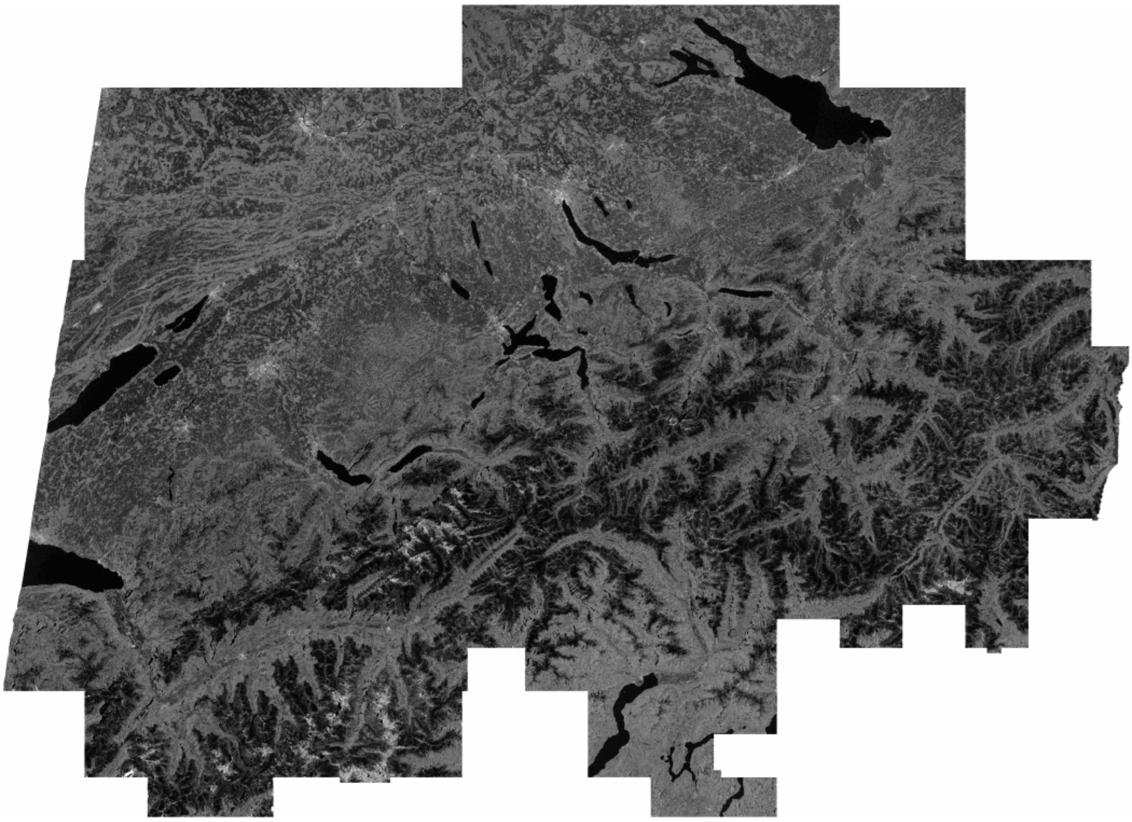

Figure 1. Melting snow observed in terrain-flattened gamma nought backscatter – Radarsat-2 ScanSAR 50m resolution VH polarisation, 27.04.2010, black= -26dB, white= -1dB – Radarsat-2 Data © Canadian Space Agency 2010, courtesy SOAR project #1985.

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P 16.6

Acquiring the relevant samples for chlorophyll estimation with hyperspectral data

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This contribution considers the problems of terrestrial campaign planning for the estimation of Chorophyll using hyperspectral data. The advent of this new technology, as well as the forthcoming missions aiming at measuring fluorescence from satellite observations (FLEX among others) have created a strong research pole aiming at linking the biophysical parameters with remote sensing spectra (Verrelst *et al.* 2008, Stagakis *et al.* 2010, Tuia *et al.* 2011).

At present, many approaches rely on the definition of statistical models of prediction of the biophysical parameter and have proven their reliability and generalization capabilities. However, such models also depend on an appropriate training set, in particularly when dealing with situations where only few samples can be acquired at once.

There is thus the need for methods aiming at planning efficiently the next measurement campaigns, where the samples are acquired where the model needs them mostly. In this optic, the framework of *active learning* (Cohn *et al.* 1994) proposes a series of criteria for selecting new training samples (new measurements) so that the uncertainty of the model predictions is efficiently reduced. In this work, we present a strategy based on committees of prediction models (similarly to the strategy for classification proposed in Tuia *et al.* 2009), where the interest of acquiring a new sample is directly related to the variance in the predictions made by the committee for each potential new measurement site.

We focus on the estimation of Chlorophyll concentration using hyperspectral spectra acquired by the spaceborne sensor CHRIS-Proba. Field data were acquired during the ESA SPARC-2003 and SPARC-2004 campaigns in Barrax, Spain. The large variety of crop types and phenological stages represented by the data provide a very complete sample of possible Chlorophyll concentrations.

An ensemble of 135 samples is available for the analysis: 20 are used for training the initial models, and 3 additional samples are selected form a set of 88 potential sites and included iteratively to the training set, either randomly or using an active learning strategy. The remaining 27 samples are used to validate the generalization capabilities of the model in the prediction task.

Figure 1 illustrates the learning rates for an active acquisition versus a random selection of the sampling sites: the plots show that planning terrestrial campaigns using active learning leads to models requiring less samples for an efficient prediction. Figure 2 shows the prediction maps after 15 sample acquisitions for the random (left) and active (middle) strategy, while the right panel shows the uncertainty function leading the selection of new samples. The uncertainty criterion forces the new samples to be located in the central area of the image, whose predictions are considered more uncertain. As an effect, the predictions in that area are strongly improved (see the central panel of Fig. 2).

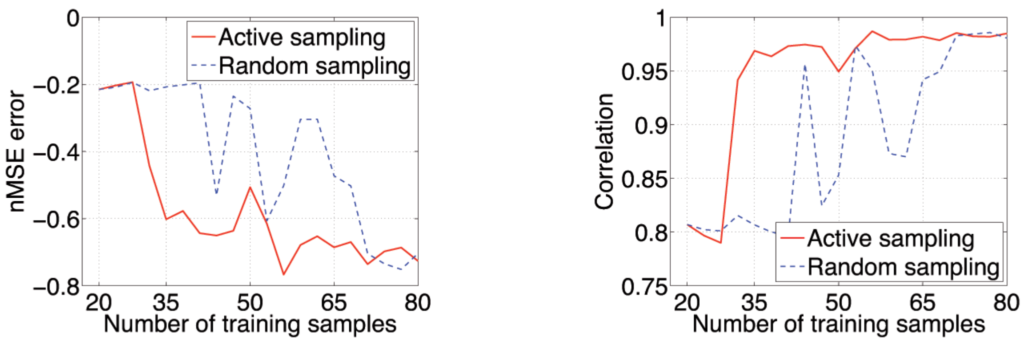
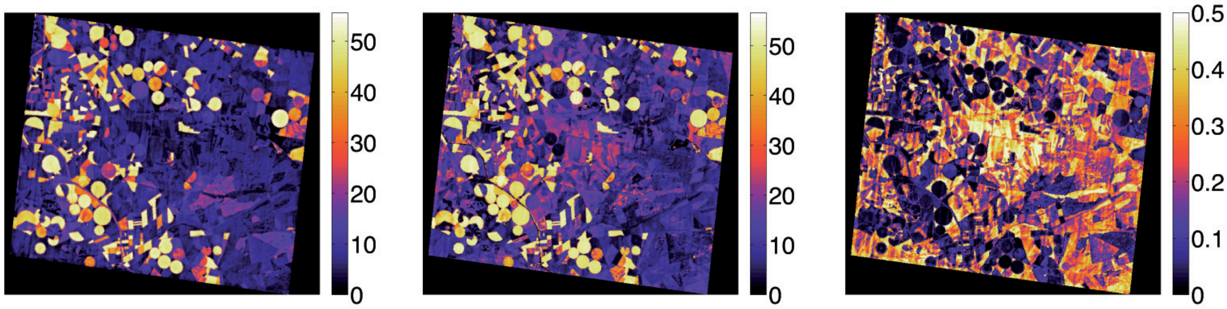


Figure 1. Comparison of random and active learning training points definition. (Left) normalized mean squared error

$$nMSE = \log_{10}\left(\sqrt{\frac{1}{Ns^2}\sum_i (y_i - \hat{y}_i)^2}\right)$$

as a function of the size of the training set; (right) Pearson correlation coefficient between predic ted and real chlorophyll concentrations.



Random selection Active selection Selection criterion

Figure 2. (Left) Chl prediction map when using random sampling (20 initial + 15 randomly selected); (middle) Chl prediction map when using active learning (20 initial + 15 actively selected); (right) Standard deviation of the prediction of the prediction models, used as a sample selection criterion.

Active learning seems a very promising way to minimize the number of training samples necessary to predict biophysical parameters using hyperspectral imagery. More results will be shown at the time of the conference.

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