### MLEG Flash Presentations Program

17th January 2019, Dübendorf

Each presentation consists of a 2-minute poster teaser.

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Vegetation height estimation from Sentinel-2 images

Nico Lang*, Jan Dirk Wegner*, Konrad Schindler*

*ETH Zürich, Institute of Geodesy and Photogrammetry, Photogrammetry and Remote Sensing (PRS)

Forests play a key role in climate change by regulating the CO2 content in the atmosphere. Not only do they absorb CO2 but they also store carbon in their trunks, branches, and roots. To assess the actual impact of forests on our climate, global biomass maps are essential. Today, the mapping of above ground biomass stored in forests relies essentially on vegetation height as it is the most important indicator.

Traditionally, vegetation height is mapped by measuring the difference between ground and top of canopy elevation. A straightforward strategy is the application of active LiDAR systems that can directly measure forest structures including the ground elevation by penetrating the canopy. Alternatively, photogrammetric stereo-matching yields the top of canopy elevation, but relies on highly overlapping multi-view aerial imagery. The main drawback of these approaches is that they rely on expensive flight campaigns. Therefore, they lack scalability and vegetation height products are rarely up-to-date.

This work addresses vegetation height mapping at country scale at 10 m spatial resolution by exploiting the recent success of deep learning methods combined with unprecedented publicly available multispectral satellite images from the Sentinel-2 mission. Multispectral satellite images such as provided by Landsat and Sentinel-2 have been widely used for land cover classification. Their spectral bandwidths, especially the near-infrared bands, are well suited to assess vegetation vitality and to classify species. However, modelling vegetation height from a single-view multispectral image is challenging because various land cover types and also vegetation heights can yield the same spectral signature. Hansen et al. (2016) show that incorporating time-series spectral information is valuable for discriminating tree heights. However, their proposed method cannot fully exploit spatial patterns correlating with vegetation heights.

Our proposed method builds on an adapted Xception network (Chollet, 2017), a state-of-the-art Convolutional Neural Network (CNN), that solve this pixel wise regression task and model vegetation height from a single 13-channel multispectral Sentinel-2 image by learning the spectral and spatial features in a supervised fashion, following the end-to-end deep learning paradigm.

Figure 1. Vegetation height prediction for a test area on the border of the cantons Zurich and Thurgau
Our method is experimentally evaluated on two regions in Switzerland (1,320,000 ha and 1,420,000 ha in size) for which a ground truth vegetation height model (VHM) from 2016 exists. This ground truth VHM was produced at a 1 m resolution by the Swiss Federal Institute for Forest, Snow and Landscape. They first created a digital surface model (DSM) using photogrammetric stereo-matching from aerial images taken by swisstopo in 2016. This DSM was reduced to the final VHM by subtracting a LiDAR based digital terrain model (DTM) and masking the buildings. For our experiments this ground truth VHM is reprojected and resampled to match the 10 m ground sampling distance of Sentinel-2 images.

Each region is split into non-overlapping training, validation and test regions. We take cloud free Sentinel-2 images from the growing season as an input to estimate vegetation height at 10 m spatial resolution achieving an overall mean absolute error (MAE) of 1.9 meter. Evaluating MAEs for separate height intervals yields 1.0 m (0-10 m), 5.4 m (10-20 m), 4.8 m (20-30 m), 4.9 m (30-40 m), 19.6 m (40-50 m), and 47.6 (>50 m). The gross errors for heights > 40 m are mainly due to errors in the ground truth data. These ground truth errors occur in mountainous and steep terrain, where it is likely that errors in the stereo matching and misalignment between DSM and DTM lead to errors in vegetation height. Additionally, vegetation heights >40 m account for only 0.06 % of the ground truth data, the model is not able to learn the characteristics of this underpopulated range from the data that is highly affected by systematic errors. Furthermore, our model tends to slightly smooth the predictions with respect to the ground truth (see Figure 1). We are currently working on the integration of time-series data as proposed by Hansen et al. (2016) to further improve our performance.

Nevertheless, our preliminary results show that estimating vegetation height from multispectral Sentinel-2 images is promising and possible at 10 m spatial resolution given a vast amount of training data. Our proposed method allows vegetation height mapping at country scale with the same high temporal resolution of (cloud free) Sentinel-2 images (approx. every 5 days) at virtually no costs.

REFERENCES


The HALOSEARCH project: search for unknown halocarbons in the atmosphere

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Halogenated trace gases are an important class of compounds in the atmosphere as they contribute to the greenhouse effect and to ozone-depletion. Currently, halocarbons of most relevance are monitored worldwide with up to hourly time resolution, for example within the AGAGE network. The technology used for such monitoring is based on sample pre-concentration, gas chromatography (GC) and mass spectrometry (MS) detection. However, the current state of the art does not permit to monitor all halogenated compounds, but only those that are purposely identified on chromatograms and therefore programmed to be detected by MS. Therefore, a certain time can elapse between new compound emission to the atmosphere and first registration in databases of atmospheric composition. To circumvent this delay we will perform non-target analyses using time-of-flight mass spectrometry (TOF-MS). With its capability of detecting all masses in high precision and high temporal resolution, this system can also be used to create an air archive, by measuring e.g. atmospheric air samples stored in cylinders. A critical step will be the identification of the detected unknown compounds, for which we will develop machine learning tools. The tools will be first tested on existing databases of ion fragments. The obtained information will be further combined with data and tests on retention time of known compounds on the used GC column, using information on boiling points and structural groups. These identification tools should be usable in a reverse mode as well: the program should allow the generation of the virtual chromatogram of a new, yet undetected compound, and automated search in atmospheric measurement data.

Figure 1. Example of chromatogram obtained on air measurements using Empa’s preconcentration-GC-TOF-MS. Shown here are the total detected ions over time.
Figure 2. Zoom on a time slice at 27 min from the previous graph, showing a subset of the masses detected at the same time slice.
Building envelope and energy system retrofit: A machine learning perspective

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According to the Swiss Federal Office of Energy [1], the highest share of energy consumption and greenhouse gas emissions, accounting for more than 40%, is due to the building sector. Social and political awareness towards tackling climate change, has led to the establishment of the Swiss Energy Strategy 2050. One of its main pillars is to improve the energy efficiency of buildings and integrate renewable technologies.

The construction of new energy efficient buildings cannot lead to a reduction of the current shares. That is why there is a vital need to focus on retrofitting and renewable integration. Retrofitting implies building envelope interventions and/or energy system replacements. However, selecting the appropriate retrofit measure is a complex task given the large range of options to select from, as well as the specific characteristics of each individual building, which influence the optimal solutions.

The retrofit process starts with collecting the necessary building information and then a building analysis follows to derive the retrofit scenario that mainly fulfills the requirements of the building owner. This building analysis process can be as simple as using some steady state calculations and energy certificates, or more complex with the use of building simulation [2] and/or optimization tools [3], [4] so as to ensure the optimality of the derived solution. Essentially, a building retrofit project can be expressed as a multi-objective optimization problem that involves various complex, heterogeneous and highly dependent building data (e.g. building characteristics, spatial information, and system characteristics) usually not available to the decision makers, such as the building owners. However, since the need for retrofitting is urgent, decision makers should be able to derive easily and fast optimal solutions for their dwellings based on already available or easily accessible building data.

The proposed methodology involves the training of a machine learning algorithm to predict optimal retrofit solutions given some easily accessible building data, such as building height, age and energy systems. The trained retrofit model can then be used to predict optimal retrofit solutions for new buildings. This process, depicted in Figure 1, implies three potential benefits. Firstly, the ability to transfer existing knowledge from previous retrofit projects to new ones. Secondly, the reduction of the computational cost in the common scenario of having to retrofit many buildings, and lastly it makes the retrofit process accessible to non-expertise building owners.

In order to collect the necessary training data set, we applied the conventional retrofit approach (Figure 1), as developed in our lab, for multiple residential buildings from the city of Zurich. Concerning the building simulation part, necessary to compute the energy profiles for different retrofit scenarios, the CESAR tool [5] was used. In order to derive the optimal set of building interventions and system replacements we applied a multi-objective optimization with the use of an Energy Hub Model [6], [7]. It is implemented as a mixed integer linear programming problem, which is able to guarantee optimality and makes the whole methodology reliable. The outcome of this process is a Pareto front solution consisting of a set of optimal retrofit scenarios. More
specifically, each optimal retrofit solution consists of the optimal energy system and renewable technology selection and its capacities, the retrofit selections as well as the corresponding costs and greenhouse gas emissions.

The first results of the application of this methodology to a case study in the city of Zurich reveal that the developed machine-learning based retrofit model is able to replicate, with considerable accuracy, the Pareto front solutions when compared to the ones from the conventional approach. This implies that there is a great potential for the decision makers to have a first insight about the optimal retrofit solutions for their buildings in a simple and fast manner.

REFERENCES
Predicting mean molecular weight and number of carbon atoms in organic PM using the normalized aliphatic C-H absorbances

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In this study, the normalized aliphatic C-H absorption profile in FT-IR spectrum is used to estimate mean number of carbon atoms, mean molecular weight, and OM/OC ratio in ambient samples of fine particulate matter for selected IMPROVE sites (Figure 1). Several atmospherically relevant laboratory standards are selected to produce a calibration set. First, principal component analysis (PCA) is applied to the spectra so that the dimensionality of data is reduced to a manageable degree. Thereafter, non-linear models are built on principal components (PCs) for estimating the mentioned properties using a full parameter selection method, which utilizes genetic algorithm (GA) to reduce the computational cost.

![Figure 1. The location of IMPROVE monitoring sites used for this study (the USA, upper pane; Alaska, lower left; South Korea, lower right); the year at which samples are taken is differentiated by color and the type of the site by point shape [1].](image)

These models are then used to predict the mean properties of organic matter (OM) in atmospheric particles. Results show that the model predictions capture the expected trend of OM chemical evolution due to photooxidation, fragmentation, etc., across seasons and site types (urban and remote) (Figures 2 and 3) represented by mean molecular weight and carbon number of organic matter (OM). The developed models estimate values for these properties –
including OM/OC (Figure 3, right) – that are within range of previous experimental and computational works that use completely different methods for estimation. The physical explanation relating the absorption profile of this relatively narrow region in mid-infrared spectrum to the molecular structure and compound composition is also investigated using classification and regression tree (CART) approach. A relatively simple model, composed of only 4 variables representing the very basic features of the absorption spectrum is used as a basis for classifying the results of the sophisticated models for interpretation.

![Figure 2](image1.png)

**Figure 2.** Kernel density estimate of molecular weight distribution (left) and carbon number (right) in urban and rural sites. MW unit: g/mol.

![Figure 3](image2.png)

**Figure 3.** Kernel density estimate of OM/OC ratio in different seasons (left). Bar chart showing OM/OC ratio calculated for each season based on samples collected in 2011 in Phoenix monitoring site using the method introduced in this study (spectrum profile) and the method introduced by Ruthenburg et. al [2] which uses mass loading data of different functional groups (right). Season name is indicated by 3 letters which are the first letters of its months’ names (DJF = winter)

REFERENCES
Over the past decade, there has been a drastic increase in the amount of data collected for environmental monitoring in both engineered and natural systems. In order to manage this vast quantity of data, dedicated tools are required; this includes implementing standard procedures for sensor validation, data importation and storage, as well as data retrieval. Furthermore, it also becomes necessary to ensure high data quality. Each of the above requirements is recognized as a challenging task. While academic research has produced a wide variety of tools for automated data quality checks, these solutions are usually very case-specific and it is hard to transfer them to other tasks. As a consequence, different research groups started to implement heterogenic practices and solutions for data management and inspection and many of their data quality checks are still performed based on visual inspection, which is time consuming and requires deep understanding of the research domain.

ADASen, Anomaly Detection for Adaptive Sensor network maintenance is an ongoing project started in July 2018 at Eawag, the Swiss Federal Institute of Aquatic Science and Technology. The main goal of the ADASen project is to address the need for guidelines on methods for automated data validation and detection of faulty data and anomalous events. To this end, we have selected a range of anomaly detection methods for benchmarking on data sets produced by six infrastructures with large-scale data collection efforts available at Eawag. More specifically, the project will address research questions regarding the utility of supervised and unsupervised machine learning models in anomaly detection for environmental systems. Supervised anomaly detection describes the setup where the data comprises of fully labelled training and test data sets and has been proven to efficiently learn appropriate representations for the input data. The disadvantage of supervised anomaly detection is that the labelling task can be very expensive and time consuming. Unsupervised learning on the other hand, does not require known target labels, yet it might not reach the same performance of supervised methods. The main question is therefore whether unsupervised methods, which can be deployed with minimal human effort, can provide an adequate level of accuracy in anomaly detection. In addition, since in the anomaly detection scenario the number of anomalous instances is only a small fraction of the full data set, we will also benchmark the performance of active learning methods as a way to efficiently obtain labelled data points and model updates. In this case, the main question is to evaluate how many data points ought to be labelled manually by querying an expert, in order to reach adequate detection performance levels.

Selected methods. The models for benchmarking can be found in Table 1. These have been identified according to their learning method; the selection
has been performed so that each supervised method matches its unsupervised analog. Furthermore, computational complexity will also be evaluated in order to investigate if linear or computational simple methods could approach the performance of computationally expensive methods in anomaly detection.

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Table 1: Identified outlier detection methods and their unsupervised analogs

**Selected infrastructures.** Critical to the benchmarking in this project is performing the labelling of normal and abnormal behavior for environmental data. Therefore, six infrastructures which produce environmental data at Eawag have been selected, in order to provide real case applications and expert knowledge for labelling. Furthermore, comparing the identified methods across a wide range of applications will give indications regarding the effective methods’ transferability to more general anomaly detection tasks.

The selected infrastructures are the platform LéXPLORE on Lake Geneva, the Eawag ponds, the field monitoring initiative Urban Water Observatory, the Water Hub, and real-time flow cytometry systems, such as the Cytobuoy and onCyt. These infrastructures present several common challenges such as the type of considered sensors and their mechanical faults, the presence of biological processes with their nonlinearity and seasonality and the presence of natural stochastic events. Targeted anomalies are faulty behaviours for engineered systems and natural event detection in natural systems.

**Impact.** The outcomes of the project will support the selected infrastructures implementing state-of-the-art tools for automatic data validation and will have impact on the time invested in sensor management. At a broad level, we foresee that the current work will inspire and bring the vision of efficient data management systems and automated data quality checks into the everyday standards of aquatic sensor-based research.

**REFERENCES**

Comparison of Machine Learning Techniques for predicting energy demand/production

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This study has been inspired by the idea of analysing the potential benefits for managing water reservoirs and hydropower plants by providing predictions of short to long term future energy demands/productions in a region or a localized area. It is assumed that the energy demand/production is mainly driven by meteorological conditions, for which forecasts will be available with different temporal and spatial resolutions. If it is possible to identify statistically significant dependency structures between meteorological variables and the energy demand/production, a regression model can be framed, which allows the prediction of the future demand/production. Although such relationships could be modelled with simple linear regression approaches, there is a great potential in improving the prediction models taking the non-linearities and non-stationarities into account, which will bias the forecast quality quite significantly at certain times of the day, weeks and months. Thus novel machine learning models have been tested in order to allow higher degrees of model complexity and to identify and to model dependency structures, which are hidden and therefore are most probably disregarded with simpler approaches. Hourly measurements of temperature, precipitation, global-radiation, wind-speed, wind-direction, air-pressure, periodicity components (intra-daily fluctuations expressed as sinus and cosine functions), as well as information of weekdays and holidays are taken as input variables for calibrating the demand model for the canton of Ticino. Additionally for the production model the information of the inflow to the hydro power plant at Verzasca has been included. The same input information necessary for the prediction and the forecasts can be derived from hydro-meteorological forecasts and could be used to predict future energy demands/productions including uncertainties. For calibrating and verifying the models the demand and production data from Swissgrid (www.swissgrid.ch) have been used.

The different machine learning techniques applied are:

- Multivariate Adaptive Regression Splines (MARS): MARS build linear relationships between predictors and a target by segmenting predictor variables. Possible non-linear relationships can be identified by integrating all segments (Friedmann, 1991).
- Quantile Regression Neural Network (QRNN): Quantile Regression (QR) models (Koenker, 2005) have been combined with Neural Networks in order to capture possible estimation problems stemming from non-linearities (Cannon, 2011).
- Quantile Regression Forest: Random forest is a tree-based algorithm which involves building several trees (decision trees) and combining their output to improve generalization ability of the model. The idea behind quantile regression forests: instead of recording the mean value of response variables in each tree leaf in the forest, all observed responses in the leaf are stored (Meinshausen, 2006).
Deep Learning: This method, which becomes increasingly popular for data sciences, uses a cascade of multiple layers of nonlinear processing units (Schmidhuber, 2015). In order to allow the estimation of uncertainties the QR loss function has been implemented. The results of this comparison are shown in Fig. 1 for the coefficient of determination (also known as Nash Sutcliffe efficiency) for the demand and production model. The outcome of this study highlights the possible improvements of ML techniques in comparison to linear approaches and their potential for estimating predictive uncertainties.

![Coefficient of Determination](image)

Figure 1. Coefficient of determination for the demand model (top) and for the production model (bottom). In the testing mode (shown in red) the MARS model shows for both cases the best results. Additionally the results of two model combination methods (BMA and NGR) are shown.

REFERENCES
Evaluating the potential of machine learning algorithms to develop a landscape typology

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Detecting and describing land use/land cover patterns has a long tradition in Geography. While new data mining technologies open the path to new approaches, current land-use changes, such as e.g. in peri-urban areas, generate new patterns, which pose new challenges for categorization. Machine learning algorithms have for example been applied in remote sensing to classify satellite images focusing on processing hyperspectral information and delivering a high accuracy. It is however not trivial to distinguish and compare the various data mining approaches as they are applied in many different fields. In general, we can distinguish between supervised and unsupervised methods, where decision-trees and random forests are examples for supervised and K-Means clustering and self-organizing maps for unsupervised. Many other algorithms and methods can be applied both supervised and unsupervised or even semi-supervised with a very small training sample. Another categorization distinguishes between parametric and non-parametric approaches and also between pixel- and object-based classifications. It can be stated that machine learning algorithms usually perform better than conventional approaches such as K-Means regarding the accuracy yet the also require more expertise and more time to train networks for example.

For our case study, we want to describe the landscape of the Canton of Schwyz using 28 classes as suggested by Stiftung Landschaftsschutz broadly covering forest (n=4) and agricultural areas (n=6), water (n=2), rocks (n=1), settlement (n=8), infrastructure (n=3) and cultural landscapes (n=4). These landscape types are characterized by fuzzy boundaries. We perform our analysis based on a set of available spatial data including elevation and land cover, population density etc. The goal of the study is to provide a spatially explicit description of the landscape types in the Canton of Schwyz and to explore if computer-based analysis provides other classes than the 28 described before. This offers a great opportunity to evaluate the potential of machine learning algorithms and compare them to conventional approaches. In particular, we compare an indicator-based GIS fuzzy logic approach to K-Means clustering, convolutional neural networks and self-organizing maps for unsupervised approaches and random forest as well as support vector machine for supervised approaches. The results are finally validated with an expert-based assessment.
Identifying shallow landslides on Swiss alpine grasslands using machine learning

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Shallow landslides occur on alpine grassland areas due to the extreme prevailing topography, climate conditions and/or land use and management. Aside from geological, morphological and anthropogenic factors making certain regions more susceptible, shallow landslides are mainly triggered by prolonged precipitation events, snow gliding and avalanches. The changes in our climate are predicted to have a pronounced impact on the alpine regions causing not only higher temperatures but also a change in frequency and intensity of precipitation events as well as strongly altered snow dynamics (CH2011, 2011; Frei et al. 2018). In combination with changing land-use practices, an increase in shallow landslides is expected in the future (Meusburger & Alewell, 2014).

For this reason it is important to understand the temporal changes and spatial distributions of shallow landslides. We use high-resolution aerial images taken between 2000 and 2016 to identify shallow landslide areas in the Urseren Valley (Canton Uri). We compare the results of Object-based image analysis (OBIA) to the results of deep learning algorithms.

OBIA is a state of the art, semi-automatic method commonly applied in the field of geoscience when mapping visible elements on remotely sensed images. The semi-automated workflow profits from the high spatial resolution of the orthophotos (0.5 - 0.25m) and takes into account spectral, spatial, contextual and textural image properties as well as accompanying information gained from digital elevation models. However, the method is labour intensive and manual corrections are required. Expert knowledge is therefore a necessity at every working step to produce reliable results.

For the deep learning approach, we use convolutional neural networks with the ResNet-152 architecture as well as fully-convolutional networks with the U-Net architecture. The algorithms are trained on a dataset consisting of manually mapped shallow landslides. Convolutional neural networks achieve remarkable results in object recognition tasks (He et al. 2016; Ronneberger et al. 2015) and can be used to identify the relevant properties or features to distinguish shallow landslides from other areas. Leveraging the aforementioned resources, the manual labour and required expert knowledge in identifying shallow landslides can be reduced.

While OBIA produces results with very precise boundary delimitations of the shallow landslides, the results of the deep learning method consist of predictions yielding probabilities of a pixel belonging to a shallow landslide. This probability threshold needs further fine-tuning for more accurate delimitations.
By analysing a time series consisting of several images, we can identify growing and recovering erosion sites. For the entire valley, we confirm an increasing trend in eroded areas. Spatial analysis reveals a high dynamic within the catchment, highlighting areas especially prone to shallow landslides.

Future goals of the project include mapping shallow landslides in other study areas and eventually increasing the scale to the alpine region. Because we are interested in all occurring types of erosion processes, our aim is to not only map shallow landslides, but also sheet erosion, management degradation and livestock trails. While this has already been achieved using OBIA, we are working towards this goal with deep learning methods.

![Fig. 1 Submaps of the Urseren Valley (year 2000) showing manually mapped landslides (yellow) results of the OBIA method (red) and results of the deep learning method (blue). The blue delimitation shows the probability threshold for 50%.

REFERENCES


Impacts of future mobility on outdoor recreation demand in Switzerland

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Recreational patterns are dependent on the supply of suitable landscapes and infrastructures for recreation. At the same time, recreation demand is highly dependent on mobility. Decarbonization efforts like the electrification of transportation, but also technological inventions like autonomous driving (AV) will impact mobility and ultimately the accessibility of recreational landscapes in Switzerland. Future changes in mobility related to modes and costs will thus influence the spatially explicit pattern of recreational demand, while changes in the landscape due to e.g. land use change will change the supply. Simultaneously, the Swiss population is projected to grow by about two million inhabitants until 2050, which will substantially increase mobility. All those developments will have effects on the landscape and its services, from their supply to their demand and make Switzerland a suitable case study to investigate its impacts on future outdoor recreation demand. Our goal is to determine which landscape and mobility factors are important to estimate preferred locations for outdoor recreation day trips on a municipality scale. Further, we want to estimate how future technological inventions, like AVs, impact the accessibility of Swiss municipalities and in turn how this impacts the spatially explicit demand for outdoor recreation. To do so, we use Machine Learning (ML) techniques, namely random forest and gradient boosting for classification and regression purposes. In a first step we use classification methods to determine variable importance of different landscape- and mobility factors for destination choice of outdoor recreation day trips. In a second step we use ML algorithms that can provide multivariate regression to predict how future accessibilities might impact the allocation and demand for outdoor recreation activities.
Figure 1. Variable importance for destination choice of outdoor recreation day trips using gradient boosting.
Incorporating Deep Bagging Ensemble Method as a Surrogate Model for Simulating Hyper-Concentrated Sediment-Laden Flows

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Macroscale and mesoscale simulations of hyper-concentrated sediment-laden flows rely on robust couplings of the Reynolds-Averaged Navier-Stokes equations in conjunction with the shear-stress transport $k$-$\omega$ turbulence model. Also other closure laws for modeling the momentum transfer between the fluid and dispersed particles phase are applied. A numerical framework is developed to couple and solve the various algebraic and Partial Differential Equations (PDEs) based on the Euler-Euler method. A 3D high-fidelity simulation of sediment transport based on two-phase modeling approaches (i.e., Euler-Lagrange and Euler-Euler models) can be computationally prohibitive. A deep bagging ensemble method based on Regression Tree and Model Tree approaches is incorporated into the coupling procedure of the ten PDEs involved in the problem to improve computational efficiency. The performance of the surrogate model was also compared with two traditional surrogate models, i.e., Artificial Neural Network and Kriging meta-modeling. The CFD and surrogate-based models were validated for horizontal transport of cuttings created during an offshore drilling process. In particular, during the hole cleaning procedure, it was challenging to simulate the two-phase flow of the cuttings and non-Newtonian drilling fluid due to the complex interactions between fluid-particle, particle-particle, and particle-wall. Therefore, a four way coupling method was utilized to consider the interdependency of motions between two phases. The values of sediment and fluid concentrations, the velocities of both phases, and pressure loss estimated by the surrogate models were compared with the results of CFD simulations and experimental investigations. The results indicate that the proposed hybrid CFD-surrogate model is capable of providing physical insights into the dynamics of cutting transport, and the resulting computational observations are in line with the relevant CFD simulations and experimental investigations.
Figure 1. General procedure of coupling and developing the surrogate model.

Figure 2. Comparisons between results of CFD and surrogate-based model.

REFERENCES
Joint Data Assimilation and Parameter Optimization in on-line Groundwater Modelling using Nested Particle Filters

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The increasing availability of wireless sensor networks encourages the development of self-optimizing groundwater models. Based on a sequential Bayesian framework, such approaches may not only assimilate data to correct their own predictive shortcomings, but also optimize their own model parameters.

In hydrogeology, this optimization is particularly challenging: Numerical models generally involve vast numbers of unknown variables, while seeking compliance with a prescribed geological patterns limits the realm of viable solutions. As a consequence, the resulting probability distribution is both high-dimensional and complex, precluding an analytic solution. Instead, it is common practice to employ ensemble-based approaches. The Ensemble Kalman Filter (EnKF) has proven relatively robust in high-dimensional problems, but its simplifying assumptions are ill-suited for the pursuit of realistic geology. Particle filters could support the necessary complexity, but are generally disregarded in high-dimensional systems due to their intrinsic ‘curse of dimensionality’.

However, a self-imposed restriction to a subset of parameter space – for example the subset corresponding to all parameter fields featuring the desired geology – can reduce the effective dimensionality substantially. Such an approach may render a particle filter implementation viable, but requires a way to draw random samples from (and efficiently navigate within) the chosen subset. Here, we present an implementation of a nested particle filter for sequential data assimilation and parameter optimization, using techniques like SMC² or hyperparameterization to ensure conformance with a prescribed geology during the optimization process.
Using machine learning to post-process numerical weather forecasts

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Numerical Weather Predictions (NWP) are at the heart of the ongoing advance in weather forecasting. Such physics-based models, however, are not free of errors due to the finite spatio-temporal resolution, imperfect model formulations, and uncertainties in initial and boundary conditions. An empirical adjustment of NWP output referred to as post-processing may therefore be used to enhance forecast quality and usability. Here we analyse to what extent modern machine learning and especially deep learning techniques may improve on traditional post-processing approaches resulting in more accurate weather forecasts. Specifically, we apply a neural network to correct hourly 2m-temperature forecasts of the COSMO-1 forecasting system, a high-resolution limited-area NWP system for Switzerland.

The neural network is trained against hourly temperature observations at 144 stations in Switzerland (see Figure 1). NWP forecasts with COSMO-1 from October 2015 to February 2018 are used. The neural network takes hourly values from 14 time-variant meteorological parameters from COSMO-1 (including a forecast of temperature, the target variable) around the target station as input. This is complemented with predictors describing the model grid (geographical coordinates, altitude, soil type, etc.), station location and temporal specifics (time of day, day of year, forecast initialization time). COSMO-1 is initialized every 3 hours and runs for 33 hours, the neural network is fitted separately for each forecast lead time. Thus, the full dataset consists of more than 900'000 cases per forecast lead time. In each iteration, we randomly draw 10% of the days in blocks of five days for the test data and use the remaining days for the training of the neural network. To avoid information leakage into the test set, we buffer each block of test days by removing the adjacent three days of forecasts from the training set.

The neural network significantly outperforms statistical bias-correction baselines. Predictions from the neural network have smaller root-mean-squared error (RMSE) than the bias-corrected COSMO-1 temperature forecasts at all stations (Figure 1). Please also note, that the neural network can be used to derive corrected NWP forecasts at any location, not only at station locations, whereas this is not the case for the bias correction without additional interpolation.
Figure 1: Root mean squared error (RMSE) skill score of the temperature prediction from the neural network against bias-corrected COSMO-1 temperature forecasts. The bias has been estimated separately at each station and for each hour of the day and month of the year (Figure from Weingart, 2018).

To investigate how well the neural network generalizes to unobserved locations, we also discard blocks of 5 randomly drawn stations from the training set. The evaluation is then only carried out for stations and times that have not been part of the training dataset. Using this spatio-temporal cross-validation, the neural network approach is demonstrated to generalize well to unobserved locations with RMSE comparable to the bias-corrected COSMO-1 forecasts at the respective stations (but without using said stations in the training set). This allows to use the neural network to produce calibrated forecasts at user-specific locations.

To better understand the inner workings of the model and thereby gain trust in the predictions, we explore techniques from model interpretation, namely feature interpretation and data valuation. Feature interpretation is used to estimate the importance and impact of the different predictors in correcting the NWP forecast. The primary impacts align with meteorological process understanding. Data valuation is used to reveal training points that are most influential in reducing forecast error. This first attempt at using machine learning to correct NWP forecasts illustrates the potential of the approach. Avenues for future development of the approach to further enhance forecast information are the explicit simulation of forecast uncertainty, the representation of temporal dependence of forecast errors and incorporation of large-scale predictors.

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Counting the uncountable: deep semantic density estimation from Space

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We propose a new method to count objects of specific categories that are significantly smaller than the ground sampling distance of a satellite image. This task is hard due to the cluttered nature of scenes where different object categories occur. Target objects can be partially occluded, vary in appearance within the same class and look alike to different categories. Sentinel-2 satellite configuration provides since 2015 multi-spectral images of up to 10 meters ground sampling distance (GSD). For such dataset, traditional object detection with tools like Faster R-CNN (Ren et al., 2017) is infeasible due to the small size of objects with respect to the pixel size, we cast object counting as a density estimation problem.

To distinguish objects of different classes, our approach combines density estimation with semantic segmentation in an end-to-end learnable convolutional neural network (CNN) to count objects of 1/3 the size of the GSD. We compare our proposed architecture with state-of-the-art semantic segmentation methods for terrestrial images that use among other ideas atrous convolutions to prevent lowering the resolution of the learned features keeping a large receptive field (Chen et al. 2017).

Experiments on four different objects show that deep semantic density estimation can robustly count objects of various classes in cluttered scenes. For the semantic segmentation task of Olive Trees we obtained Intersection over Union of 0.86 and precision of 0.90 in our test set. See Figure 1 for a visualization. Experiments with our Tree objects (Olives, Coconuts and Palms) show the importance of infrared bands in the prediction. In contrast, Cars benefited mostly from the high spatial resolution of the RGB bands. Our Experiments also suggest that we need specific CNN architectures in remote sensing instead of blindly applying existing ones from computer vision.
Figure 1. Predicted density estimation of coconuts overlaid to a greyscale version of the aerial image. Densities below 0.5 were trimmed for visualization.

REFERENCES
Assessing optimal specifications for crop classification in Switzerland using uncalibrated UAV data

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The world population is projected to grow to 9.6 billion people by 2050 (Gerland et al. 2014). Therefore, there is a need to increase the global food production and current information on crops, both at global and local scale. Detailed land cover classification of agricultural areas are important for information before end of season (Immitzer et al. 2016), e.g. for forecasting of water needs (Azar et al. 2016). These challenges can be tackled with various remote sensing technologies (Atzberger 2013).

To classify the small structured agricultural landscape in the Swiss Midlands very high resolution (VHR) data are needed (Böhler et al. 2018). Most sensors that acquire VHR data are limited to only a few spectral bands. Incorporating textural information is one of the most promising possibilities to improve classification of VHR data (Khatami et al. 2016).

In our study, we used uncalibrated image data sets consisting of near infrared (NIR), red, green and blue (RGB) bands acquired with an unmanned aerial vehicle (UAV) at multiple dates. With additional textural and morphological features we trained a random forest (RF) classifier to find the most promising spectral and spatial resolutions, as well as the most promising acquisition dates for the classification of five different crop classes (cereal, grass, maize, rapeseed, sugar beet).

The study area is located next to Mönchaltorf, situated in the Swiss Plateau within the Canton of Zurich (47.312 °N, 8.733 °E), Switzerland. The agricultural area is mainly covered by grassland and cropland. The cereal class comprises winter wheat, winter barley and spelt, and the grassland class consists of all kinds and stages of perennial and annual grass or clover.

For the data acquisition, an eBee UAV (Sensefly, Cheseaux-Lausanne, Switzerland) was flown in four consecutive flights between 11:00-14:00 local time at eleven dates between 05 May and 29 September 2015. The study area of 170 ha was split into two overlapping subareas, whereby each area was recorded once with a consumer graded Canon IXSUS 125HS for RGB data, and once with a modified camera of the same type for NIR-G-B data. The UAV was operated at a flight altitude of 150 m above ground, a lateral image overlap of 60% and a longitudinal overlap of 75%, resulting in a total of 1092 single images that were subsequently processed in Pix4D Mapper Pix4D SA, Lausanne, Switzerland). Image data mosaics with a spatial resolution of 0.05 m were generated for all eleven flight dates.

The classification and accuracy assessment was performed in six steps. First of all, the data set was resampled to 0.5 m, 1 m, and 2 m spatial resolution. In a second step, specific features were extracted. We calculated the statistical features mean, standard deviation, range and entropy based on a disk shaped structuring element (SE) of a pixel size of 3, 5, 7, and 9. Furthermore, the morphological operations dilatation/erosion, opening/closing, opening/closing top hat, opening/closing by reconstruction, and opening/closing by reconstruction top hat were computed (Fauvel et al. 2013), applying the same
SE shape and sizes to all data sets from all dates. These feature stacks were split into different spectral and textural settings with different amount of acquisition dates.

In the third step, we split the data set into train, validate and test samples to examine a 3-fold cross validation (Lyons et al. 2018). Therefore, we assigned entire fields of one third of each class to one of the splits. All six possible permutations were executed.

Fourthly, we trained the RF classifier with the samples in the training split and identified the best amount of trees using the data points in the validation split. Then, we trained the final RF model with both the data samples from the training and the validation split. The test data set was classified with this final model for a pixel-based land cover map.

Next, the values in a single field from the pixel-based classification were aggregated to a parcel-based classification by assigning the most frequent crop class to the whole parcel.

In a last step, we derived the confusion matrix for each fold from the classified test data set to calculate the overall accuracy, kappa coefficient, as well as user and producer accuracy. From each of these accuracy metrics we calculated the average of all six folds, resulting in the overall accuracy (OA), kappa coefficient, average accuracy (AA) and average reliability (AR).

We conclude on the best setting for crop classification in our study area using uncalibrated UAV data, with regard to spectral, spatial, temporal, textural/morphological, and size of the SE criteria.

REFERENCES


Extracting Buildings from Historical Maps with Convolutional Neural Networks

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Historical geodata is of interest for a multitude of different disciplines, including ecology (renaturation), urban planning (buildings), and even linguistics (toponymy), to name a few. However, features such as rivers, buildings and roads are “locked up” in the scanned images. Extracting them typically requires tediously hand-crafting image-analysis algorithms for each feature type of interest (Leyk et al. 2006).

Recent advances in machine learning, specifically in the field of fully convolutional neural networks (FCNNs), represent an alternative to this approach. These architectures are able to learn the required processing steps simply by providing them with an appropriate training dataset.

Such a training dataset has been built for the buildings layer from the Siegfried map, a map series covering the whole of Switzerland for a period between 1870 until 1949 and comprising more than 4000 map sheets. At first, buildings have been manually vectorized for six randomly selected sheets. Rasterized representations of these buildings along with the original sheets were subdivided into tiles to fit into GPU memory. In addition, padding has been added to the original map tiles to provide contextual information required by a FCNN to correctly detect features at the border areas. The tiling scheme is illustrated in Figure 1.

![Figure 1](image)

Figure 1. A: Tiling scheme for a map sheet. B: Input-tile with padding. C: Output-tile with pixel-based labels for buildings.

Several architectures are being explored to carry out the segmentation task: a simple encoder-decoder FCNN (Wick & Puppe 2018), a stacked FCNN (Castrejón et al. 2017) and a U-Net FCNN (Ronneberger et al. 2015). At the time of writing, an ensemble of U-Nets achieves the best results of ~94% for both, precision and recall. The resulting pixel-based predictions are being fed
into a tailor-made vectorization module, which produces an idealized vector representation of each building. The vector dataset is then being manually corrected to serve two purposes. First, it will be published in the geodata4edu.ch geoportal to be accessible by other researchers and, second, is being rasterized to serve as additional training data for the FCNNs. The results of the workflow are illustrated in Figure 2.

Figure 2. A: Pixel-based predictions. B: Vectorization based on predictions. C: Manually corrected vectorization.

Experiments showed that this approach works particularly well for flat areas with many small buildings. False positives are mainly encountered for some labels and in mountainous areas depicting hachures. In addition, the vectorization module needs to be adapted to perform better for larger buildings as for example encountered in city centers.

Hence, it is aimed to further improve the workflow to provide a comprehensive high-quality vectorization of the buildings of the Siegfried map and to subsequently apply this approach to other feature types and map series.

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Nowcasting Foehn Wind Events Using the AdaBoost Machine Learning Algorithm

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The south foehn is a characteristic downslope windstorm in the valleys of the northern Alps in Europe that demands reliable forecasts because of its substantial economic and societal impacts. Traditionally, a foehn is predicted based on pressure differences and tendencies across the Alpine ridge. Here, a new objective method for foehn prediction is proposed based on a machine learning algorithm (called AdaBoost, short for adaptive boosting). Three years (2000–02) of hourly simulations of the Consortium for Small-Scale Modeling’s (COSMO) numerical weather prediction (NWP) model and corresponding foehn wind observations are used to train the algorithm to distinguish between foehn and nonfoehn events. The predictors (133 in total) are subjectively extracted from the 7-km COSMO reanalysis dataset based on the main characteristics of foehn flows. The performance of the algorithm is then assessed with a validation dataset based on a contingency table that concisely summarizes the cooccurrence of observed and predicted (non)foehn events. The main performance measures are probability of detection (88.2%), probability of false detection (2.9%), missing rate (11.8%), correct alarm ratio (66.2%), false alarm ratio (33.8%), and missed alarm ratio (0.8%). To gain insight into the prediction model, the relevance of the single predictors is determined, resulting in a predominance of pressure differences across the Alpine ridge (i.e., similar to the traditional methods) and wind speeds at the foehn stations. The predominance of pressure-related predictors is further established in a sensitivity experiment where ~2500 predictors are objectively incorporated into the prediction model using the AdaBoost algorithm. The performance is very similar to the run with the subjectively determined predictors.

REFERENCES
Data-Driven Interpolation of Urban Temperature

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Machine Learning methods require large amounts of data for training. In today’s increasingly digitized world, novel kinds of data are more and more ubiquitously available. An example is data generated by private weather stations (PWS), which are used by individuals to measure temperature and other weather variables on their private property or balcony. Several providers allow to access to this data by application programming interfaces (API). Despite the uncertainties and risks associated with PWS data, the increasing ubiquity of data generated by cheap sensors makes it desirable to make use of it for scientific practices. The use of PWS data seems promising for at least two reasons. First, to increase the spatio-temporal measurement coverage of variables that can only be measured on coarser resolution. Such as temperature measurements following the standard of the world meteorological organization (WMO). Second, to use it as input data for statistical data-driven approaches, such as machine learning, which can complement or replace process-based modelling, as for instance urban heat models based on numerical weather predictions (see GEO-NET Umweltconsulting GmbH 2018).

In my talk, I will present results from a case study demonstrating the feasibility of using PWS data to increase the spatial measurement coverage. I further discuss if and to what extent PWS data can be used to spatially interpolate temperature values with machine learning. The case study is based on hourly temperature data of 26 non-standardized PWS in Zurich in July and August 2018. Using a random forest algorithm, which has been successfully applied to interpolate environmental variables (see Li et al. 2011), I predict the temperature at 14:00 and at 04:00 at the individual stations (see figure 1) for the time period under consideration. The predictors are selected based on literature on urban climatology and include soil type, weather, altitude and other factors (see Oke 1982). In a next step, I construct a machine learning model that predicts the temperature at any location in Zurich only using data that is available at a high resolution. The model is evaluated concerning its performance in predicting temperature at the location of the PWS stations and validated using reference stations from the measurement network from MeteoSwiss. Confidence in the interpolation results is further assessed by referring to scientific background knowledge.

In conclusion, I show that PWS data can help to (i) provide additional insights into the spatial distribution of temperature relevant for urban climate adaptation and (ii) that it is in practice possible to use machine learning to construct data-driven high-resolution spatial interpolation models for urban temperature.
However, further research is needed to increase the performance and accuracy and to increase confidence in machine learning based interpolation models.

Figure 1. Preliminary results of machine learning model. The figure shows the prediction of trained random forest algorithm versus observation for PWS for test data at 14:00. Next steps include reducing the bias and increase the accuracy of the model by more advanced feature engineering. Subsequent the model is used to predict the temperature values at different locations and compared with reference temperature data to assess its validity.

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**DATALAKES - data platform and stochastic Bayesian forecasting for Swiss lakes using supercomputers**

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DATALAKES is a multi-disciplinary and multi-institutional project involving Swiss Data Science Center, Eawag, ETH Zurich, and EPF Lausanne.

As Château d’Eau of Europe, Switzerland requires a scientifically grounded lake management. Lakes are often misrepresented uniformly in blue, hiding rich spatio-temporal dynamics (see Figure 1). Past researches have focused on vertical fluxes and structures. Today’s additional challenge is to quantify horizontal transport and mixing processes influencing greenhouse gases emission (carbon and methane), oxygen depletion, harmful algae bloom, among many other ecologically relevant phenomena. New instrumentation, such as in situ observation platforms, remote sensing and computational resources enable the investigation of the temporal evolution of the environment’s spatial heterogeneity. Yet, today, environmental scientists still rarely manage to handle in a global integrated way these data for their studies. A key prerequisite are 3D numerical simulations, capable of delivering forecast with uncertainties. Yet, required in situ observations, remote sensing and computational resources are under-utilized.

![Figure 1. Lakes as dynamic ecosystem. The integration of remote sensing chlorophyll-a data together with currents from three-dimensional hydrodynamic model provide a new tool to understand the ecosystem. Here we specifically show the spatial variability in the algae concentration resulting from the lake circulation.](image-url)
The first milestone of the DATALAKES project is to create a centralized data platform (see Figure 2) including in situ acquisition, storage, curation, patching, visualization, and extraction frameworks, together with an accessible online interface for visualization of historical data, future predictions, and allow user friendly online data extraction. Besides the end-to-end data platform, data mining techniques will be applied to analyze patterns and improve parameterization of deductive models, for instance, to provide a data-driven model of input processes (skin-to-bulk). The second milestone focuses on development of a scalable compute cluster enabled framework for predictive lake simulations that allow us to calibrate and predict lake dynamics. High performance computing will allow detailed quantification of uncertainties using Bayesian inference and modern Markov Chain Monte Carlo methods with multi-level variance reduction. The third milestone consists in demonstrating the benefit of data science and of the data platform for environmental lake study.

Figure 2. DATALAKES consists of 3 interconnected parts: data (WP1), model (WP2), product scientific validation and use (WP3).

The DATALAKES project will provide a new data platform for the processing of massive amounts of hydrological and ecological data that will empower scientists, stakeholders, and citizens to view lakes as a dynamic system. The system will be first validated for Lake Geneva. This step is a prerequisite for future initiation of large interdisciplinary work. We envision a platform for monitoring lakes dynamics, including reliable weekly forecasts of three-dimensional lake ecological and physical states with hourly time series and associated uncertainties. Exploration of the dataset (e.g. machine learning, theory-based data science etc.) will allow more accurate water constituents budgets, including greenhouse gas emission, oxygen balance, harmful algae bloom, and fates of pollutants. We also hope to incite new collaborations between scientists, stakeholders, and citizens, and aim to further improve scientifically grounded management of water resources in Switzerland.
Bayesian Inference for Stochastic Models

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Bayesian statistics allows us to express domain knowledge about model parameters as a probability distribution and, by means of Bayes' theorem, to update this knowledge using measured data. It is thus a perfect example of interpretable data science and a proven tool for making probabilistic predictions. It forces us to conceptualize our knowledge about the system, the measurement process and the dominant sources of uncertainty in the form of a stochastic model for the measured data.

Bayesian inference is almost never consistently applied in connection with non-trivial stochastic models, because it is computationally extremely expensive. In recent years, sophisticated and scalable algorithms have emerged, which have the potential of making Bayesian inference for complex stochastic models feasible, even for large data sets. It is the primary goal of this SDSC project to explore the potential of these algorithms and to make them accessible to researchers from various domains.

The Bayesian inference algorithms we apply fall into two classes: Approximate Bayesian Computation (ABC) and Hamiltonian Monte Carlo (HMC). While the former class is technically easy to apply but yields only approximate results, the latter requires much more tailoring to a particular problem, but has the potential of yielding exact results. The basic idea behind ABC is to compress data into a few so-called summary statistics and accept or reject model parameters depending on how well associated model outputs (pseudo-data generated via model forward simulation) comply with the (real) data in terms of these statistics [1]. Today, ABC is used in many domains, but little is known as to (i) how the summary statistics should be chosen and (ii) how accurate the inference results are. In this project, we’re using machine learning tools for the generation of summary statistics and compare the inference results to exact results generated with HMC. The basic idea behind HMC is to re-interpret the Bayesian posterior as the partition function of an interacting particle system and use the tools of Statistical Physics to calculate it efficiently [2].

We will show first results from an application in solar physics, where we’re trying to infer parameters of the solar dynamo from time-series of radionuclides (recorded in tree rings and ice cores), which are a proxy for solar activity.

REFERENCES


Automated Detection of lunar Rockfalls using a Convolutional Neural Network

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This study implements a novel approach to automatically detect and classify rockfalls in Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) images using a single-stage dense object detector (RetinaNet) [1] [2]. The convolutional neural network has been trained with a data set of 2,932 original rockfall images. In order to avoid overfitting, the initial training dataset has been augmented during training using random image rotation, scaling, and flipping. Testing images have been labelled by human operators and have been used for RetinaNet performance evaluation. Testing shows that RetinaNet is capable to reach recall values between 0.98 and 0.39, precision values between 1 and 0.25, and average precisions (AP) ranging from 0.89 to 0.69, depending on the used confidence threshold and Intersection-over-Union values. Mean processing time of a single NAC image in RetinaNet is around 10 seconds using a GeForce GTX 1080 Ti and GeForce Titan Xp, which is orders of magnitudes faster than a human operator. The processing speed allows to efficiently exploit the currently available NAC data stack with more than 1 million images in a reasonable timeframe [3]. The combination of speed and detection performance can be used to produce lunar rockfall distribution maps on large spatial scales for utilization by the scientific and engineering community. A similar machine learning-based approach could be adopted for Earth or other planets to handle the ever increasing wealth of space-borne remote sensing data.

The workflow is entirely based on open source software. The developed tool will potentially be accessible online on the Moon Trek platform that is being developed by NASA JPL at Caltech, USA [4].
Figure 1. Example of RetinaNet detections (white rectangles, TP) in testing patch, the trained network is able to detect features that are situated directly at the edge of the patched NAC images (e.g. top of fig.). Yellow bboxes indicate rockfalls that have not been recognized by the network (false negatives, FN). Red background colors indicate high terrain, blue background colors represent low terrain, detail taken from M113242798RC_pyr. Double detections occur locally and require an application of post-processing algorithms, such as NMS (not performed here for visualization purposes). North is up.

REFERENCES
The WSL Environmental Data Portal EnviDat


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The Swiss Federal Research Institute WSL develops and maintains EnviDat, an overarching environmental data portal for facilitating the access to research data. EnviDat is designed to publish, connect and search existing data, while data curation and quality control remain with the experts.

WSL has a long tradition in environmental data collection, operating a comprehensive network that includes more than six thousand observation sites for studying the terrestrial environment. The environmental data collected by WSL researchers include long-term monitoring data sets spanning over 130 years that cover most of Switzerland.

The integration of existing datasets in EnviDat, currently mainly originating from WSL, is accompanied by their documentation with appropriate metadata. Formal publication of research data with proper citation information and Digital Object Identifiers (DOIs) is supported and encouraged. Extending this service beyond WSL to, e.g., other institutions within the ETH Domain is a mid- to long-term goal of EnviDat.

EnviDat similarly supports WSL data producers with the registration, documentation, storage and publication of their data sets, and data users worldwide with an efficient search and retrieval of a wide range of heterogeneous data sets from the environmental domain. This is schematically depicted in the EnviDat conceptual framework summarized in Figure 1 (Iosifescu Enescu et al., 2018).

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Figure 1. The EnviDat Concept (Iosifescu Enescu et al., 2018)
Innovative EnviDat features include (a) a flexible, three-layer metadata schema, (b) an additive data discovery model that integrates geospatial technologies and (c) a DataCRediT mechanism designed for specifying data authorship. A user-friendly access to data through EnviDat ultimately fosters advances in environmental science, since long-term data sets are particularly valuable towards obtaining an integrated view of the Earth System.

Further advances of the EnviDat system are currently being explored. Integrating innovative machine learning approaches with the more classical data portal functionalities could open up a range of interesting options and opportunities for the EnviDat portal of the future. Machine learning, and especially its subfield of Deep Learning, might be useful for parsing the data and enhancing the metadata records with additional information without human effort. Furthermore, the management of environmental monitoring data represents another possible area that can profit from machine learning, e.g., with potential applications in data anomaly detection or automatic data mappings.

The availability of rich environmental data in an accessible and effective system such as EnviDat that is complemented by machine learning approaches, opens unprecedented opportunities for advancing environmental science and has the potential to further stimulate cross-disciplinary research.

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Remote Plant Stress Phenotyping using Spatio-Temporal Spectral Data

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We present a generic framework for remote plant stress phenotyping that consists of a dataset with spatio-temporal spectral data following sugarbeet crop growth under optimal, drought, low and surplus nitrogen fertilization, and weed stress conditions, along with a machine learning based methodology for systematically inferring these stress conditions from the remotely measured data. The dataset contains biweekly color images, infra-red stereo image pairs and hyperspectral camera images along with applied treatment parameters and environmental conditions like temperature and humidity, collected over two months. We accompany the dataset with derived phenotypic parameters such as canopy cover, height, hyperspectral reflectance and vegetation indices along with a spectral 3D reconstruction of the plants to serve as a benchmark. Additionally, we provide fresh and dry weight measurements for both the above (canopy) and below (beet) ground biomass at the end of the growing period to serve as indicators of expected yield. We use the phenotypic parameters to evaluate 8 different classification approaches for detecting water, nitrogen and weed stress. A support vector machine based classifier performed the best with a mean cross validation accuracy of ~ 93, 76 and 83% for drought, nitrogen and weed stress level classification respectively. We also show that the multi-modal approach taken significantly improves classifier performance over using a single modality.

Figure 1. Framework overview. This work presents a dataset, image preprocessing and classification algorithms along with ground truth parameters for monitoring of plant stress necessary to build and benchmark machine learning based models for the prediction of stress occurrence based purely on multi-modal remote sensing data.
Our project compares leaf coverage estimation techniques using machine learning and thresholding algorithms on a set of soybean images captured in a field under natural illumination conditions. Using Amazon Mechanical Turk for image segmentation, we developed a labeled training data set of 285 early growth soybean plant images. These training masks and images were used to train and evaluate three segmentation techniques: thresholding, random forest classifiers, and a deep convolutional neural network. The color based thresholding performed the best on our dataset with a mean intersection over the union score of 87.52% while the random forest and the deep learning model scored 51.24% and 78.65% respectively.
Feature-based approaches for geomonitoring using terrestrial laser scanning point clouds

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Areal-based deformation monitoring based on point clouds can be a very valuable alternative to the established point-based monitoring methods. However, the corresponding points in point clouds of two or more epochs are not readily given. The established deformation analysis approaches for point clouds (e.g. cloud to cloud (C2C) method) do not expose the true 3D changes in parts that actually did change. The correspondences between points are either established by selecting the respective nearest point in the other epoch, or the analysis yields the distance between the surfaces locally approximating the point clouds. This can lead to a wrong quantification of the actual displacements and to apparent deformations.

We recently addressed this challenge by proposing feature-based methods for the identification of corresponding points in point clouds of two or more epochs (Gojcic et al. 2018a). Our low dimensional learned local feature descriptor is trained on indoor point clouds derived from RGB-D scene reconstructions, but can seamlessly generalize to outdoor scenes derived from true laser scans (Gojcic et al. 2018b). The results of the feature-based correspondence search is a dense 3D displacement vector field. However, we found that this vector field might contain a high percentage of outliers, often with a systematic spatial distribution and occurring within separated smaller patches of the point cloud.

Therefore, we propose to smooth out the derived 3D displacement vector field by formulating the estimation of the dense scene flow in point clouds as an optimization problem with a local rigid body motion prior, following the ground assumption of the local feature descriptors that the objects of interest are locally not deformed.

Figure 1: Mechanical rockfall simulator. Blue circles in the middle figure denote the location of the mini prisms used to establish the ground truth. Right: point cloud of the first epoch.
We evaluate the proposed method in a controlled environment using a mechanical rockfall simulator (Figure 1), which enables vertical displacement and tilting of its movable part (c.f. red colored points in Figure 1 right). We scan the simulator in two epochs using a Leica MS50 and establish the ground truth using the total station measurements to mini prisms mounted on the front part of the simulator. Between the epochs, the moving part of the simulator was displaced for about 30 mm. We compare the results of our method before (FBC) and after smoothing (FBC + smoothing) to the C2C method. Figure 2 shows the deviations of the derived displacement vector fields from the ground truth. Whereas the C2C method underestimates the displacements of individual points and in fact regards the whole scene as stable, the FBC yields correct, nonetheless very noisy, correspondences for the majority of the scene. After the smoothing step, the deviation from the ground truth for approximately 90% of the points lies below the median resolution of the point cloud.

The results in the controlled environment point at the applicability of the method on the challenging outdoor scenes. Future work will include evaluation on the method on the real geomonitoring data and development of a rigorous deformation analysis model based on the established point cloud correspondences.

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Semantic Segmentation of Ice in selected Swiss Lakes

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Lake ice, as part of the Essential Climate Variable (ECV) "lakes", is recognized as a sentinel for monitoring climate change and global warming. Since there exist no systematic and reliable observations of ice in Swiss lakes, we use and integrate various sensors and methodologies to operationally accomplish this. We propose a future-oriented sustainable system for lake ice monitoring, using mainly satellites and WEBcams, which together form a stable data source. The four target lakes include: Sihl, Sils, Silvaplana and St. Moritz, with variable altitude (medium to high), area (1-11 km²) and surrounding topography (flat/hilly to mountainous). The input data include: Suomi NPP VIIRS and Terra MODIS optical satellite images. We also use WEBcam data, which are becoming increasingly available for free and are much less affected by the grave problem of clouds in Switzerland and also errors in cloud masks for the optical satellite sensors. Independently using the data from each sensor, we detect the extent and duration of lake ice (including the ice on/off dates). Regarding the methods, we propose a) supervised classification approach using xgboost [1] and Support Vector Machines for VIIRS and MODIS and b) Convolutional Neural Network [2] for WEBcams.

REFERENCES
Exploiting Structure in Human Mobility Behavior using Graph Convolutional Neural Networks

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In the last years, convolutional neural networks (CNN) led to breakthroughs in areas such as image or speech recognition. Their success is based on their ability to exploit the structure that lies within the data by using self-learned instead of handcrafted features. Despite this success, CNNs are not yet widely used to analyse human mobility behavior, also because it is difficult to present trajectory and tracking data in an appropriate way for neural networks [1]. To overcome this problem, we explore the potential of graph neural networks (GCNN) for the classification of human activities based on mobility behaviour (cf. [2,3]).

We use semantically enriched GPS tracking data from a one-year long travel survey of 139 users. During this period, participants recorded their movement with an app on their phone, which automatically detected points of static behaviour (staypoints) and asked users to validate and label them with one of the following activities: Home, Work, Errand, Leisure, Study and Wait. We transform the data into a bidirectional graph by spatially clustering all staypoints for each user using a density-based algorithm (DBSCAN [4], see Figure 1). The clustered locations form the nodes of the graph; we then create an edge between any two locations that a user visited consecutively, using the number of transitions from one cluster to the other (or vice versa) as the weight of the edge (Figure 2). For every node, we create features based on the aggregated information of the associated staypoints and based on their location (e.g. average stay duration, distance to public transport stations, etc.). Finally, we use the GCNN presented in Figure 2 to predict the main activity for every node. The convolution essentially allows the network to take into account features of nodes up to “two hops away” for the prediction of any node label.

Our first experiments show that the GCNN is able to learn on the graph and solves the classification task with a comparable accuracy to a carefully trained random forest classifier (~66%), while both outperform a well-optimized support vector machine. Further research will focus on the combination of the mobility graphs of different users and the enrichment of user graphs with graphs carrying context information such as public transportation or road networks.

REFERENCES


Figure 1. The clustered staypoints of an exemplary user, used as input graph for our GCNN.

Figure 2. The graph representation of the staypoint clusters (violet lines have a higher weight, i.e. more transitions between clusters).

Figure 3. The architecture of the network presented in this work. Adapted from http://tkipf.github.io/graph-convolutional-networks.
Forecasting the effects of environmental change on densities of bloom-forming cyanobacteria in Swiss lakes

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Lake ecosystems provide important services to society, including recreation, fisheries, and the provision of clean drinking water. Anthropogenic eutrophication and climate warming have altered lake ecosystems, resulting in increased prevalence of several potentially toxic cyanobacteria species in many lakes worldwide, and threatening lake ecosystem services. Several studies have used process-based deterministic models to attempt to uncover the causes and likely future trajectories of cyanobacteria populations under scenarios of climate and land-use change (Mooij et al. 2010). Processed-based models of lake physics frequently perform well, replicating thermal structure and circulation patterns accurately when forced with meteorological driving variables and hydrologic inputs. Coupled with projected climate data, these models are likely to provide reasonable estimates of future changes in lake thermal structure. In contrast to the reliability of physical models, reliable deterministic models for forecasting cyanobacteria dynamics remain elusive, particularly at the level of individual taxa. Because of the high level of complexity of lake biogeochemical and ecological systems, deterministic ecological models are usually highly parameterized, and include many parameters which cannot be easily measured, resulting in large uncertainties in predictions of future scenarios.

Machine learning methods (e.g. random forests, neural networks, and empirical dynamic models) may provide useful alternatives to mechanistic models of lake phytoplankton, because the training of the algorithms can incorporate complex non-linear interactions among variables. These methods are becoming increasingly useful with the recent proliferation of large environmental monitoring datasets. In addition to their predictive capabilities, machine learning techniques may also be helpful in determining mechanisms controlling phytoplankton dynamics (Thomas et al. 2017, Leach et al. 2018), which can be difficult with traditional linear statistical methods because of high covariance and complex interactions among variables (Sugihara et al. 2012).

In this project, we will use a combination of processed-based physical models and data-driven machine learning models of lake biogeochemistry and plankton ecology to (1) identify the chemical and climatic drivers of cyanobacterial growth and abundance at multiple temporal scales using long-term and high-frequency data from perialpine lakes in Switzerland, Italy, and France using random forest
models (Thomas et al. 2017) with an particular focus on the deep, meromictic Lake Lugano; (2) generate scenarios of lake change based on GCM projections, likely changes in the frequency spectra of abiotic drivers, and nutrient loading scenarios; (3) produce short- and long-term forecasts of the abundances of key taxa of bloom-forming cyanobacteria using empirical machine-learning methods (random forest models, empirical dynamic models, and neural network clustering), and (4) generate web-based forecasting tools and recommendations for lake management under scenarios of environmental change.

REFERENCES
Carbosense - CO₂ sensor network and simulations

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The Carbosense project establishes a uniquely dense CO₂ sensor network across Switzerland as well as a dedicated CO₂ modeling framework. The main goal of the project is to improve the understanding of the small-scale CO₂ fluxes in Switzerland and concurrently to contribute to a better top-down quantification of the Swiss CO₂ emissions. This requires an improved understanding of the emission patterns and the biosphere fluxes which are both highly variable in space and time. The selected approach combines sensor measurements and modeling output. Data analysis and machine learning tools are applied to optimize sensor and model performance as well as to identify processes that have not explicitly been taken into account but have an impact on the results.

The Carbosense sensor network consists of (i) 250 nodes of battery-powered CO₂ low-cost diffusive NDIR sensors (SenseAir LP8), (ii) 20 temperature stabilized, mains-powered NDIR low-cost instruments with active sampling and reference gas supply (SenseAir HPP) and (iii) seven high-precision laser spectrometers (Picarro G1301/G2401, CRDS). Data of the LP8 sensors is transmitted via Swisscom’s LPN (LoRaWAN) every 10 minutes, data of the HPP sensors every minute. Both types of sensors require careful calibration prior to deployment. A special focus of the Carbosense network is the city of Zurich where more than 50 nodes are deployed.

Atmospheric CO₂ simulations are performed using the COSMO numerical weather prediction model with an extension for the passive transport of trace gases (COSMO-GHG). The model has a spatial and temporal resolution of 1-by-1 km and 1 hour. Model input data are CO₂-boundary conditions from the global CO₂ model CAMS (ECMWF), emission inventories (TNO/MACC-3 for

Figure 1. Left: Carbosense CO₂ network (September 2018). Red circles depict the LP8 sensor units, yellow circles the HPP nodes, and green circles the Picarro instruments. Center: LP8 sensor unit. Right: LP8 unit installed at a utility post in Zurich.
Europe and CarboCount for Switzerland) and biosphere fluxes (VPRM, MPI Jena).

Figure 2. Left: CO$_2$ background concentrations derived from the boundary conditions. Center: Anthropogenic CO$_2$ emissions. Right: Biosphere fluxes.

The CO$_2$ sensor network has been running since July 2017. A first version of the data processing scheme is operational. Key routines are the linking of the LP8 sensors to reference instruments during specific meteorological conditions for the adjustment of sensor drifts and the analysis of an individual sensor's normal behavior for outlier detection. The COSMO-GHG model was successfully set up with all required input data and tested for first CO$_2$ model runs for October 2017. The output is being analyzed to optimize the settings of the computations. Eventually, the complete time period covered by the observations will be simulated.

The data processing scheme is going to be extended towards an optimal exploitation of the continuously growing data set. One current task is the development of methods for the geospatial prediction of atmospheric CO$_2$ based on measurements (CO$_2$ and meteorological parameters) and land use information. Such an algorithm must be capable of selecting the most important factors that determine the current CO$_2$ concentration at a specific location. Spatio-temporal CO$_2$ predictions are an option to assess the performance of an individual sensor by using information provided by its neighboring sensors. These predictions also facilitate the link between the sensors' point measurements and the spatial mean of a grid cell in an atmospheric model. Unresolved subgrid-scale processes due to the limited spatial resolution of the model have to be addressed and interpreted carefully.

Feature extraction from the output of the atmospheric model is another data analytical task. Continuous 3D-fields are expected to provide additional context compared to site measurements (e.g., inversion situations). CO$_2$ concentration, wind, pressure and temperature fields will be searched for time periods and regions in which the CO$_2$ concentration can be transferred within the sensor network from high precision to low-cost instruments.
Roadmap for “in-situ” calibration of environmental measurements


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Cost-effective techniques for air pollution measurement such as low-cost sensor suites (Zimmerman et al., 2018) and infrared spectroscopy (Takahama et al., 2018) can exhibit cross-sensitivities to a wide range of chemicals or factors found in the environment. These techniques can benefit from statistical calibration against collocated reference measurements in the field, rather than in the laboratory where simulated conditions do not reflect the complexity encountered in the natural environment. This “in-situ” calibration approach permits proliferation of cost-effective measurement techniques to provide spatial and temporal coverage of atmospheric pollutant concentrations that cannot otherwise be attained by reference techniques on account of cost restrictions.

In this presentation, we highlight the central role that machine learning plays in the life cycle of such a calibration model. A thorough example for quantitative calibration of spectra obtained by Fourier Transform Infrared (FT-IR) spectroscopy to organic and elemental carbon measured by thermal optical reflectance (TOR) in the US Interagency Monitoring of Protected Visual Environments (IMPROVE) and Chemical Speciation Network (CSN) is demonstrated. We describe procedures for data preprocessing, data selection, model training, and model evaluation to determine a suitable calibration model among a suite of candidate models that can be generated. Furthermore, we discuss methods for identifying limitations in model applicability. Model understanding in the form of variable importance assessment can identify the most discriminating features and how their relationships are used by the calibration model. In the operation phase of the model when reference (and possibly other auxiliary measurements) are not available, methods for anticipating precision errors and large prediction errors due to biases that arise from differences in sample composition must be estimated from the primary measurement to monitor model performance. These topics are presented alongside strategies for model updating to reflect changes in atmospheric composition that occur over time, or at new sites where measurements are to be extended.
Figure 1. Diagram of the calibration roadmap (top left) and selected sites in the US IMPROVE and CSN networks (bottom left), we demonstrate the capability to calibrate FT-IR spectra to predict organic and elemental carbon equivalent to that reported by the TOR method (right).

REFERENCES


Machine Learning Strategies for Regional Scale Slope-Instability Identification from Earth Observation Data
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Landslide processes are a major hazard concerning mountainous regions. Mapping unstable slopes is crucial for an effective hazard assessment, hence updated and reliable landslide catalogs are essential. The procedures for generating these catalogs are, however, mainly dependent on human-based interpretations. Depending on the extension of area of interest and available data, this procedure is very slow and usually biased. Fortunately, the constantly growing fleet of Earth Observation (EO) systems provides high-resolution information and repeat coverage required for mapping of unstable slopes. Automatic processing of this EO Big Data can reduce the dependency from human involvement, thereby increasing the frequency of updates to landslide catalogs.

In this work, we study machine learning strategies for the analysis of slope instabilities at a regional scale. The idea is to reduce dependency from slow and subjective human-interpretation, which in turn will facilitate with the generation of quick, consistent and reliable landslide inventories. The available archive of EO datasets and landslide inventories will be used to train machine algorithms for automatic classification of stable and unstable slopes. We compare the effectiveness of individual and ensemble learners in object-based image analysis (OBIA) system. Deviating from the conventional practice of image segmentation from optical imagery, we introduce a new approach to defining objects by grouping the aspect values in digital elevation models (DEM). This pushes the definition of objects to resemble more like a hill-slope face and is a better representation for slope stability classification problem. We further identify key features which are critical in the determination of the object’s stability. A case study is presented for a region in the Himalayan range of North-Eastern Bhutan. A complete inventory of landslide was manually mapped by integrating the information from a 5-meters DEM, high-resolution optical images, and radar interferometry. This mapped inventory had a hold-out set for validation, while the rest was used for training the learning algorithms. Here we present the initial results and observation from this work.

This work is done in the framework of European Commission's Horizon 2020 project "BETTER", with the main objective to facilitate the usage of large volume and heterogeneous datasets by downstream users, so that they can focus on the analysis of the extraction of the potential knowledge within the data and not on the processing of the data itself. More information is available on the website https://www.ec-better.eu/.

Keywords: Landslide mapping, Image segmentation, object-based image analysis, machine learning
The ability to automatically monitor agricultural fields is an important capability in precision farming, enabling steps towards more sustainable agriculture. Precise, high-resolution monitoring is a key prerequisite for targeted intervention and the selective application of agro-chemicals.

The main goal of this paper is developing a novel crop/weed segmentation and mapping framework that processes multispectral images obtained from an unmanned aerial vehicle (UAV) using a deep neural network (DNN).

Most studies on crop/weed semantic segmentation only consider single images for processing and classification. Images taken by UAVs often cover only a few hundred square meters with either color only or color and near-infrared (NIR) channels. Although a map can be generated by processing single segmented images incrementally, this requires additional complex information fusion techniques which struggle to handle high fidelity maps due to their computational costs and problems in ensuring global consistency. Moreover, computing a single large and accurate vegetation map (e.g., crop/weed) using a DNN is non-trivial due to difficulties arising from: (1) limited ground sample distances (GSDs) in high-altitude datasets, (2) sacrificed resolution resulting from downsampling high-fidelity images, and (3) multispectral image alignment.

To address these issues, we adopt a stand sliding window approach that operates on only small portions of multispectral orthomosaic maps (tiles), which are channel-wise aligned and calibrated radiometrically across the entire map. We define the tile size to be the same as that of the DNN input to avoid resolution loss. Compared to our baseline model (i.e., SegNet with 3 channel RGB (red, green, and blue) inputs) yielding an area under the curve (AUC) of [background=0.607, crop=0.681, weed=0.576], our proposed model with 9 input channels achieves [0.839, 0.863, 0.782]. Additionally, we provide an extensive analysis of 20 trained models, both qualitatively and quantitatively, in order to evaluate the effects of varying input channels and tunable network hyperparameters. Furthermore, we release a large sugar beet/weed aerial dataset with expertly guided annotations for further research in the fields of remote sensing, precision agriculture, and agricultural robotics.
Figure 1. A sample dataset of a large scale sugar beet farm (left) and qualitative results, dense semantic segmentation, of our weed mapping system using the proposed approach (right).

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