Abstracts for the NoRSC'19 Conference at AIAS

(In order of presentation at the conference)

ORAL PRESENTATIONS

Spring bloom dynamics as predicted by winds and remote sensing

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The onset of spring bloom is regulated by the upward flux of nutrients, the seasonal onset of light, and the stabilization of the water column causing the mixed layer depth to become shallower than the critical depth allowing phytoplankton production to start. We have investigated remotely sensed chlorophyll-a and high-resolution sea surface winds to quantify and understand high latitude spring bloom dynamics and the effect of varying winds. The winds affect the upper oceans through frictional stress that transfers energy to the ocean generating waves, currents and mixing. Hence, as the wind stress increases the turbulent mixing in the mixing layer may deepen the upper mixed layer, which may eventually extend beyond the critical depth and prevent onset of bloom. By combining SeaWIFS and MODIS data for the period 1998 to 2017 with atmospheric reanalysis of winds dating back to 1958 we find that at the key spawning ground of the worlds' largest herring population the variation in the strength of winds may explain a significant and large part (>60 %) of the inter-annual variation in the spring bloom onset. Furthermore, since atmospheric reanalysis extend much further back in time than remote sensing winds may act as a good proxy for investigating trends across decades on the time scales of multi-decadal variability and climate change.

Improved interpolation scheme for remotely sensed ice sheet elevation changes - a case study in northeast Greenland

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Satellite radar altimeters have continuously mapped the Greenland ice sheet since the early 1990s, providing a unique long-term data set for evaluating ice sheet changes. One issue with these conventional radar measurements is the large footprint size, which hampers the ability to map the marginal areas of the ice sheets as these are characterised by rapidly varying topography. The lack of data near the ice sheet margins is especially problematic since this is where the most profound changes are happening, leading to an underestimation of the actual ice sheet changes.
Here, we attempt to improve the inter-/extra-polation scheme used to derive elevation change maps that fully cover the Greenland ice sheet. We do this by including high resolution ice velocity maps as well as maps of ice velocity *changes* to find a suitable map to use as external trend map in a Kriging procedure. The rationale for this approach is the correlation between (changes in) ice velocity and surface elevation changes, if the latter are dynamically driven - as it is often the case near the outlet glaciers.
We focus on an ice sheet drainage basin in northeast Greenland because this includes outlet glaciers with very different dynamic behavior. One of these glaciers is Storstrømmen Glacier, which is one of the only glaciers in Greenland that is currently thickening because it is recovering from a previous surge (dynamically driven).
We evaluate the performance of different inter-/extra-polation schemes by validation using airborne measurements and bootstrapping.

Automated mapping of cultural heritage in Norway from airborne lidar data using faster-RCNN

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We present a new method for automated mapping of historic monuments such as grave mounds, pitfall traps and charcoal kilns. The method is based on a region-proposal convolutional neural network called "simple faster R-CNN". The network was pre-trained on a large database of natural scene images. Each image had annotations in the form of bounding boxes with associated class labels. Then the network was trained on images derived from airborne lidar data. The lidar point cloud data was converted to a digital terrain model (DTM) by keeping all points that were labelled as 'ground'. The DTM was then converted to a simplified local relief model by subtracting a smoothed version of the DTM. The local relief model enhances local detail in the DTM while suppressing the general landscape topography. Thus, cultural heritage remains such as grave mounds, pitfall traps and charcoal kilns are often visible.

Each geographic area was divided into disjoint areas for training, validation and testing. Training, validation and test images of sizes 150 m × 150 m were extracted from the local relief model data. Each image contained one or more cultural heritage objects clearly visible.

For the test images, the overall correct classification rate was 83%, and for the specific classes: grave mound 81%, pitfall trap 78% and charcoal platform 95%. 16% of the true cultural heritage objects were missed by the method. 1% of the cultural heritage objects were detected with wrong class. 21% of the objects that the method predicted as being cultural heritage were in fact not.

The new method was implemented in an automated processing chain that will be used by the Norwegian Directorate for Cultural Heritage (Riksantikvaren) to improve the

national cultural heritage mapping. The main focus is on grave mounds and pitfall traps, since these are protected by Norwegian law.

Upscaling vegetation structure from terrestrial laser scanning using satellite imagery

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Three dimensional vegetation structure is a key ecosystem variable that is strongly related to biodiversity, human-driven land-degradation and Earth-atmosphere exchange, including carbon sequestration. Increasingly, vegetation structure can be quantified using laser scanning (lidar) and progress has been rapid in recent years, particularly in forests. However, little work has been done in tropical savannas, which cover 20% of Earth's surface. Savanna vegetation is a heterogeneous mix of grasses, shrubs and short trees and highly dynamic in time, due to regular fires and large herbivores. Standard forest metrics are thus not useful in savannas.
In this study we have two aims. First, we identify metrics that are ecologically meaningful and can be derived reliably from handheld terrestrial laser scanning (TLS). These metrics are validated using extensive data from traditional ecological field methods. Second, we upscale metrics from TLS scans to the landscape scale, using neural networks and satellite imagery in a two-step process. In the initial step we relate 3D metrics to very high resolution multispectral WorldView3 scenes (10×10 km). In a subsequent step we upscale and extrapolate the WorldView3-based surfaces to the entire study region using Sentinel 2 multispectral imagery.

Results show that TLS scans are strongly related to field-based measurements and thus accurately capture ecologically relevant vegetation attributes. In addition to traditional metrics, we identify novel metrics related to vegetation heterogeneity that are difficult to quantify using traditional field techniques. Preliminary upscaling results look promising, with the neural network achieving high predictive capacity in internal cross-validations and testing on independent data.
We identify good potential for using comparatively affordable handheld laser scanners to generate landscape level estimates of vegetation structure that are valuable in conservation and ecological research. This is especially useful in remote regions, where aerial or UAV-based lidar is not achievable, and to researchers with limited research budgets.

Drone data reveals fine-scale variation of tundra greenness and phenology that is missed by satellite and ground-based monitoring

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The Arctic is warming at twice the global average and the rising temperatures are driving rapid vegetation change in the tundra observed in satellite products and ground-based measurements. However, the medium-grain size of long-term satellite products (tens of meters to kilometres) and the limited extent of ground-based monitoring (due to logistical costs) have restricted our ability to link observations from plot- to biome-scales, creating a "scale-gap" in our understanding of tundra vegetation

change. Recently emerging drone technologies have been suggested to be able to close such scale-gaps by providing fine-grain data at flexible temporal and spatial scales.

We present a novel dataset of twelve within-growing season time-series of fine-grain multispectral drone imagery captured over two years (2016 and 2017) at our field site in Arctic Canada. We derive the Normalised Difference Vegetation Index (NDVI) as a measure of vegetation greenness and combine it with satellite (Sentinel 2 and MODIS) and ground-based observations of seasonal change in the tundra.

Our findings show cross-sensor correspondence (satellites and drones) of tundra greenness at landscape-extents for our eight 1 ha plots during the growing season of both years, but highlight a notable loss of variation when resampling from fine-grain drone (approx. 0.05 m) to medium-grain satellite pixel sizes (10 – 30 m), potentially obscuring key ecological variation in productivity and phenology. Changes in greenness observed by the drone sensor were strongly correlated with ground-based measurements of changes in leaf-length for five common tundra plant species in associated ground-observation plots.

We demonstrate that fine-grain drone data can bridge scale-gaps between satellite and ground-based observations, and show that notable variation in tundra landscape greenness and phenology is missed by both ground-based observations and satellites. Particularly in the tundra were vegetation is often structured at sub-meter scales, multispectral drone sensors can capture key ecological variation that will allow us to better understand landscape-scale patterns and drivers vegetation change.

Calibrating temporally transferred models in forest inventory.

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Area-based forest management inventories (FMI) assisted by airborne laser scanning (ALS), have become common practice in many countries, and Norway is now entering into the second cycle. A major cost component of these inventories is the field measurements of sample plots used for calibrating the models between ALS and the field measured biophysical forest attributes of interest. To reduce cost of repeated ALS-based FMIs, one strategy can be to apply models constructed on data from the preceding FMI (temporal transfer of models). Because the properties of ALS point clouds depend on parameters specific for each acquisition, a re-calibration of models and/or predictions with up to date field measurements might still be necessary. However, the number of new plots to be measured for this purpose can most likely be reduced compared to the number of plots necessary to construct "new" models. The aim of this study was to analyze accuracy of predictions based on models re-calibrated with different numbers plots with up to date field measurements.
We applied two different approaches; 1) a correction of predictions based on the ratio between plot predictions using the model from the first measurement occasion (T1) and the ground reference values at second measurement occasion (T2) on same plots, and 2) a re-estimation of the T1 model coefficients based on the ground reference values at T2. Both approaches was tested in a simulation where different number of new plots were selected, repeating the simulation 500 times for each number of plots.
Preliminary results indicate that calibration increase the accuracy of the transferred models, especially the re-estimation approach. However, the results suggest that the ratio approach performs better when there are only a few new plots were selected.

Visual Question Answering from Remote Sensing Images

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This presentation introduces the task of visual question answering for remote sensing data (RSVQA). Remote sensing images contain a large amount of information which

can be useful for a wide range of tasks. However, the developed methodology is often task-specific, preventing a generic and easy access to the information contained in remote sensing data. With RSVQA, we propose to use questions formulated in natural language as a way to interact with remote sensing images. This way, the images can be queried to obtain high level information about specific image content or relational dependencies between the objects sensed. Using an automatic method that we describe in this presentation, we built a dataset of image/question/answer triplets using OpenStreetMap (OSM) data. This dataset can be used to train and evaluate models to solve this task or any of the sub-tasks, such as object detection and counting. In addition, we present two methods (based on Convolutional Neural Networks (CNNs) for the visual part and on a Recurrent Neural Network (RNN) for the natural language part) showing first results on this new task.

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Inorganic Suspended Matter as an indicator of terrestrial influence in Baltic Sea coastal areas - algorithm development, validation and ecological relevance

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The concentration of suspended particles can be derived from particle scatter if the specific scattering properties of the respective water body are known. We derived an empirical algorithm between *in situ* particle scatter (AC9 data) and ISPM (measured gravimetrically). This algorithm is then applied to Sentinel-3 (S3) data over the Baltic Sea. The generated S3 composite image from spring 2018 show that most of the ISPM falls out rather close to the shore, whereas only a small proportion of SPM is carried

further off-shore. This is also supported by *in situ* ISPM transects measured in the coastal zone.
The ISPM images clearly highlight the areas that are most strongly influenced by terrestrial matter. Differences between the NE Baltic and the SE Baltic proper can be explained by the difference in hydrology and coastal influence as well as bathymetry and wind-wave stirring. The method is of interest for coastal zone management and for assessing the effect of seasonal changes e.g. in precipitation onto coastal run-off. It can also be used to evaluate the effect of climate change which has led to an increase of extreme storm and flooding events that are usually accompanied by increased erosion and run-off from land. Last but not least, turbidity caused by particles influences the light conditions in inner coastal areas and bays, which has a profound effect on productivity and fish behaviour.

Keywords: Inorganic suspended matter; remote sensing reflectance; scatter; algorithm development; Sentinel-3 Ocean and Land Colour Instrument (OLCI); light limitation

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Agricultural land cover classification with deep learning

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Automatically classifying the agricultural land cover of the Earth in satellite imagery is an essential task for many applications, such as environmental monitoring, food security, and precision agriculture. The fact that crops change their appearance over time complicates their classification for any particular observation. On the contrary, a temporal sequence of observations may allow machine learning methods for automatic classification to identify unique growth patterns of different crop types for improved prediction performance. Recently, he temporal capability of remote sensors is increasing greatly, now delivering data at daily to weekly intervals.

Existing machine learning based classification of crop types with artificial neural networks (deep learning) uses an encoder structure with convolutional recurrent layers. Accurate results are obtained on raw, top-of-atmosphere reflectance data with no prior cloud masking, demonstrating the robustness of these types of models. However, they are computationally costly, which hinders large scale applications.
In this work, we reduce computational cost while increasing classification performance by introducing a new structure based on the U-Net, a fast convolutional neural network for single-image segmentation. We add recurrent layers, allowing the network to extract temporal information along with spatial and spectral information. In our experiments, we obtain substantial improvements over the state-of-the-art on a crop classification task based on temporal sequences of Sentinel-2 observations over Denmark, both in terms of accuracy and in terms of computation time. Our approach is not limited to crop classification, and may be used for other remote sensing tasks with temporal information. In particular, robustness against clouds as achieved via recurrent layers is attractive in many applications. This work is done in collaboration with FieldSense A/S, who create crop monitoring applications based on satellite data, and develop a fast and accurate crop classifier for benchmarking and other applications.

Simulative assessment of model assisted and hybrid estimation of change using repeated ALS sampling

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When airborne laser scanning (ALS) is used with the purpose to estimate forest parameters over large areas, a strip sampling approach has been proposed as a cost effective alternative to wall-to-wall acquisition. In large-scale applications, biomass stocks and change may be estimated using repeated ALS strip sampling in combination

with national forest inventory field measurements. We assessed and compared different post-stratified model assisted (MA) and hybrid (HY) estimators under sampling simulations. For biomass change estimation both a direct and indirect approach were tested, where the latter means that change is derived by the difference in stock estimates. A methodology to generate spatially explicit AGB-ALS change populations with prescribed properties tailored to an area of interest was devised paying particular attention to the spatial autocorrelation as described by stratum specific semivariograms. The sampling simulations showed that regardless of the estimator, ALS strip sampling increased the accuracy of biomass stock and change estimates when compared to field based estimates. The relative efficiency (calculated by the ratio of RMSE) of the ALS assisted biomass stock estimators ranged from 1.53 to 1.74, and for biomass change estimators between 1.16 and 1.33. In general, HY estimators had lower RMSE than MA for biomass stock as well as change estimates. Direct change estimators had lower RMSE than indirect estimators. Bias was negligible (<1%) for biomass stock estimators, and was below 10% for biomass change estimators.

The use of multi-scale and multi-source remote sensing dataset for geological mapping in the Arctic terrain

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Most of the studies using hyperspectral data for geological applications have addressed areas in arid to semi-arid climates. Here we present research examining how well geological mapping works under the arctic, high relief conditions of Greenland, using hyperspectral data acquired from different platforms and at various scales. New strategies are developed to capture the hyperspectral data as part of a large-scale operation (i.e., areas of hundreds or thousands of square kilometres) in a time- and cost-effective manner. Coastal cliffs are examples of major well-exposed outcrops in the

Arctic that are mostly inaccessible and not observable by air/spaceborne nadir remote sensing sensors due to steep topography and are often only fully visible from an opposing location such as a neighbouring mountain or shoreline. The distance between the sensor and the target of interest can then easily extend to several kilometres. For this reason, a new data acquisition strategy, namely long range terrestrial outcrop sensing is proposed. The method is tested in South West and West Greenland. Despite the promising results achieved by using this approach, the rugged topography and difficult terrain accessibility often hinder the instrumentation setup and limit the employment of such a data acquisition strategy. To overcome these limitations, the potential of using a platform in motion (such as a boat/ship) to continuously acquire the hyperspectral data while sailing along the fjords is investigated. The two-dimensional maps generated from hyperspectral imaging are transformed to three-dimensional hyperclouds and integrated with terrain models generated from oblique photogrammetry. Performing the required preprocessing for data captured from distant targets is not straight-forward. Firstly, the logistical setup of "visible" reference targets for radiometric correction with the same orientation and distance as the distant target outcrop is not possible. Secondly, large distances between the sensor and the outcrop lead to major atmospheric distortions. Thirdly, owing to the large scale of the observed surface and the sensor viewing perspective, pixels within one scene can represent a range of different distances and orientations, leading to highly variable radiometric distortions. For those reasons, correction methods established for nadir acquisitions are adapted to account for the special conditions of long-range sub-horizontal sensing of outcrops.

Change detection in polarimetric synthetic aperture radar data

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Based on an omnibus likelihood ratio test statistic for the equality of several variance-covariance matrices following the complex Wishart distribution and a factorization of this test statistic with associated p-values, change analysis in a time sequence of multilook polarimetric SAR data in the covariance matrix representation is carried out. The omnibus test statistic and its factorization detect if and when change occurs. Also, a measure of change direction is calculated. Using spaceborne dual polarization Sentinel-1 and full polarization Radarsat-2 data this contribution focuses on change detection based on the p-values, on visualization of change at pixel as well as segment level, and on computer software for local as well as cloud processing.

Greenland surface elevation change from 25+ years of satellite radar altimetry data

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A long and unbroken record of ice sheet surface elevation change has been recognized as an essential climate variable (ECV) by the Global Climate Observing System, as the change in ice sheet surface elevation change is of the utmost importance when assessing the state of ice sheets and directly relates to global sea level rise. The Greenland ice sheet has in the last decade been accelerating in its contribution to global sea level rise and only with a long and unbroken record of ice sheet surface elevation can we start to investigate the ice dynamic imprints of the observed climate warming.

The launch of ERS-1 in 1991 started the Greenland ice sheet wide coverage of radar-altimeter measurements and enabled estimation of surface elevation. As every ERS-successor mission has provided new and improved measurements an effort is needed

to ensure continuity in the long and unbroken record of surface elevation change from satellite radar altimetry. Here, we present the processing strategy in the EU Copernicus Climate Change Service to drive operational surface elevation change record of the Greenland ice sheet on a monthly basis.

Furthermore we look at the more technical challenges of such an operational product such as (1) Strategies for determining the geolocation of the individual radar echo. (2) Modeling of different radar waveform parameters to limit the imprint of volume scattering in the derived elevation. This is especially important for the Greenland ice sheet were changes in the subsurface properties can be mapped into the elevation change if the processing is not tailored for this change in climate over the 25+ years of satellite altimetry.

Earth Observation for coastal monitoring

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The coastal zone is highly dynamic and there is high demand for up-to-date base-maps of the entire zone. In this presentation we will demonstrate how advanced image processing methods combined with bio-optical modelling and machine learning is used to derive accurate and high-resolution information about the coastal zone at large scale based on data from Sentinel-1 and Sentinel-2.

The presentation will provide three examples on how the new Sentinel data can be used to monitor the coastal zone based on state-of-the-art methodologies:

- Satellite-derived bathymetry in 10m spatial resolution: a first-ever national shallow water bathymetry model in 10m spatial resolution is now available for

Denmark. This enables more accurate and detailed hydrodynamic and ecological modelling.

- Mapping submerged aquatic vegetation: a first-ever national mapping of the submerged underwater vegetation has been completed. The new data product provides a first fully spatially coherent baseline of the submerged aquatic vegetation abundance and distribution in Denmark.
- Coastline delineation based on synergistic use of Sentinel-1 and Sentinel-2: accurate delineation of the active coastline enables better planning of coastal protection facilities and general spatial planning both onshore and nearshore.

The tools and methods we have developed are globally applicable and the potential for large-scale uptake is therefore considerable. Also, the three demonstration cases are good examples of how new technology and data sources are rapidly changing our coastal monitoring processes – it is becoming much more dynamic and data driven.

A global quantitative analysis of the link between forest structure and land surface albedo

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Forests are critical in regulating the local climate by altering the Earth's surface albedo (reflectivity). Albedo can be modified by forest structure; however, contradictory results from different studies suggest that their relationship has not been understood sufficiently well. The conflicting results can be explained by the fact that, in addition to forest structure, various factors such as leaf and forest floor optical properties can influence forest albedo. This raises the question if forest management actions can be used to modify forest albedo, and hence, also local climate. To address this knowledge gap, satellite data offer repeated and consistent observations that allow us to investigate the local effects of forest structure on albedo from a global perspective. In this study, we used remotely sensed data of forest density (the number of trees per hectare), tree cover (percent), leaf area index (m2/m2) and forest types (evergreen needleleaf, evergreen broadleaf, deciduous needleleaf, and deciduous broadleaf, mixed and woody savannah forests), estimated from Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat satellite images. Furthermore, we used the most recent version of MODIS (version 6), to quantify albedo at shortwave, near-infrared and visible spectral regions. We explored the relationships between albedo and forest structure using Generalized Additive Model in different forest types in major climate zones (i.e., boreal, mediterranean, temperate and tropical). Additionally, for the first time, we generated a global map that represents the magnitude of the relationships at a 0.5-degree resolution. The results showed that, depending on the forest type and major biome zone, the R2 of links between albedo and forest structure markedly varied from 0.03 to 0.98. The strongest relationships were observed in boreal and tropical evergreen needleleaf forests, and in woody savannahs in the Mediterranean and temperate zones. These results enhance our understanding of how forest management strategies can affect albedo.

Remote sensing of snow properties with Sentinel-3

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Seasonal snow is an important component of the Earth system heavily affecting the energy balance and the water cycle at high latitudes and elevations. Vast land areas in the north and in mountainous regions are weakly monitored by in situ sensors due to the fact that most of these regions are sparsely populated. Earth observation is the only practical means of frequent and accurate monitoring of snow properties in these regions. As snow properties might quickly change, moderate resolution sensors with frequent coverage (~daily) are crucial.

This presentation gives an overview of snow algorithms and products that have been developed for the MODIS sensor over more than 15 years and are now being ported, adapted and optimised for the use with Sentinel-3 OLCI and SLSTR sensors. The revisit time is 0.5-1.0 day over most regions having seasonal snow cover (two satellites).

Optical snow products developed in the MODIS era include snow cover, snow surface temperature, snow grain size, snow surface wetness, snow surface hoar, snow spectral albedo, snow impurities and black carbon in snow. Several of these variables are important in snow hydrology, meteorology and climate monitoring. Snow cover is a key to energy balance modelling and warning of potential flood situations. Snow surface temperature and snow surface wetness give information on the progress towards and within the snowmelt season. Snow albedo is crucial in energy balance modelling and modelling the snowmelt progress.

The presentation will go through the algorithms for the different products and compare retrieval results from MODIS and Sentinel-3. Examples of multi-sensor/multi-temporal fusion of SLSTR and Sentinel-1 SAR data will also be given. As there is no one-to-one match in general between the bands of MODIS and SLTSR/OLCI, we had to make algorithmic changes and adaptations. There are also bias and saturation effects with some of the sensor channels. The related challenges will be discussed, and the performance between the two compared.

Remote sensing benchmark data set of Hekla volcano, Iceland

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Hekla volcano and its surrounding is a showcase for many of the global environmental changes that challenge present day societies including tectonic, volcanic, glacial and extreme weather processes causing significant changes over short periods of time.
In such environment fast and reliable mapping and monitoring techniques are needed on a big spatial scale. Hence, multi-source remote sensing benchmark data sets promoting the development of new, automated classification techniques of areas subjected to rapid environmental changes are needed. However, very few large-scale, multi-source benchmark data sets of such environments exists, meaning that operational and effective mapping techniques are lacking. This causes insufficient environmental monitoring, despite data availability.

Addressing this deficiency we propose an open-access, large-scale benchmark data set of Hekla volcano, Iceland, named EMMIRS. EMMIRS contains lidar and hyperspectral data of high spatial, spectral and radiometric resolution as well as well-illustrated and detailed land cover and landform reference data capturing the ecological and geological diversity of the area.

The EMMIRS benchmark data set will enable the community to develop solutions to challenges that present day national mapping agencies face such as (i) classification of land cover habitats and landforms, (ii) data fusion, (iii) atmospheric correction, (iv) mosaicking and stitching and (v) pixel unmixing.

Multi-temporal land cover mapping using recurrent neural network

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The Satellite images provide higher-level valuable information for recognizing, management and monitoring of agricultural domain. Land classification is an important first step to assessing land cover and land use. In many cases, existing approaches emphasize on single-date analysis or considering only few images for main growing season. However, land cover mapping using multi-temporal satellite images with high resolution in temporal dimension is still challenging in agricultural domain. The aim of this study is to develop an algorithm based on recurrent neural network for recognizing six different crop types in Denmark. The result showed that the proposed method could classify all classes with 0.96 and 0.92 as pixel-based accuracy and Intersection over Union, respectively. The network prediction showed that in field borders the level of classification confidence was lower than the center regions of the fields. Also, for our experiments, large area of around 700 and 250 thousand hectares were used for training and evaluation, respectively, which demonstrates the generalizability of proposed approach for recognizing various crop types. The result of this study approved that the capability of deep learning approach to analyze time-series radar images from Sentinel 1 satellite for classifying six different crop types in the main growth season.

Changing urban density of Denmark and Taiwan in the past 20 years over horizontal and vertical scales

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City compaction is argued to be the most sustainable strategy for the development of cities by the European Commission's Green Paper and the UN-supported Millennium Ecosystem Assessment. However, the health effect of city compaction is dubious based on the literature because temporal profiles of urban density are usually lacking. Here, we propose an innovative remote-sensing approach to trace the two and three dimensional urban density over the past 20 years. To overcome the common dilemma in remote sensing data between temporal coverage and spatial resolution, we combine optical USGS Landsat 8 OLI and very high-resolution satellite imagery available via Google EarthTM mapping service to train machine learning models for urban density mapping. We reconstructed building density change from 1999 to 2018 using the examples of Copenhagen, Denmark and Taipei, Taiwan—large cities in Europe and Asia, to compare the performance of the developed method in different geographical settings. We define neighbourhood-level horizontal density as the ratio of the built-up area to the total area of a neighbourhood, and vertical density is a category of the mean building height (<4m, 4-10m, 10-20m, >20m) of a neighbourhood. During the

session we expect to present preliminary results of our method on deriving the spatial-temporal information of building density. We expect this study will of high interest to a GEOMED audience for a glimpse at the temporal dimension of urban environments, with potential to help better understand human-environment interaction that is critical to public health solutions.

Sentinel-1 long and short-term interferometric temporal coherence in peatlands

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Peatlands are known as significant pools of stored carbon in northern temperate and cold climates. It is known, that they can be either net sequester or emitter of greenhouse gases (GHG-s), depending mostly on the water regime. The balance is highly vulnerable both to climatic changes and direct human impact. Understanding of seasonal dynamics of peatland surface and volume, so-called bog breathing, is the key to improve spatial models of material flows (dissolved carbon, nutrients) and gas exchange (CO2, N2O, CH4). Monitoring of this dynamics over large areas is only possible by remote sensing instruments.
The objective of this study was to examine the feasibility of Sentinel-1synthetic aperture radar interferometry (InSAR) to characterize seasonal dynamics of peatland surface and groundwater level over open raised bog areas. Endla mire complex in central Estonia was selected as a test site, because of existing ground truth measurements. The SAR dataset of 12 images was collected by Sentinel-1 SAR satellites during growing season of year 2018.

Our results show that interferometric temporal coherence is preserved over open peatland areas surprisingly long. The coherence was sufficient for differential InSAR even between images acquired 6 months apart. Moreover, the results show that the magnitude of coherence in the open bog is responsive to groundwater table fluctuations. Instead of gradually decreasing over time, the coherence made a significant recovery in autumn when the groundwater table re-achieved the level comparable to the groundwater table corresponding to the master image in spring. It was also demonstrated that differential InSAR phase analysis shows bog surface dynamics which is slightly different for different bog areas with different vegetation. It is concluded that the interferometric coherence could perhaps be used to gauge seasonal bog groundwater level fluctuation and classify peatland types according to long term temporal coherence.

Predicting tree-level quantitative attributes for the Norway spruce breeding program in Sweden using drone remote sensing

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National tree breeding programs are facing nowadays an increasing pressure for providing planting material resilient to climate change and sustaining a high-volume production. Selection of well-performing genotypes for the Norway spruce breeding program in Sweden is based on height (H) and diameter (DBH) measurements during genetic field trials taking place between 4-7 years and 12-15 years after planting. Due to dense vegetation conditions, the tree heights are not measured at the second occasion, as it requires an intensive workload and there is a high risk for large measurements errors. However, tree height information from repeated measurements would be highly relevant for the success of the breeding program.

To increase the cost-efficiency of the field data acquisition, we will test a new procedure aiming to provide the tree height information for the second genetic field trials using remotely sensed data collected by unmanned aerial vehicles (UAV). The study will take place during the early spring 2019, on a study area located in Tagel, Southern Sweden, consisting of a 2.4 ha field trial containing georeferenced trees with H and DBH manually measured during autumn 2018. The imagery data will be acquired using a consumer-level DJI Mavic drone, and 3D point clouds will be generated form dense image matching using ESRI's Drone2Map software. Statistical models will be used to link the tree-level H and DBH field measurements with the 3D point cloud auxiliary data. The prediction accuracy on H and DBH on individual trees will be validated on independent datasets. The assessment will be twofold: (1) to evaluate the accuracy level on H and DBH predictions with regard to operational deployment of the method, and (2) to estimate the cost-efficiency of the proposed method relative to existing field-based procedures.

Usages of UAV and multispectral images in the Danish field trail experiments

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Since 2017, Danish farmers have been able to access the digital field management tool, CropManager, which gathers all information for each of his individual fields. The digital platform combines registrations of management and satellite images that allow farmers to follow the development of crop biomass during the growth season. CropManager also contains maps for variable rate application of nutrients and pesticides in the field automatically generated from satellite images of NDVI/NDRE, soil types and management praxis. SEGES (The Danish Knowledge Center of Agriculture) develops the algorithms for CropManager based on field experiments. Every year, SEGES conducts

more than 1000 field trial experiments in collaboration with local advisory services and farmers. The experimental plots of the field trails are too small to be detected by satellites. Therefore, SEGES have extended normal registration of growth parameters with measuring NDVI/NDRE in several trials, with a drone installed with a multispectral camera with a high resolution, to con-vert this information to a more individual management praxis.

The aims of one study were to examine 1) the relationship between biomass measured by satellites (NDVI and NDRE) and the nitrogen (N) uptake in winter wheat, 2) which vegetation index (NDVI or NDRE) best de-scribes the development of the crop in relation to N uptake, 3) when it is possible to measure a significant difference between N treatments in the field trails during the growing season. The results showed a good correlation between NDRE and NDVI and N uptake (R2 = 0.69 and 0.42), in growth stage 31 to 34 before the second N application independent of location. In relation to N uptake, NDRE was more sensitive than NDVI. It was possible to distinguish significantly between treatments up to 150 kg N pr. ha using NDRE and up to 100 kg N pr. ha using NDVI.

In 2019, the relationship between drone- and satellite images in winter wheat, winter rape and spring barley are examined. Time of measurements and camera used are also examined. The overall vision of implement-ing drone measurements in field trails with nitrogen respond is to implement an algorithm in CropManager that estimates the residual need for nitrogen within the field during the growth season from satellite images of biomass.

Understanding Arctic cold seep and their impacts on the larger Arctic marine ecosystem through remote technology

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Cold seeps are specialized ecosystems fueled by the seafloor release of reduced gases. They are ubiquitous in the world's oceans and have been intensively studied in the 40 years since their discovery. However, seeps in polar regions such as the Arctic received very little attention and represented a major gap in our knowledge of cold seeps. We used ship based remote technology such as towed cameras and ROVs (remotely operated vehicles) to gain a significant understanding of Arctic seeps within the span of only a few years, and in a fraction of the time needed to gain the same level of understanding through more traditional ecological methods and sampling. Our results indicate that Arctic seeps deviate from certain trends considered general of seeps and therefore offer a whole new dimension to our understanding of seep systems. We further reveal unexpected connections to and impacts on the larger marine ecosystem. This includes the potential for shaping evolutionary trajectories of high latitude fauna and the possibility of them functioning as 'refuges' for northern species in the wake of influxes and migration of southern species. Therefore, our methods have allowed for a progression from nearly a blank slate to revealing new, fundamental insight into both cold seep and Arctic ecology within a short period of time.

Remote Sensing of Tailings Storage Facilities

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Minerals and metals are essential for generating and supplying «green» energy and they play an increasingly central role towards a low carbon future. The total consumption of metals (e.g. Al, Co, Fe, Pb, Li, Mn and Ni) is expected to rise significantly. Mining these resources, however, produces immense amounts of mine tailings, which pose a risk to people and the environment. Failure of a tailings storage facility can have a catastrophic physical, environmental and societal impact on the surroundings. In the

past four years only, eight tailings dam failures of significant scale have occurred world-wide.
Given the size of such dams and their often remote location, remote sensing is an important tool to monitor such structures. Here, we present case studies from tailings dams in Europe and South America, for which interferometric SAR and multispectral data have been analysed. Sentinel-1 stacks have been analysed for displacements, which can provide direct indications for weakness zones. For the recently collapsed Feijao Mine tailings dam (Brasil), a detailed analysis is presented discussing the applicability of SAR interferometry as a precursor to potential collapses. Multispectral Sentinel-2 data has been analysed to detect changes in soil moisture, which also can indicate weakness zones inside a dam.

Surveying seals with spectral aerial imagery

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Seals in the waters around Denmark are surveyed regularly by flying over known haul-out areas and imaging the seals with spectral cameras. An automated system is under development that employs nadir-looking thermal infrared and color cameras operating in tandem from an aircraft to identify, count and measure seals rapidly. The inherently low spatial resolution of thermal cameras can only detect warm targets, so their coordinates from the thermal imagery are used to extract portraits from the corresponding high resolution color imagery for identification. Thermal thresholding differentiates warm animals from cooler backgrounds and is applied with discretion to retain cold seals newly emerged from the water and small seals with low thermal contrast. A significant challenge arises when seals are too close together. The thermal camera may detect a cluster of seals as one unit and not discrete individuals. Such occurrences are easily flagged as objects larger than a single seal, however, clusters of seals must still be counted manually. Currently, the candidate seal targets are confirmed

and species identified by supervised review of the selected portraits. To automate this process a convolutional neural network is being trained upon aerial imagery taken by our cameras. Haul-outs often contain seal-size-and-shape patches of seaweed, bushes, wood or rocks as potential false positives. Birds are often present too, so all portraits are filtered by object size and topology to further isolate the seals. Biometric statistics of the seal populations are produced by photogrammetry. A laser altimeter provides accurate altitudes for determining image scale and automatic measurements of seals are made from the major and minor axes of their portraits. However, seals seldom stretch out to their full linear length so there is a negative bias. Manual measurements of seal dimensions are also made from the imagery more accurately, but is time consuming.

The Norwegian Public National Ground Motion Service - InSAR.no

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A public national ground motion service, based on Copernicus Sentinel-1 data, was launched in Norway in November 2018, as part of Norway's collaborative ground segment. The service provides government, industry, scientists, and the general public with a consistent free and open InSAR based ground motion data source. The data are available in a web interface, with tools for simple data analysis, as well as download. Using Persistent Scatterer Interferometry (PSI) software developed by our team, along with over 4000 Sentinel-1 images each year, over 2 billion measurement points are provided, with full deformation time series.

The main motivation for the service is to aid in the management of natural hazards, such as subsidence and landslides, as well as to help monitor critical infrastructure. Ground

motion data is critical throughout the process of natural hazards mapping and monitoring, especially landslides and subsidence.

InSAR data are used to identify moving slopes. Movement rates are also fed into a semi-quantitative assessment process for hazard and risk classification. Long term monitoring during the winter months is assisted by the use of snow protected corner reflector (CR) networks.

While landslides represent the largest potential risk to lives, subsidence may be the natural hazard with the greatest economic impact, due to its impact on critical infrastructure. Rising sea levels threaten coastal cities around the world. In Norway, postglacial isostatic rebound is ongoing, and counteracts the effects of rising oceans. However, many of the coastal cities have expanded, building out into the sea on anthropogenic fill. In most of these areas, subsidence rates far exceed the rate of isostatic rebound, resulting in an increased threat from sea level rise.

Data from the national ground motion service is also being used for several scientific applications. One example is within the field of geomorphology, where active slope processes can now be studied with unprecedented detail and scale.

Ice Maps - Data Fusion of Sentinel 1 and AMSR2 For Sea Ice Segmentation

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Automatically generated high resolution sea ice maps have the potential to increase the use of satellite imagery in arctic applications such as a marine navigation. In this work we explore data fusion and image segmentation techniques with Convolutional

Neural Networks to produce per pixel predictions from Sentinel 1 (S1) images and AMSR2 measurements of Ice/water. The work is carried out under the Automated Sea Ice Products (ASIP) project in a collaboration between the DMI, DTU Space and DTU Compute, which aim to automatize the currently manual process of providing arctic marine users with ice information.
For the study a dataset of more than 900 ice charts and corresponding S1 imagery has been collected, which to our knowledge is the largest scale study of such algorithms to date. The core of our algorithm consists of a Convolutional Neural Network that models image features at different scales by the use of dilated convolutional filters. The architecture of the algorithm further allows us to merge S1 images with AMSR2 measurements in a data fusion approach that exploit the best properties of each measurement. While the 40m pixel resolution in S1 data enables extraction of ice information at an unprecedented high resolution, the AMSR2 measurements contributes with a high contrast between ice and water independent of sea wind conditions.
The current results from the algorithm is an accuracy of more than 95%, which is satisfying for experts in the ice-service at DMI. Future studies in the project will investigate the importance of additional meta data in the ice prediction, such as weather information, sensor viewing angles, geographic location, etc.

Predicting clover proportion in Danish grasslands using Sentinel 2 satellite data: combining functional principal components and generalized additive models.

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Clovergrass is an important crop in Danish dairy production, covering approximately 10% of arable land in Danmark. Most clovergrass leys are fertilized without considering

differences in legume proportion within and between leys. This results in suboptimal distribution of nitrogen within and between fields, as the nitrogen response decreases with increasing legume proportion. Hence, knowledge on the actual clover proportion in a given field is crucial for an efficient grassland management, but accurate data are often difficult to obtain for farmers in practice. Here, we present a model predicting clover proportion at the field and subfield level by making use of remote sensing data available through the Copernicus Open Access Hub. We combined Sentinel 2 satellite data with ground truth data on clover proportion at the subfield level (point level, 10 × 10 m pixel size) obtained using the clovergrass app by AgroIntelli on drone-collected orthophotos. Data were collected in a total of 37 fields on up to two occasions yielding a total of 47 time-field-combinations. In order to handle scarcity in available satellite data due to cloud coverage we used functional principal components (FPC) for feature extraction of satellite bands as a function of time within a 30-day time window prior to clover coverage assessment. The logit transformed clover percentage was then modelled as a function of satellite band FPC scores using a generalized additive model with observations inversely weighted with field size. Field level predictions were obtained as the average point level prediction within a field. Model performance at the point and field level was assessed using a 5-fold 2-times repeated cross validation strategy using all point level observations within a field as hold out sets. Here, we present and discuss our findings concluding that satellite-based prediction of clover percentage in Danish grasslands indeed may be feasible.

Area-based mapping of site index in operational forest inventories using bitemporal airborne laser scanner data

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Site productivity reflects the capacity of a site to produce plant biomass, and provides crucial information for sustainable forest management. It indicates the economically optimal rotation age, selection of tree species in regeneration after harvest, choice of optimal form of final felling, and many other important management decisions in forestry. The most widely accepted measure of site productivity is site index (SI), defined as the average height of dominant trees at a given reference age for a given species. The so-called H40 SI system is used in Norway, defined as the dominant height at the breast height index-age of 40 years. SI is commonly estimated with large errors in operational inventories, leading to economic losses due to incorrect management decisions. Few studies have explored the use of multi-temporal airborne laser scanner (ALS) data for SI determination, and none of those studies have proposed a practical method for mapping SI over large areas. We demonstrate such a method using bitemporal field and ALS data acquired as part of three large-scale forest inventories in southeastern Norway. First, we used kNN classification to identify areas in which forest growth remained undisturbed during the observation period. We then regressed field measurements of SI against bitemporal ALS-derived canopy height metrics. Finally, we used the models to predict SI for grid cells classified as undisturbed, generating SI maps with a grid cell resolution of 15.81 m. User accuracies of class predictions of undisturbed forest ranged from 89% to 95%. Leave-one-out cross validation revealed root mean squared errors of SI predictions ranging from 1.72 to 2.21 m for Norway spruce, and 1.29 to 1.73 m for Scots pine. Thus, we demonstrate a practical method for mapping SI that can be adopted in operational ALS-assisted forest inventories.

High resolution mapping on vegetation distribution in Greater Maasai Mara Ecosystem and its environmental drivers

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The Greater Maasai Mara Ecosystem (GMME) in Kenya is an iconic savannah ecosystem, which inhabits important natural and cultural heritage including the largest remaining seasonal migration of African ungulates and the semi-nomadic pastoralist Maasai culture. Comprehensive mapping of the vegetation distribution and its variation trend in GMME is important for understanding habitat changes across time and space, since recent reports suggest dramatic declines in wildlife populations alongside troubling reports of grassland conversion to cropland and habitat fragmentation due to small-holder fencing. Here, we mapped vegetation distribution in GMME by upscaling high-resolution land cover maps from WorldView3 images (1.2m) from small parts of the ecosystem to the entire region with Sentinel-2 images (10m) using random forest modelling in Google Earth Engine. Meanwhile, trend analysis on the greening rate was conducted to quantify the temporal vegetation changes in GMME using the 250m MODIS NDVI data during the period from 2000 to 2016. Then, we analysed how the vegetation distribution and greening rate responds to different environmental drivers including anthropogenic, topographic, and climatic factors with land use management categories - protected, semi-protected, and unprotected - as an important mediator using generalized linear regression models. A new metric called wildness quality degradation was developed by quantifying the influences from anthropogenic and topographic factors. Our results showed that both anthropogenic and climatic factors affect vegetation distribution and greening rate in GMME, modulated by land use management status. This suggests that land protection is essential for maintaining high-quality natural habitats in the culturally important GMME. High accuracies obtained by the mapping workflow suggested the high potential of Sentinel-2 images in monitoring savannah ecosystem structure and dynamics.

Which set of LiDAR metrics reveals fine-scale habitat structures in wetlands?

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Openly accessible nation-wide Airborne Laser Scanning (ALS) data provide high precision point clouds for characterizing 3D vegetation structure. Until now, the potential of using ALS for wetland mapping and monitoring remains largely unexplored. Here, we use nation-wide ALS data and quantify how different LiDAR metrics contribute to classifying fine-scale habitat structures within wetlands.
For the analysis, we developed an R-based open-source workflow (using LidR) and tested it in the Lauwersmeer, a 100 km2 protected wetland area in the north of the Netherlands. The workflow contained i) pre-processing, ii) calculating area-based LiDAR metrics, and iii) application of a random forest classifier. The calculated LiDAR metrics (at total 26) were grouped based on ecological relevance into a) cover, b) 3D shape, c) vertical variability, and d) horizontal variability. Recursive Feature Elimination (RFE) was used to test the optimal number of LiDAR metrics needed to achieve sufficient accuracy. We used three different classification levels. At the first level, we distinguished overall vegetation from planar surfaces. At the second level, we classified different wetland habitats (forest, high grassland, reedbed, and shrub). At the third level, we differentiated reedbeds into land reed (structurally rich and structurally poor) and water reed.
The results of the RFE showed that the original 26 LiDAR metrics can be reduced to five keeping overall accuracies high (83%, 69%, and 61% for level 1, 2 and 3, respectively). For identifying vegetation, metrics related to horizontal variability were the most important. Within wetland vegetation, height and vertical variability metrics played the most important role. Within reedbeds, height and horizontal variability were key metrics.

Our results demonstrate that nation-wide ALS data can be used to separate fine-scale habitat structures within wetlands. Moreover, our workflow could allow the country-wide mapping of suitable habitat structures within wetlands, with applications for the conservation of wetland birds.

Enhancing water use efficiency using machine learning

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Satellite remote sensing of evapotranspiration (ET) is an essential component of global observation systems and provides critical input for agriculture, water resources management, weather forecasts, climate studies and many other applications. Access to reliable ET estimations is a key requirement within these domains, and if ET can be estimated in high enough spatio-temporal resolution, at field level, it could provide critical input for irrigation managers and farmers to increase water use efficiency and prevent crop water stress. While extensive research has assessed actual ET for water management using Earth Observation data at regional scale, previous technology and satellite sensors have not been optimal to assess ET at field level (farm level). The recently launched Sentinel 2 (optical 10m) and Sentinel 3 (thermal 1km) European Space Agency satellites have a combination of frequent revisit times, novel spectral capabilities and high-resolution images that makes the satellites ideally positioned to derive ET at a field scale. However, while the native resolution of the optical data is sufficient to detect changes at field level, ET estimations are impeded by the coarser resolution thermal sensor. Using advanced machine learning and data mining algorithms we have developed a novel sharpening technique which enhances the spatial resolution of the thermal data from the Sentinel-3 satellite to 20 m, with the use of Sentinel-2 optical data. Those datasets are then used together with meteorological inputs in a physical model of ET. We have validated the technique against flux towers measurements located in Europe, North America and Africa and as well tested it in the

challenging conditions of the Mubuku irrigation scheme in Uganda. Preliminary results indicate that the sharpened thermal data can be used to obtain accurate ET estimations in high-resolution.

POSTER PRESENTATIONS

Detecting pioneer trees in the forest-tundra ecotone by digital aerial photogrammetry

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Climate change is assumed to affect the forest-tundra ecotone and approaches for monitoring these changes are needed. Previous studies have looked at the potential for airborne laser scanning (ALS) to detect trees in the ecotone. In comparison to ALS, digital aerial photogrammetry (DAP) is a relatively cheap and effective method for obtaining three-dimensional data for monitoring tree migration. The aim of this study was to analyse the adequacy of DAP to detect pioneer trees in the forest-tundra ecotone. Field- and aerial images were collected at 31 field sites along a 1100 km latitudinal gradient in Norway. The field data comprised tree heights and crown diameters for 755 positioned trees (mountain birch, Scots pine and Norway spruce). Point clouds with a mean point density of 92 m^{-2} were created from the aerial images by means of image matching. The point clouds were normalized using terrain models from ALS data. Circular polygons with radii defined by the respective observed crown diameter were created around the individual trees, and trees were considered to be

detected if the polygon contained at least one positive height value. The detection success rate was for all trees 73 %. For short pioneer trees (<1m), the detection success rates were 45, 25, and 78 % for mountain birch, Scots pine, and Norway spruce, respectively. Furthermore, the point cloud height distributions of the polygons around each tree were compared to corresponding distributions of tree-less polygons. Both the standard deviation of the heights as well as the mean-, maximum-, and median height were significantly different between tree- and tree-less polygons. Our results suggest DAP to be a promising method for monitoring changes in the forest-tundra ecotone.

Successful semi-automatic count of gulls in a large breeding colony

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Monitoring breeding seabirds is fundamental for conservation and long-term studies, but conventional methods of counting face several challenges, e.g. high dependency on the observer's skills, difficulties regarding the access to the breeding colonies and high disturbances to the breeding birds. Therefore, the use of UAVs is a powerful tool to monitor large colonies of seabirds in remote areas causing low disturbance.

The use of UAVs is linked with one major challenge: a large amount of data needs to be accurately transformed. In general, this process is conducted by manual counts of birds and nests on images. This is highly time-consuming, and in some cases negates the efficiency gained during data collection.

In this project, we conducted a semiautomatic method for counting breeding Herring gulls (*Larus argentatus*) in the uninhabited island of Langli in the Danish part of the Wadden Sea. Using ArcMap 10.5, we trained the computer to detect different classes by their spectral signature in six images taken by a fixed-wing drone (model E384) at 50m

of height. A first automatic detection produced a slight overrepresentation of the real number of birds, with an omission error of ~5 % (birds not detected), and a commission error of ~3% (birds classified by the method, but missed by the manual count). A later fast manual check allowed us to correct for these errors and we established a final precision of ~96±2 %. The total time required to run this semiautomatic method rounded 2 hours, and could be potentially conducted in a similar way with larger amounts of information, only depending on the processing capacity of the computer used, reducing the manned supervision required. In addition, adding an extra band to the sensor may increase the accuracy of the technique, potentially allowing the semiautomatic counting while differentiating species of breeding birds.

Contextual mapping of soil organic carbon and clay content at field extent.

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Shallow machine learning techniques, such as Random Forest, Cubist or Artificial Neural Networks, are now traditionally used for Digital Soil Mapping. These methods relate soil observations with point information extracted from environmental covariates at corresponding locations. This representation of data as vectors at point location only partially describe a soil property. Including spatial contextual information extracted from the covariates around soil observations may constitute a more accurate data representation and lead to improved prediction accuracy. Among the variety of contextual mapping approaches, a specific deep learning algorithm called Convolutional Neural Networks (CNNs) enables the prediction of a soil property at different depths while preserving the interrelation between depths. The present study aims at assessing the use of CNNs for the predictive mapping of two soil properties, namely the soil organic carbon (SOC) and clay content, in a 12-ha agricultural field

located in Jutland, Denmark. Moreover, using CNNs may enable to determine the optimal spatial resolution to select at a field extent. Based on a 20-m grid-sampling scheme, 614 soil samples (i.e. 307 samples for each top- and subsoil horizon) were collected and analyzed for SOC and clay content. Various terrain attributes derived from a LiDAR-based Digital Elevation Model, and 10 spectral channels from Sentinel-2A satellite images (with two different spatial resolutions: 10 m and 20 m) are tested in the present study. The relative importance of the terrain attributes and spectral images will also be computed. Finally, the predictive maps for SOC and clay content in both top- and subsoil will be compared with existing maps generated with shallow machine learning approaches.

High precision urban mapping based on machine learning combining airborne lidar and hyperspectral data

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[The municipality of Bœrum, Norway, together with the aerial survey company TerraTec AS, has secured funding from Regional Research Funds to carry out a research project on precise urban mapping from the fusion of hyperspectral and lidar data. The project consortium includes the Norwegian University of Life Science (grant for PhD position), Norwegian Computing Centre and the Geovekst Initiative. Project duration is 2019-2022 with a budget of 13 MNOK.

Cities have an increasing need to improve their detailed knowledge of the urban area and its components. Important factors of the modern city such as detailed base maps, green/blue areas, biodiversity, respect for urban heritage, sustainable land use, pollution monitoring and extreme weather impact all require a high level of knowledge. We aim to extract this knowledge through advanced maps of the city combining high precision

geometry in 3D (from lidar) with high resolution spectral information of city surfaces and materials (from hyperspectral imagery). Advanced machine learning algorithms will be optimized to analyze and map objects and areas automatically. As a bonus, acquired data will be highly valuable for geologists, hydrologists, botanists, archaeologists and other research communities.

The recent technology enabling this research is the excellent georegistration of both lidar and hyperspectral data, obtaining for each lidar point the combined information of *detailed lidar geometry* and *chemical composition* through its *spectral signature*. In addition, existing basemaps (FKB-B) are abundant and of high accuracy, providing high quality training data for machine learning.
Our presentation will outline the unique possibilities of such data fusion for urban mapping as well as the main challenges (expected and unexpected). By September 2019, the first season of data capture will be completed and we foresee some exciting preliminary results, showcasing the objects and areas so far proven possible to detect and extract.]

Lidar nDSM expression of forest structure patterns for the Danish Biodiversity Map

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The Danish Biodiversity Map, 2014, presents a bioscore of the potential as habitat for threatened and rare species, per 10x10 m cells over Denmark, as an administration adopted, web-enabled tool for applied ecology and planning. In 2018, the bioscores were re-evaluated by inclusion of additional so-called proxies. New proxies included one representing forest structure, based upon analysis of 2014-2015 leaf-off national airborne lidar digital elevation raster data. Whilst lidar point cloud data represent richer

forest structure information, analyses that can utilize single channel raster data, such as nDSM, are still relevant, and more amenable for national mapping. Expressions of canopy complexity with nDSM data have been reported, but the diversity of tree species and densities in Danish forests reduces the ability to simply and adequately describe the structure complexity. Gaps between trees too easily dominate the apparent revealed structure. A novel method was therefore developed to overcome that. This uses object-based image analysis methods to isolate parts of the canopy with relatively low vertical variability. The transitions between these objects are evaluated in terms of the relative height differences, thereby creating a map of canopy steps. To represent the typical form of single tree crowns and uniform forest patches the canopy step map was evaluated via a hexagonal frame (25m and 50 m sides). Hexagon summary variables were subject to biodiversity data multi-variate modelling and significance testing. The forest structure proxy, "variability in crown height per 50 m hexagon", derived from the canopy step analysis, was found to be significant and applied to the 2018 update of the Biodiversity Map. This poster describes the object based image analyses methods applied to the lidar nDSM data.

Automated mapping of buildings

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Urban areas are changing rapidly. In order to document the new situation in topographic databases, efficient methods are required. Vector data of buildings are of special interest. A new methodology for an automated generation of cartographically enhanced data is presented and applied to test material. The results of these tests and the experiences with them will be discussed.

The characteristics of the method are the following. Overlapping high-resolution aerial imagery is used to derive a digital surface model (DSM), from which an orthoimage is derived. Other features are extracted from the orthoimage and the DSM, e.g., the height above ground, normalized difference vegetation index (NDVI), attribute profiles (APs)

and used to carry out a supervised classification using methods of machine learning. The thematic accuracy of the mapped buildings is assessed. The result of such a classification is then cartographically enhanced so that the outlines of buildings will have straight and orthogonal lines. Small areas are removed using a threshold for their size. The extraction of lines is supported by the Hough transform and least-squares adjustment. The assessment of the thematic and geometric accuracy uses reference data for each pixel.
The first example uses images of a medium-format aerial camera, the other examples use images of a large-format camera. Both cameras have four co-registered spectral bands. The used examples represent different types of buildings. The achieved thematic accuracy of the class 'building' was close to F1≈90% (harmonic mean between user's and producer's accuracy) at pixel-wise assessment. Sub-meter accuracy in the planimetric position of the corner points has been obtained in the assessment of the geometric accuracy. The work is based on the research of the author in the last seven years including experiences of course work on this topic for the European Organization of Spatial Data Research (EuroSDR).

Using machine learning for mapping the distribution of acid sulfate soils in northern Sweden

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Acid sulfate soils (AS soils) could release metals and increase acidity in water bodies, and therefore cause fish death. In Sweden AS soils are mainly found along the northernmost coast. These soils are usually associated with organic-rich clay and silt sediments that were deposited, and reduced during anoxic conditions, in brackish-water environments. Due to the postglacial isostatic rebound potential AS soils have been uplifted in many coastal areas and can thereby be exposed to oxygen causing

formation of active AS soils. The previous map of AS soils in this area is based on the distribution of clay and silt in areas uplifted during the past 5000 years. However, recent studies show that AS soils are not only associated with clay and silt, but also with sand. Furthermore, some silt and clay deposits are not AS soils.
We have produced a distribution map of AS soils along the coast of northern Sweden with machine learning. Samples were collected in the field and classified after lab incubation and the dataset were used to train the model. As input data, the Quaternary map of surficial deposits, vegetation and land-use classification based on satellite data, a high-resolution digital elevation model based on LiDAR and parameters based on the elevation model were used. The model predicted three classes: 1) No AS soils, 2) Active on top of potential AS soil, and 3) Potential AS soil.
Initial results show that large coherent areas of active AS soils are predicted to be found in artificially drained areas close to the coast. However, potential AS soil are predicted to be found up to 100 m above sea level. The new distribution map of AS soils can for example be used during planning of infrastructure projects, ditch cleaning and for recognising sites suitable for restauration of wetlands.

Linking structural variables from terrestrial laser scanning with spectral features from WorldView3 satellite imagery – mapping freestanding trees in Maasai Mara

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Integration of WorldView-3 satellite images with terrestrial *light detection and ranging* (LiDAR) scans of free-standing trees in savanna landscapes is used to link species specific structural features with spectral signatures. This research aims to identify and map dominant tree species of free-standing trees (*Acacia gerrardii, Balanites aegyptiaca, Boscia angustifolia, Elaeodendron buchananii and Gardenia ternifolia*) in

the Maasai Mara savannah ecosystem, Kenya using object-based spectral information and essential structural variables from high-density 3D point clouds.

Denmark seen from the air - a unique open-data repository for historical aerial imagery

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Since 2012, the Royal Danish Library has digitized more than 1.5 million historical aerial images from its collection of analog aerial photographs. The digitized imagery consists of both vertical and oblique images originally recorded by several private companies and government agencies between the 1930s and 2010, which means that the data provides a high temporal and spatial coverage of most places in Denmark. All images have been geo-located by the help by volunteers using an online crowdsourcing platform and is freely accessible at the platform and through an Application Programming Interface (API). The archive of digitized and geolocated images offers a unique historical repository, which documents both urban and rural spaces in Denmark throughout the 20th century. Previously these aerial images have, in their analog form, been used in land use and land cover mapping, aerial archeology and for the identification of environmental risk (identification of historical dumpsites and petrol stations). However, as digital, geo-located and open data, these images can represent an interesting historical data-source for other remote sensing work, for example, as reference data for use with satellite (e.g. 1970s – 2010 Landsat and SPOT) imagery and "gap-filling" in longitudinal studies. This poster will present examples of image types held in the repository and how to retrieve data from the platform and API. Moreover, the poster will also reflect on quality of the data and the use of volunteers in data processing.

Combining Sentinel-1 and Sentinel-2 for mapping of Young Forest Stands in Norway

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There is a great need for mapping of young forests in Norway, as a basis for sustainable forest management. Without doing anything, the long-term consequences of this will lead to low forest production, poor timber quality and high risk of snow and wind damage. Within this context, remote sensing can provide an important tool to guarantee an effective and relatively cheap monitoring system. Optical images have the great advantage of being used for forest and vegetation monitoring because they are easy to interpret and easy to access. However, they are severely affected by cloud cover and meteorological conditions, and they are dependent on solar illumination. These problems can be solved using synthetic aperture radar (SAR) sensors, which provide day-and-night and almost all-weather conditions. These two instruments can present intrinsic limitations, which prevent operational young stand mapping while using them separately. In order to overcome SAR and optical system restrictions, this research will assess the potential of fusion of these two sensors for young stand detection. Using very frequent, routine, and comprehensive data from Sentinel-1 and Sentinel-2, we develop a basis for an operational mapping of young stands in Norway. Sentinel-1 provides 8 images for every 12-day period in the southern part of Norway, and more frequently further north, by combining four relative orbits. In the same way, Sentinel-2 also provides 8 images for every 20-day period by combining two relative orbits, but we can only use summer images when the vegetation is developed, and we have sufficiently strong solar radiation to be able to utilize the spectral properties. Clouds, however, are a common problem, and in practice, we can expect that by assembling cloudless pixels we will be able to obtain one such cloudless composite image per year. We show the potential of radar and optical features extracted from Sentinel-1 and

Sentinel-2 to discriminate young stands from other stands. Two important indicators could be 6/12 days repeat-pass interferometric coherence from SAR and the normalized difference vegetation index (NDVI) from optical data. Increasing forest height and density also result in lower SWIR reflectance due to increasing shadowing. As tree height increase, the backscatter increases and coherence decreases. The more vegetation and the number of trees in the area unit represents higher NDVI. To differentiate between young stands that need a pre-commercial thinning and young stands that do not need that, we can use these types of indicators.

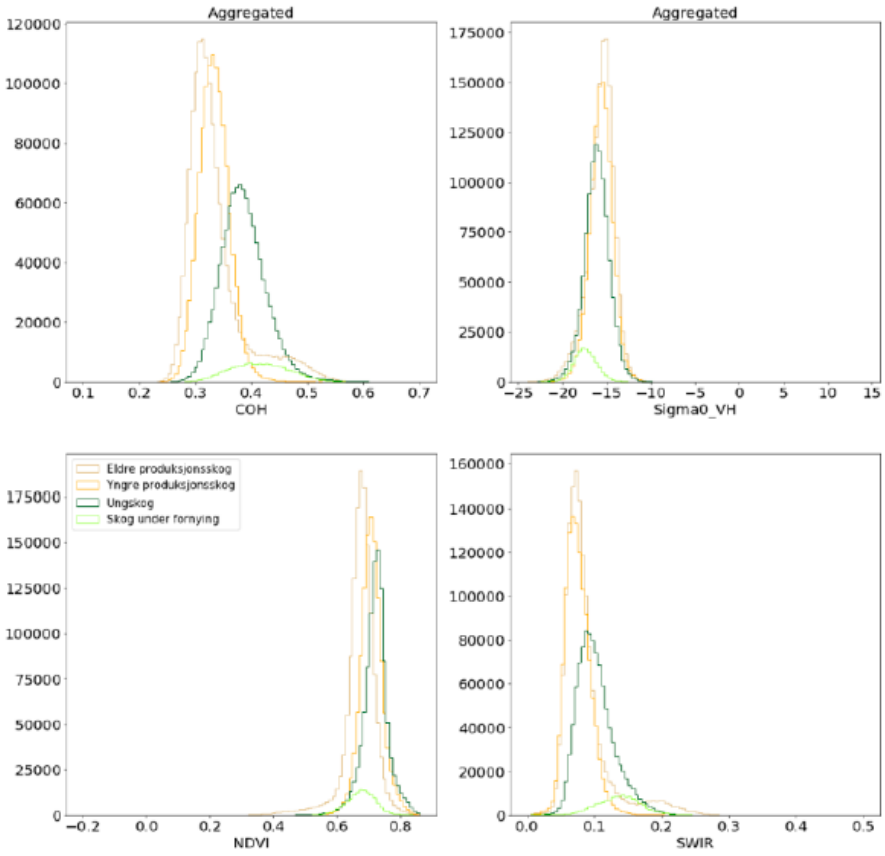

Fig. 1 Comparing histograms of different forest types for four different parameters of optical and radar data

Fig. 1 Comparing histograms of different forest types for four different parameters of optical and radar data

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3D web visualization of elevation models, oblique images, and city models.

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The Danish National Elevation Model (DHM) was produced in 2014-15 and is released as open data. The data set was recorded from aerial LiDAR and processed in a very high resolution to produce a raster that covers the whole country of around 45000 km2 with a resolution of 40cmx40cm per pixel. This new and improved data quality enables new applications in a range of domains such as construction industry, hydrological modeling, and archaeology etc. However, the amount of data and distribution format can be intimidating for non-experts.

We have developed software that is capable of visualizing such a massive 3D data set in real time directly in a web browser. This visualization platform provides easy and intuitive access to the elevation model for everyone. The techniques and performance optimizations behind the rendering software will be explained and demonstrated.

In 2018 the Danish Ministry of Energy, Utilities and Climate further released nationwide oblique aerial images as the first country in the World. This data set is also released as

open data. We have worked on data fusion of the oblique images with the surface geometry of the elevation model. In this case we also developed a web based real time visualization system where we show a fairly detailed 3D model with surface textures everywhere in the country. In contrast to existing services our system covers the whole country with equal data quality and is based entirely on open data sources.

Finally we demonstrate a similar visualization technique with oblique images and 3D city models.

Online demo available at
https://denmark3d.alexandra.dk/skraafoto/
https://denmark3d.alexandra.dk/bymodel/

Mapping and detecting structural changes in a Cytisus scoparius population using UAS-LiDAR

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Natural grasslands are experiencing a severe pressure from anthropogenic influences such as nutrient enrichment, and land-use change which may favor the encroachment of certain shrub species. Plant diversity dynamics in dry, temperate grasslands can be influenced by shrub encroachment that may structurally homogenize the landscape and thereby influencing taxonomic diversity negatively. Dense populations of Cytisus scoparius are known to be problematic in grassland ecosystems, but there is little research on the structural features that characterize the species. This study investigates

how accurate we can classify and map different C. scoparius and estimate structural metrics important for plant diversity. Previous studies have used laser-scanning data (LiDAR) to classify vegetation using traditional two-dimensional techniques, however without exploiting the full capability of LiDAR. Thus, structural measurements are usually delimited to vegetation height and cover. With the integration of novel light weight laser scanners for drone platforms (UAS-LiDAR), we are now able to achieve a much higher level of detail in the resulting point cloud. The increased amount of information means that we can separate different shrub species based on their structural appearances using a 3D point-based classification. Furthermore, it is now possible to compute structural measures as volume, density and biomass, which might be more indicative for assessing the effect from shrubs in grassland areas. Our study demonstrates a workflow of processing ultra-high density point clouds from a UAS-LiDAR system to detect and map C. scoparius. The results are then applied to quantify biomass and biomass change in a semi-natural grassland area in Denmark.

Using UAVs for morphometric measurements of harbour porpoises *(Phocoena phocoena)*

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An animal's body condition directly influences its survival and reproductive fitness, and therefore also the health of the populations. Monitoring cetaceans' morphometric measurements are usually obtained from stranded or bycaught individuals. This may bias interpretations on age - and sex-related growth as well as the status of their

populations. The purpose of this study was to determine morphometric measurements of harbour porpoises *(Phocoena phocoena)* by using overhead video recordings from commercial UAVs (Unmanned Aerial Vehicles). From a customised program that implements the UAV parameters (height, gimbal orientation, camera parameters and Field of View), we were able to obtain the length and girth of 7 individual harbour porpoises of known sizes, very similar to the actual measurements and with a maximum error of 7.4%. Using length and girth, enabled determination of a body condition score (BMI Index) for each animal with an overall average error of 0.8 points. The method was then applied on recordings of free-ranging harbour porpoises with calves to determine the body condition. Furthermore the length was used to predict an approximate age, that all corresponded with the calves being born during spring. This is a very cost-effective monitoring method and a valuable complement to the current body assessment methods from bycaught or stranded animals that can aid in monitoring the growth and health of calves and adults on population scales throughout various seasons.

From geo-spatial datasets to urban tree inventories

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Urban greenery provides a range of ecosystem services and plays an important role in creating liveable cities. Mapping urban vegetation is a prerequisite for the planning and management of these resources for equitable urban development. Although high-resolution geospatial datasets are becoming freely available in many countries, they are often under-utilised for urban planning. Airborne Laser Scanning (ALS), using the technique of Light Detection and Ranging (LiDAR), is increasingly being used to investigate the three-dimensional (3D) structure of vegetation, though the main emphasis has been on trees in forests. Elevation, an important attribute of ALS data from which heights of objects can be derived, helps in classifying vegetation as grass, shrubs,

or trees. Urban areas, with their complex spatial arrangement of features, including buildings, pose challenges for classification and information extraction. In this study, local maxima in elevation models and contours representing tree crowns, generated from ALS data, are used to estimate the locations and structural attributes of urban trees as a first step in creating an urban tree inventory. Building footprints and aerial imagery are used as auxiliary data. Building polygons aid in separating treetops from other local maxima, while Normalised Difference Vegetation Index (NDVI), calculated from the infrared and red bands of the aerial imagery, is very useful in separating trees shorter than 3 m from other features. A workflow, using free national geospatial datasets, is developed in this study, which can be implemented in GIS for applications in urban planning.

An inventory of ice-marginal lakes in Greenland

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The objective of this project is to construct a comprehensive inventory of ice-marginal lakes for Greenland that can be used to assess spatial and temporal trends, relations, and impacts of ice-marginal lakes in the context of a warming climate. It is carried out under European Space Agency (ESA) Climate Change Initiative (CCI) “Glacier and Icecaps”, option 6.
Ice-marginal lakes are of common occurrence in Greenland, and many of them are of endoheric character, i.e. have no outflow. Therefore, they are of great relevance in connection to glacier lake outburst floods (GLOFs).
Due to the often remote location and difficult access to ice-marginal lakes, a remote sensing approach is the only viable method to detect their existence, and to monitor

their changes. In this project, we present an inventory on ice-marginal lakes in Greenland based on Sentinel-1, Sentinel-2 and ArcticDEM.

Object-based frame-wise image analysis of near-surface remote sensing time-lapse image data for study of Arctic plant phenology

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Under climate change, increased understanding of the phenologic responses of low species diversity Arctic environments is a major research challenge. Herbaceous vegetation, with pollination that occurs mainly via insect visitation, represents a key component of the Arctic ecology. It is predicted that these plants will see marked changes in their distributions, related to disturbances to their abilities to set seed. An ongoing research programme, led by Aarhus University, is using multi-year collection of throughout-the-flowering-season, "near-surface remote sensing" time-lapse image data to study Arctic plant and insect phenology. Stabilised, optical wavelength imaging is made of vegetation plots from a height of ca. 1 m, with one minute intervals. A key research issue is study of the patterns of (a) flower visitation by insects and (b) plant seed set. The image data volume (several TB per plot, per season) demands use of automated image analysis methods. Several IA methods are under development, including machine learning solutions, for individual flower and insect detection and labelling, and flower stage (bud, flower, wilt, seed set) recording. A second IA approach, for the individual flower detection and stage recording, has involved development and application of an object-based IA, including frame-wise timeline object interrogation (e.g. "Flower-object-X, was your plot-space, within the following two days, occupied by a seedset object?") workflow. This poster presents the applied research topic, the near-surface remote sensing and the object based methods for individual flower detection

and stage recording, for one patch of ca. 40 Mountain Avens (*Dryas octopetala*) flowers. Comparisons with control data are presented.

Assessment of different DEMs in SAR-based forest monitoring to account for topographic effects

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Forests provide all kinds of ecosystem services and are some of the most biodiverse ecosystems in the planet. During the last century forests have been affected by numerous disturbances, including land use change and climate variability. These disturbances can be tracked using earth observation systems, which offer a continuous and systematic coverage at short revisit intervals. Sentinel-1, offers new possibilities for forest monitoring. However, in mountainous regions steep slopes strongly influence SAR data and their effect need to be considered.
The objective of this study was to assess to which extent the use of different digital elevation models (DEM) such as the Shuttle Radar Topographic Mission (SRTM) DEM, the ALOS Global Digital Surface Model (AW3D30), the TanDEM-X DEM, or LiDAR-derived DEMs influence the effectiveness of geometric, radiometric, and interferometric corrections (e.g. geocoding accuracy, scattering area estimation, topographic phase removal). For such an evaluation, we tested the accuracy of the geocoding process (through the residual offsets), the difference in backscatter coefficient and interferometric coherence between acquisitions from different orbital paths, as well as the presence of residual uncorrected effects. These tests were carried out at two sites

located in mountainous regions from Romania and Spain. The Romanian site is a North-South transect in the southern Carpathians, has humid climate with a dense and tall tree cover, whereas the Spanish site was located in Sierra Nevada and was covered by more open pine forests under a drier climate.
In the experiments testing global DEMs we found the minimal range value for the backscatter was obtained by the TanDEM-X DEM, followed by the SRTM and the AW3D. However, for interferometric coherence the maximum range was obtained for the TanDEM-X DEM, which may be caused by the different penetration depth of C- and X-band.

Estimating Daily PM2.5 using MAIAC AOD – A Case Study of Copenhagen, Denmark

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Human exposure to particular matter (PM) is linked to various serious illnesses. Traditionally, spatio-temporal patterns of PM specifically in urban areas have primarily been assessed using ground measurements and dispersion modelling algorithms. Recent advances in satellite-based datasets, however, also allow assessment of PM concentrations at high spatial resolution. This study uses 1 km Aerosol Optical Depth (AOD) product of Moderate Resolution Imaging Spectroradiometer (MODIS) Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm to assess the spatial and temporal levels of $PM_{2.5}$ (PM less than 2.5 µm in aerodynamic diameter) in the Danish capital during May – July 2018. The main objective is to evaluate the use of MODIS-

based MAIAC datasets in terms of $PM_{2.5}$ estimation at high spatio-temporal resolution. A statistical model is being developed to derive daily $PM_{2.5}$ estimates using 1 km x 1 km MAIAC data and several land use and meteorological parameters. Model estimates are being compared with $PM_{2.5}$ ground monitors. Poster presentation will provide details on the study, data, and results together with strengths and limitations of the research work.
Keywords – Human exposure, PM, satellite data, MODIS, MAIAC, AOD.

Analysis of open remote sensing data using deep learning techniques

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Thanks to the EU Copernicus space programme and Denmarks open geodata strategy there is a wealth of remote sensing imagery available for Denmark with associated meta-information in the form of polygon data.

We would like to present how we combine raster layers and polygon layers with deep learning techniques, to allow training of neural networks for segmentation. We present examples of segmentation of buildings in orthophotos - both with and without associated photogrammetrically reconstructed elevation maps. We also present a system for segmentation of agricultural field parcels in optical satellite images from Sentinel-2. In addition, we will tell you about the use of deep learning techniques to perform visual searches in very large raster areas. This technology is based on the extraction of a compact representation of the contents of an image patch by the use of a convolutional neural network. This representation, called a descriptor, allows us to estimate the probability of two images containing the same object by comparing the similarity of their descriptors. By subdividing an orthophoto data set over Denmark into

48 million image patches and computing descriptors for these, we can perform a search for objects in the entire data set in less than 100 milliseconds.

Online demo available at: https://denmark3d.alexandra.dk/geosearch

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Estimation of potato biomass by using high-resolution small unmanned aerial vehicle and Sentinel 2 multispectral imagery

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Micasense Rededge camera (blue, green, red, red edge, near-infrared) mounted on the fixed wing drone (DJI Matrice 100) was used to obtain 80 m height (ca. 5 cm spatial resolution) images over a potato experimental field with variable rate irrigation and nitrogen fertilization from May to September 2018 in Denmark. Concurrent Sentinel 2 images (blue, green, red, near infrared; 10 m spatial resolution) were also obtained. A method to calculate intercepted photosynthetically active radiation (IPAR) originally developed at field scale was applied and upscaled for each remotely sensed data (drone and satellite) at pixel scale. Spectral indices were also calculated and all variables were correlated to harvested dry matter (DM) at plot scale. The result showed that it is possible to satisfactory upscale and calculate IPAR of potato using drone and Sentinel 2 multispectral data. The estimated IPAR had significant positive correlation with DM ($R2 = 0.74$, $p<0.01$). The indices were also significantly and positively correlated with DM during July and August - the main tuber growth period of the starch potatoes. This indicates that drone and Sentinel 2 multispectral images are useful to estimate IPAR and DM of potato.

Associations between natural surroundings in childhood and schizophrenia later in life – A remote sensing approach to human health

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Higher exposure to natural environments have been associated with lower schizophrenia rates and improved mental health in general. High exposure is linked to low air pollution, improved stress restoration and better immune functioning and is one of the proposed hypotheses behind the pattern of higher rates of schizophrenia in urban compared to rural areas. However, it is still unclear if characteristics of natural environments are behind the association. Here, we investigate the association between schizophrenia and growing up surrounded by four major land cover groups: urban, agriculture, green space, and blue space. We use a subset of the Danish population (943 027 people) and remotely-sensed environmental data from the European Union programme CORINE to determine the major land cover group and vegetation density

around each individuals residence. The effect size of the association from each person's place of residence on schizophrenia rates was estimated using Cox regression and adjusted for air pollution, socioeconomic status, and urbanization. Children growing up surrounded by more natural environments (agricultural areas, green, or blue space) had lower schizophrenia rates compared to children in urban areas. The protective association in agricultural areas was mainly explained through a mitigating association with air pollution unlike the protective association for green and blue space. Rates was associated with the quantity of vegetation in a dose-response relationship for urban and agricultural areas with higher rates for children growing up at the lowest compared to the highest level of vegetation. This study shows that protecting and ensuring access to natural environments especially in urban areas may be important for schizophrenia prevention, whilst being the first study to show that different natural environments may influence schizophrenia rates through different pathways.

Site index predictions for precision forest planting combining harvester data and auxiliaries derived from airborne laser scanning

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For meeting the precision forestry demands, Swedish forest industry is developing the infrastructure for storing individual tree information from logging operations. Building stem data banks allows relating individual tree information to remotely sensed data and GIS products to provide site-specific forest management solutions, such as the recommendation system for precision planting (PlantVal). A key system input is the site index (SI) obtained from tree lists compiled at minimum 0.5 ha, however, planning solutions (e.g., natural regeneration versus planting, the choice of reproductive material

and planting schemes) suited to local changes in terrain configuration and growth conditions would require higher resolution site productivity maps.

The main objective is to investigate the prediction accuracy for site index at various spatial resolutions for six harvested objects of 1.0-4.5 ha, dominated by Norway spruce at 105-120 years age and located in East Middle Sweden. The auxiliary information was derived from the national airborne laser scanning (ALS) survey and consist in the canopy height model (CHM), topographic wetness index, terrain aspect and elevation, available as 2 m resolution rasters.

The methodology comprises the following steps: (1) a tree map is produced for each object by combining the harvester tree lists and the CHM, (2) the tree maps are rasterized into rectangular areas of 0.04-0.49 ha for obtaining the SI and local terrain conditions, and (3) the feasible spatial resolution is assessed by analyzing the prediction errors of linear mixed models linking SI with terrain conditions and CHM data. Propensity score weighting was used to adapt the models to new observations, in a cross-validation approach.

The results suggest that the method can help identifying the spatial resolutions for SI mapping that minimizes the SI prediction errors on each object. Using the propensity scores as observation weights can improve the accuracy of SI predictions, at all spatial resolutions.

Estimation of drought stress in winter wheat using UAV thermal images

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The research focus on detection of drought stress in winter wheat using the unmanned aerial vehicle (UAV) thermal imagery on a field scale. The experiment was performed in 30 m x 30 m plots on coarse sandy soil (Danish soil classification, JB 1) in central Jutland, Denmark. A total of 24 experimental plots with three different irrigation regimes were studied during the period from May to July 2018, extremely hot year in Scandinavia. Thermal information was collected using the UAV DJI Matrice 100 with mounted sensor FLIR Longwave Infrared Thermal Camera Core Tau™ 2. Plant physiological data of stomatal conductance, leaf water potential and canopy cover was measured. These were supplemented by soil water content. The crop water deficit was estimated through comparison of the variability of canopy temperature and plant physiological changes. The resulting correlation indicates that it is possible to quantify crop water status using thermal data. These might be useful to develop a site-specific application of irrigation.

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