**Using satellite snow cover images to enhance performance of snow, glacier and rain runoff projections for hydro power usages**

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**Presentation Type**: Oral

**Abstract:** The quantification of snow, glacier and rainwater contribution to runoff in mountain streams is of major importance in order to anticipate adequate water management of hydropower reservoirs. While seasonal glacier melt contribution depends on general meteorological conditions during the summer months, snow cover is governed by winter precipitation and spring temperatures and direct runoff depends on rainfall patterns (e.g Crochet 2013). Besides direct field investigation such as chemical fingerprints in water samples and artificial tracer experiments (e.g. Finger et al., 2013), the contribution and prediction of snow, glacier and rain can also be estimated and predicted with hydrological models, given that the modeling accounts adequately for snow-, glacier and rainwater runoff. In this presentation we will present an overview of half a decade of research on multi-variable calibration techniques to estimate runoff composition using physically based, distributed models and conceptual lumped models. We will first present the multi variable calibration technique using satellite derived snow cover images, seasonal glacier mass balances and discharge data (Finger et al., 2011), then show how the technique can be used to identify significant impacts of climate change on hydropower production (Finger et al., 2012) and finally demonstrate how modelling technique can be used to enhance estimates of seasonal snow, glacier and rain runoff (Finger et al., 2014). Most of the study sites presented are located in Switzerland: i) Rhoneglacier (39km2; ~50% glaciation), ii) Vispervalley (778 $km^2$; ~29% glaciation), iii) Hinterrhein (53km2; ~17% glaciation) and iv) Silvretta glacier (103km2; ~8% glaciation). Nevertheless, the modelling approach can be applied to any mountainous area in the world. Currently we are developing methods to use the presented techniques for short-term, medium-term and seasonal predictions. Our contribution will conclude with an outlook on how the hydrological predictions could be used for flood risk warnings and enhanced management of hydropower reservoirs.

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**Timing of Retrogressive Thaw Slump Initiation in the Noatak Basin, Northwest Alaska, USA**

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**Abstract:** In the North American low arctic, increased retrogressive thaw slump frequency and headwall retreat rates have been linked with climate warming trends since the mid-20th century, but specific weather drivers of slump initiation timing are less clear. We examined relationships among retrogressive thaw slump initiation and annual air temperature, precipitation and snow cover using time series of satellite imagery and weather station data in northwest Alaska. Synthetic aperture RADAR and optical imagery were used to examine retrogressive thaw slump initiation between 1997 and 2010. Over 80% of the slump features examined in this study first appear within a 13 month span from late June 2004 to July 2005. Remote weather station data show that 2004 and 2005 are among several years exhibiting above average thawing indices and average summer temperatures between 1992 and 2011. However, 2004 is distinct from the rest of the record, with unusually warm temperatures primarily occurring early in the thaw season between April and early June, and including two intense precipitation events in May. Regional weather reported by the NOAA National Weather Service also reflects these local findings. Snowmelt timing in 2004 corresponded with warmer air temperatures and precipitation between April and May, exposing the ground surface more than two weeks earlier than average for 2001-2012 within the Noatak Basin. Future rates of thaw slump initiation may be linked with changing trends in the timing of weather, in addition to general climate warming.

**Repeat terrestrial laser scanning surveys to describe and quantify slope dynamics in an Arctic glacier basin (Austre Lovénbreen, Svalbard 79°N).**

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**Abstract:** Slopes in Arctic environments are subject to different time-scale and amplitude processes. The combination of glacier constraints, snow drifting phenomena, water flow, rock quality and permafrost thawing, contribute to the shaping of slopes. Repeat terrestrial laser scanning surveys have been conducted in the glacier basin of Austre Lovénbreen, in the Norwegian high Arctic.

Each year, laser scans were acquired at the annual snow maximum (late April/early May) and at the expected annual snow minimum (late August). Digital surface models derived from acquired point clouds are at the base of all subsequent analysis. They allow for the description of the slopes ground surface in Summer and of the slopes snow cover in Spring. They also provide general information on the slopes rugosity, slope angle, and curvature. A first assessment step therefore consisted in providing an overview of the main characteristics of the slopes. The settlement of the snow cover on these slopes constituted the second step.

Seasonal and year to year comparisons were then undertaken. At the seasonal scale, the global volume of snow was derived by subtracting Spring and Summer surface models. The comparison of the amount of snow present in Spring and the remaining snow in Summer gives an insight on the perennial snow accumulation usually found at the bottom of slopes and caused by snow drift but primarily caused by avalanches.

Year to year comparisons provided estimations of rock movements from Summer to Summer. Rock avalanches volumes were derived. Inter-annual variability of the snow cover settlement was also highlighted. It showed major differences from one year to the other. The consequences of these differences on the residual snow and rock movements identified later in the season could also be discussed.

Slopes dynamics seem to be linked to major climatic events such as heavy rainfalls or intense snow precipitations rather than to general seasonal indicators. Rain precipitations are the major cause of rock avalanches and of rock movements in general. Snow storms account for major snow accumulations and potential resulting large avalanches.

**Architecture comparison of an in-situ data processing application applied to glacier mass balance analyse**

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**Abstract:** Analysing environmental evolution and particularly analysing the snow cover evolution of a glacier requires to collect frequently and regularly data from the site during a long time period. Because of the bad weather conditions at polar latitudes and because of the cost, daily satellite imagery is not always accessible. And if the frequency is too low, fast events like flood or blanket of snow are ignored. In order to fill this gap, a set of ground based autonomous automated digital cameras were placed on the ridges surrounding the glacial basin (Hydro sensor flow, frenche ANR scientific program). They have been programmed to take 3 pictures a day, thereby generating a large database. Due to the extreme conditions of the site and the oblique view of the pictures, various processing (cleaning, cropping, projecting, classifying, ... ) have to be applied in order to extract some information.

Until now, these different tasks have been performed using several tools, which need more or less human interactions and which usually do not support mass processing. Moreover, due to the different disturbances, the processing workflow may vary. There is a need to provide a tool that can dynamically adapt the processing, support the quantity and be generic enough to fit other needs. We had proposed a model for a stand alone tool which can classify a large variety of phenomena with a minimum of human interactions. The image processing was split into several elementary jobs. Each job was an implementation of a specific complex algorithm in order to correct one particular disturbance. These jobs have been deployed as a web service and integrated in the cloud computing.

Cloud computing is a set of resources, servers and applications, offered "as a service" and accessible from the network. It provides several advantages like scalability, modularity,

easiness of access, ... Moreover large amount of data can be loaded in the cloud computing. Three different models of cloud exist. It is called public cloud when resources are managed by an external provider. It is called private cloud when they are internally managed. And when both configuration are mixed, it is called hybrid cloud.

Depending on the number of images to be processed and the variability of the workflow, the architecture to use in order to have the best performance may vary. In our case, the performance of the application is measured by the time processing. We have compared different architectures: a computer, a server, a virtual private cloud computing, a private cloud computing and a public cloud computing. Further, we can create a metric to select the best architecture to use according to different input factors.

**Sub-ground permafrost data management and complementation by remotely sensed data for circumpolar assessment of changing Permafrost within PAGE21**

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**Abstract**: Sub-ground permafrost characteristics are monitored as part of GTN-P (Global Terrestrial Network on Permafrost). A Central Data Management System (DMS) has been developed within EU FP7 by the PAGE21 project (Changing Permafrost in the Arctic and its Global Effects in the 21st Century, FP7, www.page21.eu), and Arctic Portal for permafrost monitoring parameters of GTN-P and others. Each component of the DMS, including parameters, data levels and metadata formats were developed in cooperation with the GTN-P, the International Permafrost Association (IPA) and Arctic Portal. The researchers can now edit, visualize and download standardized datasets, metadata, charts and statistics of all relevant parameters for a specific site in all partner countries (http://gtnp.arcticportal.org/). Remotely sensed information complements these borehole datasets with surface and near-surface measurements. Surface characteristics such as temperature, moisture, snow, surface waters dynamics, and land cover can be used to support modelling of sub-ground thermal properties. In addition, remotely sensed data offer the possibility to capture landscape heterogeneity and thus

representatively of in-situ point measurements. Specifically data available within the framework of the ESA DUE Permafrost and STSE ALANIS-Methane projects are utilized for circumpolar characterization of GTN-P sites with respect to multi-scale applications within PAGE21. Further on new datasets on Landsurface Temperature (SSMI), landcover and moisture indicators are developed circumpolar. Higher resolution satellite data are used to characterize the spatial heterogeneity of the PAGE21 sites.

**Developing remote sensed environmental indicators for responsible resource development in Canada's Arctic**

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**Presentation Type**: Oral

**Abstract**: Natural resource potential in Canada's Arctic is both exceptional and not yet fully discovered. Within or around the Bathurst caribou habitat alone, there are five mining operations (a zinc-silver complex, 3 gold mines, and a diamond mine), with more developments likely to come. On the other hand, subsistence harvesting of caribou and other wildlife remains a central part of the culture and relationship with the land of aboriginal peoples in the Arctic. How to resolve the confliction between the two interests is one of the biggest questions facing responsible northern resource development. One of root-causes of the confliction is the lack of detailed quantitative information on impacts of resource developments on caribou and other wildlife, which could result in unwarranted fears among parties. For example if 1%, 10%, or 50% of land area within the Bathurst caribou's summer range (or calving ground or winter range) was affected by industrial developments, to what degree would the herd's productivity and population be affected? Ability to address such question before the habitat has been affected is highly desirable. To develop this ability, we need first to develop environmental indicators capable to adequately describe the complex relationship among resource development, habitat, and caribou. Over the vast, difficult-to-access Canadian arctic landscape, satellite remote sensing

is arguably the most cost- effective way for monitoring many of these environmental indicators. In this presentation, we will use the Bathurst caribou habitat as the case study to illustrate the methods and results on the development of remotely sensed environmental indicators, their relationships with caribou's productivity and population changes, and the potential of using these quantitative relationships to answer what if questions on resource developments' impacts on caribou.

**Regional correction of 'satellite' near-surface chlorophyll**

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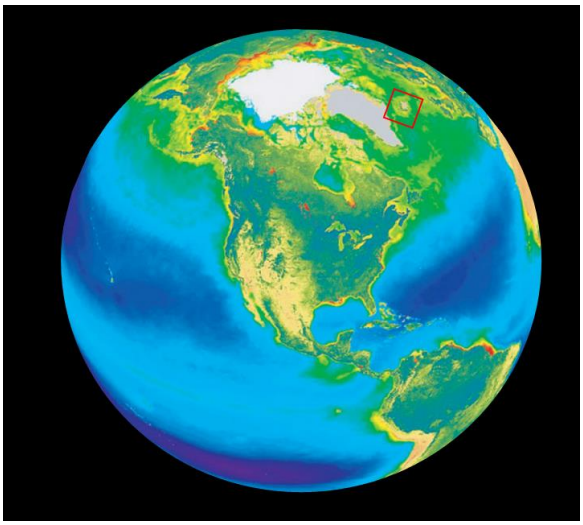
**Presentation Type**: Oral

**Abstract**: At the Marine Research Institute (MRI) in Iceland, chlorophyll *a* has been measured in water samples collected around Iceland for decades. Looking back, the results may at best be used to obtain a fair idea of the average chlorophyll values one might expect in the region. Obviously information on seasonal changes in phytoplankton biomass, on annual basis and for any given area is desirable for various ecological studies. Satellite remote sensing of ocean colours, e.g. that offered by the GlobColour Project (GCP), now facilitates this more than ever. Nevertheless, one must be aware of and preferably take care of possible systematic biases that may obscure the results in some regions, especially those defined as case II waters.



Here we explain our approach to the above-mentioned task, including the development of a statistical model for explanation of some of the residual variation from simple correlation between measured surface chlorophyll from water samples and the GCP's standard variable on merged chlorophyll estimates from satellite records (CHL1_mean), matched by the day and location (L3 pixel). The correlation coefficient (adjusted $R^2$), calculated for simple linear regression on logarithmic transformed chlorophyll values, is 0.48 for our research area, defined (60° - 72° N and 3° - 33° W). The statistical model that best explained the residual variation in our data set (62% of the total variation explained) is a General Additive Model (GAM) using time of the year (month), bottom depth, as well as the year of sampling, as the

independent variables.  On the other hand, for the prediction of regionally corrected chlorophyll (minimizing systematic error that may be reasonably explained) we prefer to use a multiple linear regression model (LM), in spite of somewhat lower prerformance. Accordingly, a LM was composed with regard to the mentioned GAM, based on a comparable set of explanatory parameters (reducing the total explained deviance to 57%). Skipping the parameter year of sampling, in order to obtain a timeless model for predicting corrections of GCP chlorophyll values, further reduces the explained deviance in our data set to 51%. To some extent this may be due to low number of 'out of season' *in situ* observations on chlorophyll concentrations, an issue that needs to be amended.

It is apparent form climatological studies, as shown in another presentation at the symposium, that the local revaluation in accordance with the above mentioned regional statistical model make improvements to the downloaded GCP data in question, especially in early spring and late in the growth season.

**Phytoplankton climatology according to regionally corrected satellite chlorophyll in sub-arctic waters**

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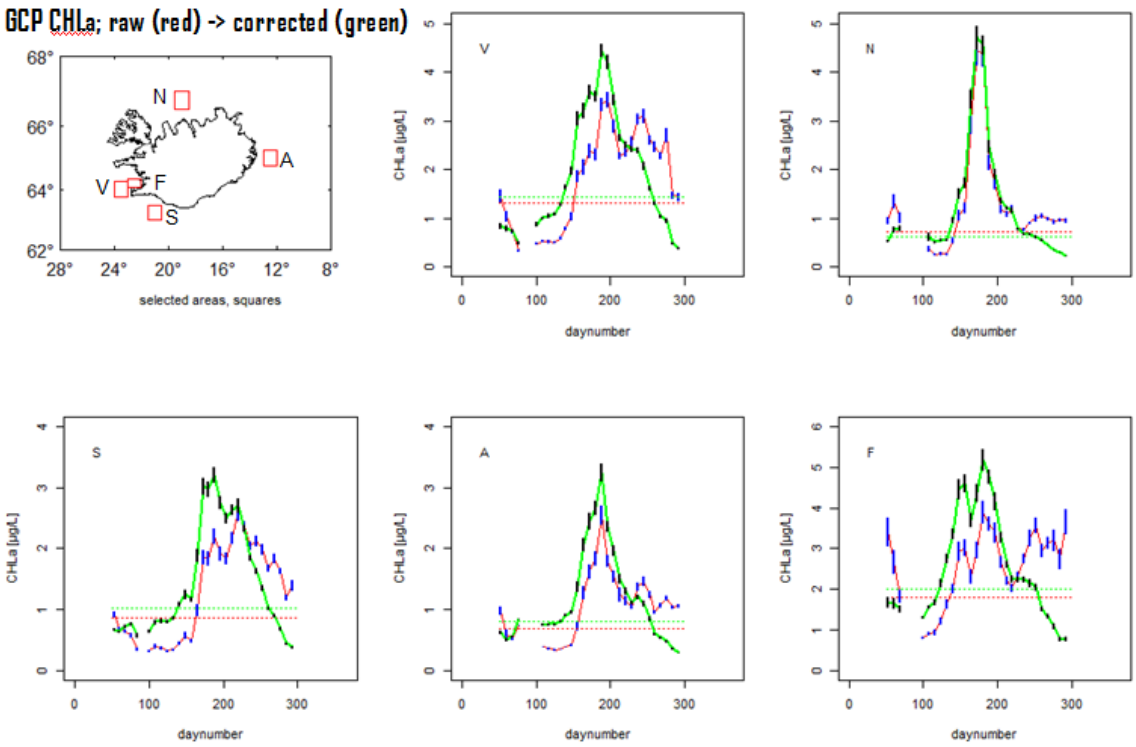
**Abstract:** Records of multi-spectral reflections off the world ocean surface, obtained by remote sensors onboard polar-orbiting satellites, facilitate studies of phytoplankton climatology. The GlobColour Project (GCP) makes efforts to merge the available records from both NASA and ESA and offer continuous data-series for the last 16 years (1998 – 2013). The values on merged surface chlorophyll-a are averages of carefully coordinated chlorophyll estimates, i.e. adjusted from the standard conversions from ocean colors. Regardless of the origin of satellite chlorophyll values, one needs to be aware of and take care of possible systematic biases that may obscure the results regionally, especially in those areas defined as case II waters.

A statistical model was developed (Guðmundsson et al.) for regional correction of GCP's near-surface chlorophyll in the subarctic waters around Iceland (60° - 72° N and 3° - 33° W). The presentation is based on study of the corrected data set, predicted according to that model. The study underlines the need for local corrections of satellite chlorophyll in the region (as apparent from the attached figure). Results from climatological studies on corrected surface chlorophyll data will be presented, revealing the distribution of selected definable indexes for characterization of phytoplankton seasonal growth pattern. Furthermore, mapped results will be shown, along with discussion of apparent changes, and these results view in context with distinct local trends. Finally, the prospects for growing interest for information offered by GCP, or comparable data, for diverse ecological studies, *e.g.* on the variations in fish or zooplankton reproduction success, as well as for research on climatological changes, will be outlined.




Surface chlorophyll-a seasonal change, according to records downloaded from the GlobColour Project. Stipled lines show the calculated medians for chlorophyll 1998 – 2012, for the respective selected areas.

**Assessing Carbon Balance in Ecosystems of Alaska: the Role of Remote Sensing**

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**Presentation Type:** Oral

**Abstract:** Arctic and boreal ecosystems in Alaska are experiencing rapid changes in major ecosystem composition, functions, and processes as the result of the onset of climate change. These changes pose risks to the large quantity of carbon stored in the ecosystems. To understand the current and future potential risks to ecosystem carbon balance in Alaska and to evaluate climate change policy options, remote sensing, in combination with simulation modeling, is required and serves an integral role for these needs. In this paper, we will outline the context of a major and comprehensive carbon balance assessment in Alaska, and discuss roles, methods, and challenges of remote sensing products used. New remote sensing products required for the assessment of ecosystem carbon balance include general land cover, different surface water classes, wetland types, active layer depth, presence and depth of permafrost, and wildfire burn scars. The availability and quality of these data products play a significant role influencing the size and distribution of uncertainties associated with estimates of carbon and methane fluxes produced for the assessment.

**Digital vegetation map of the central highlands of Iceland**

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**Abstract:** In early 2014 a digital vegetation map of the central highlands of Iceland was completed. This is a milestone in vegetation mapping of the country which has been ongoing from 1955. The new map is in a scale of 1:25.000, it covers 42.700 $km^2$ or 41% of the country. The vegetation is classified into 100 different plant associations and 14 different land types (e.g. glaciers, lakes, rivers, barrens, etc.). Vegetation cover is divided into four classes. The map is based on a revision of earlier published and unpublished maps with the aid of new aerial photographs and satellite images. The new map will be a public domain and available online for the public and private sector. The digital map and associated data set will allow multiple usages, such as comparison of distribution of different vegetation types in the highlands, evaluation of vegetation cover and condition of common grazing lands, and in environmental impact assessments. The new map confirms the sparse vegetation of the central highlands as it reveals that only 31% of the mapped area has a vegetation cover of ≥ 10%. Of vegetated land the most widespread vegetation types are moss heaths (14%), heathlands (10%) and wetlands (5%).

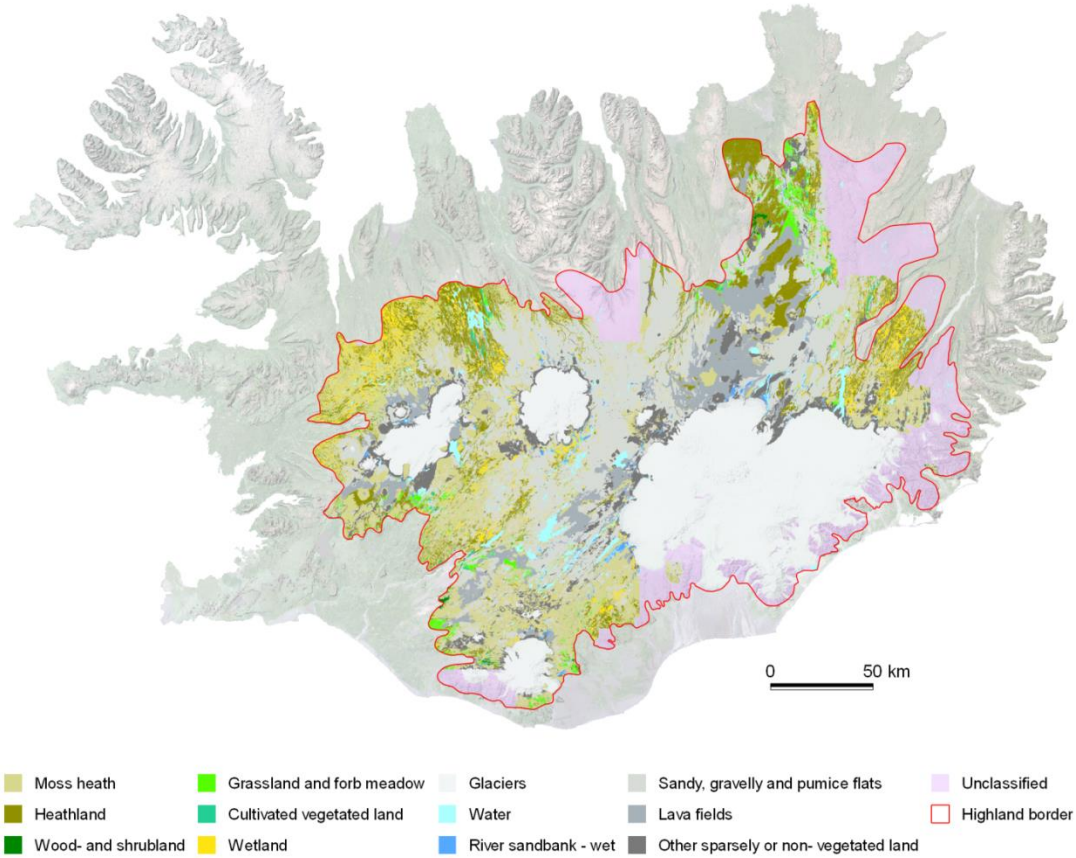


Fig. 1. A simplified vegetation map of the central highlands of Iceland.

**Natura Island: Mapping habitat types in Iceland using remote sensing**

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**Abstract:** Natura Island is a project aiming at mapping habitat types in Iceland. To map the whole of country in a short span of time it was decided to use satellite images and remote sensing as the main method. To define habitat classes extensive ecological research was carried out in 2012-2013, prior to the fieldwork satellite images were classified using unsupervised classification scheme to achieve preliminary habitat classes. Image selection were based mainly on two criterias; diversity in habitat types (based on expert knowledge) and distribution of images to cover different parts of the country. In order to describe the classes loosely, ancillary datasets were used, such as; vegetation, soil erosion , soil, bedrock, forests, cultivated land and hydrology. After processing the ecological data 61 habitat types were identified in 11 main groups. To locate these habitats RapidEye satellite images are classified, using field work locations as training grounds along with other data such as vegetation information, elevation model and topographic position index (TPI). It is not realistic to use automatic classification on all habitat types, so some types are classified using semi automatic processing such as segmentation, prior knowledge and screen digitized. Preliminary results from the project will be presented at the symposium.

**Use of extremely high resolution images to upscale carbon fluxes and stocks**

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**Abstract:** When aim is to understand the regional carbon dynamics, detailed spatial information about vegetation and soil properties is needed, as carbon dynamics in the Arctic are known to vary greatly between vegetation types. Existing land cover maps especially in the Arctic are typically produced in such a coarse resolution, that they can't pick up the level of actual vegetation patterns. It is known that tundra ecosystems consist of a mosaic of different vegetation and other land cover types, which are distributed in the landscape in a more fragmented manner than probably in any other biome. This fragmentation is a consequence of several factors connected to a harsh arctic climate. The sparse vegetation cover is prone to different physical factors like wind and snow erosion, which in combination with frost and permafrost dynamics impacting soil properties, cause small scale variation in vegetation and land cover. We have studied vegetation, land cover, and soil properties around two $CH_4$ and $CO_2$ flux measuring tower sites: Sodankylä (67°22N', 26°39E'), Finland, and Tiksi (71°36N', 128°53'E), Russia. Using field data and Geoeye, Quickbird and WorldView satellite images and aerial photographs, we are developing land cover, leaf area index, biomass, and soil property maps. These are the most relevant data sets, when variation in carbon fluxes in the landscape is explained. Typically, segmentation techniques are needed, when these kinds of extremely high resolution images are classified. However, due to lowness of the vegetation causing lack of shadow effects, even pixel based methods can produce relatively good results in the Arctic environments where trees are not anymore found.

**Hyperspectral characterisation of arctic vegetation**

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**Abstract:** The motivation for this research is to improve our ability to map and monitor the vegetation of the subarctic region using satellite remote sensing data. Such mapping almost always depends on associating a particular vegetation type, phenological or physiological state with the variation of its ability to reflect electromagnetic radiation, as a function of wavelength in the visible and near infrared parts of the spectrum. This, termed the 'reflectance spectrum', can be estimated from satellite imagery, and the ability to do so has already proved enormously valuable in mapping subarctic environments around the world, and monitoring their response to climate change and to local or regional disturbances such as from industrial pollution. However, such measurements are very much more useful if the reflectance spectra of characteristic vegetation types are first accurately measured in the field. This can, if enough measurements are available, give a spectral library against which satellite images can be measured to deduce vegetation type and state, in a way that can be standardised over large areas. By combining the field measurements of reflectance spectra with plant-physiological measurements, it can also become possible to infer physiological status (for example, degree of exposure to an atmospheric pollutant) from satellite imagery. This is much easier if the spectra are measured at high spectral resolution (1-10 nm). Although most satellite remote sensing systems currently give fairly low spectral resolution (around 50-100 nm), spectra measured at higher resolution can often allow us to recognise which regions of the electromagnetic spectrum have the greatest diagnostic potential. Furthermore, new satellite systems are being developed that will provide significantly higher spectral resolutions. Thus, fundamentally, the goal of the research described here is to greatly expand the spectral library of arctic plants and vegetation types at high spectral resolution.

Specific investigations are described from the area around Abisko in northern Sweden and around Kirovsk on the Kola Peninsula, Russia. Results are presented for a range of functional types including fruticose lichens, dwarf shrubs, shrubs and trees, and some general principles of measurement are identified. We propose the establishment of a freely accessible online library of

reflectance spectra.

**Remote Sensing of Circumpolar Sub-Arctic Forest Tree Species Information using Spectral Mixture Analysis and Multi-Temporal Satellite Imagery, Northwest Territories, Canada**

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**Presentation Type:** Oral

**Abstract:** Natural resource management in circumpolar subarctic forests in northern Canada requires land cover and tree species identification for improved decision making for sustainable resource development. For example, in the Northwest Territories (NWT) of Canada, the Biomass Energy Strategy and the Boreal Woodland Caribou Action Plan require detailed forest resources information, from which resource inventory and maps of wildlife habitat, landscape disturbance, and vegetation cover can be produced. These are important for industry sectors through policy compliance and for obtaining permits for exploration, and also for government for resource monitoring programs and inventories. However, the acquisition of forest information is often time-consuming and expensive due to the large areas involved in remote, inaccessible northern forest terrain. Therefore, satellite-based remote sensing is increasingly used to derive these products over large areas. Although information regarding the distribution of tree species has been obtained using remote sensing in forest regions in southern Canada, these approaches are either unsuitable or have not been tested in these higher-latitude, more sparse forest stands of the NWT. In these lower density, open forest stands, satellite spectral response patterns (pixel signals) are highly mixed due to the presence of tree shadows and understory cover together with the trees of interest. To resolve this and obtain information about the trees only (essentially factoring out the other non-tree parts of the signal), spectral mixture analysis (SMA) was used to

obtain information at sub-pixel scales for sunlit canopy (trees), sunlit background (forest understory) and shadow. SMA, and specifically multiple endmember SMA (MESMA), was investigated as a method to obtain tree species information represented as the leading or dominant species of a forest stand using Landsat Thematic Mapper imagery. Furthermore, the performance of multi-temporal imagery was investigated for its potential to improve forest leading-species discrimination accuracies. Results showed that improvements of over 30% at the 95% confidence level were achieved using multi-temporal imagery (overall accuracy = 79 %, Kappa = 0.67) compared with individual (single-date) mid-summer imagery. This was based on four coniferous and deciduous tree species with validation obtained at 48 ground plots. Recommendations for future work include expanding the scope of the study to other areas, assessing additional northern boreal forest types in the NWT, and the integration of this derived information into a polygon-based forest inventory system used for operational management through the enumeration of leading species composition at the pixel scale.

**Onset of the growing season and annual plant production in relation to climate on Svalbard, mapped by MODIS data**

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**Presentation Type:** Oral

**Abstract:** The study area is the High Arctic archipelago of Svalbard, located between 76°30' and 80°50'N. The goal of this study is first to use MODIS Terra data (the MOD09Q1 and MOD09A1 products, both with 8-day temporal composites) to map the onset of the growing season on Svalbard for the 2000 to 2013 period interpreted from field observations, and then to analyze the relationship to climate and annual plant production. Due to a short and intense period with greening-up and frequent cloud cover, all the cloud free data is needed, which requires reliable cloud masks. We used a combination of three cloud removing methods (State QA values, own algorithms, and manual removal). This worked well, but is time-consuming as it requires manual interpretation of cloud cover.

Phenological field observations along tracks close to the village Longyearbyen on Svalbard has been established. These tracks are designed to detect the phenological variation at a scale that can be compared with MODIS data. The onset of the growing season is defined as flowering catkins of arctic willow (*Salix polaris*), as is represents well the general greening of the vegetation. The onset of the growing season was then mapped by a NDVI threshold method, which show high correlation ($r^2$=0.60, n=25, $p < 0.001$) with field observations of flowering of arctic willow. However, large bias was found between NDVI-based mapped onset and field observations in bryophyte-dominated areas, which indicate that the results in these parts must be interpreted with care.

On average for the 14-years period, the onset of the growing season occurs after July 1st in 68.4% of the vegetated areas of Svalbard. The mapping revealed large variability between years. The years 2000 and 2008 were extreme in terms of late onset of the growing

season, and 2002 and 2013 had early onset. Overall, no clear trend in onset of the growing season for the 2000-2013 period was found. The MODIS mapped onset of the growing season shows significant correlation with June and early July temperatures, but the analyses also indicate that snow rich winters probably delay the onset in some areas. A preliminary study also indicate that time-integrated NDVI from onset of the growing season to peak of the season correspond with field measurements of annual plant production on graminoids, and show two-fold variations between a short/cold growing season compared with a long/warm growing season.

**Vegetation trends in Iceland, 2002-2013, based on MODIS NDVI product**

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**Presentation Type:** Oral

**Abstract:** NDVI trends have documented increases in northern vegetation throughout much of the North since the 1980s. These increases have been correlated to increases in temperature, especially summer temperatures. A linear trend analysis of the MODIS NDVI product from 2002-2013 for Iceland showed an average significant NDVI trend of 0.002 NDVI units/year ($p < 0.2$). However, there was more area with significant decreases (20,296 km2 ) than increases (11,501 km2 ). Increased NDVI can be seen in rings around most of Iceland's glaciers. NDVI also increased along most east-facing coasts. Unlike more remote areas of the Arctic, the vegetation in many parts of Iceland is significantly affected by patterns of human land use. Increases in NDVI due to decreased sheep grazing, planting of trees, and revegetation projects are evident. Decreased NDVI was evident due to the construction (2002-2009) of Kárahnjúkar, a large hydroelectric project on two rivers flowing from the northeastern side of Vatnajökull, Iceland's largest glacier.

**Effects of Climate Fluctuation to Subpolar Ural and Subarctic Forest Changes**

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**Presentation type**: Oral

**Abstract**: In the last years, changes of plant cover at protected areas of subarctic and subpolar zone reflecting general features of natural ecosystems' transformation affected by regional or global natural factors, mainly climatic, attract attention of researchers. The purpose of the present work is to reveal principal trends of changes for some quantitative characteristics (crown density, special composition index, NDVI and other) of forest phytocenoses at submountain and mountain areas of the sub-Polar and Northern Ural using remote sensing materials taken for period 1980-2013 of high (*Landsat TM 4,5*) and mean (MODIS) resolution combination in order to evaluate trends of vegetation/carbon budget changes.

The principal changes of forest phytocenoses at the specially protected areas of the Urals (Northern and sub-Polar Urals) for a period of 24 years according to the Landsat and MODIS satellite images. In the last decades, old-aged forests at the plain part of the Northern Urals saw stable statistically valuable trends of NDVI index decrease due to forest aging and windfalls which negatively affect the productivity of forest ecosystems (Terra-MODIS images for a period of 2000-2010). The main 'catastrophic' after-effects of windfalls and fires were followed by a slow demutation restoration of plant cover at single plots. The sub-Polar Urals had preferably positive trends of NDVI index changes. The crown density index of non-disturbed phytocenoses of larch forests and open forests at the ecotone between forest and tundra zones grew by 1-2% on average per year. For transect of Subpolar Ural-North Ural the intensity of forest changes is reduced. The number of windfall increasing per year is increase and can be consider as a non-direct climatic effects.

The work was done in frames of the project of Seventh Framework Programme (FP7-SPACE-2013-1) "Enabling Intelligent GMES Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems (North State)" (№ 606962).

**Mapping the distribution of circumboreal forest carbon with field measurements, airborne and spaceborne LiDAR**

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**Presentation Type:** Oral

**Abstract:** The boreal forest accounts for one-third of global forests1, but remains largely inaccessible to ground-based measurements and monitoring. It contains large quantities of carbon in its vegetation and soils2, and research suggests that it will be subject to increasingly severe climate-driven disturbance3. Here, we use a suite of ground, airborne (PALS, ALTM) and space-based (Landsat, MODIS, ASTER, ICESat GLAS) measurement techniques to derive the first satellite-based map of aboveground carbon, for the entire circumboreal forest biome. Incorporating these mapping techniques with uncertainty analysis, we estimate total aboveground carbon of 38.0 ± 3.1 petagrams. This boreal forest carbon is mostly concentrated from 50 − 55º N in eastern Canada and from 55 − 60º N in eastern Eurasia. Both of these regions are expected to warm > 3º C by 21004, and monitoring the effects of warming on these stocks is important to understanding its future carbon balance. Our maps establish a baseline for future quantification of circumboreal carbon and the described technique should provide a robust method for future monitoring of the spatial and temporal changes of the aboveground carbon content.

**Quantitative interpretation of spectral characteristics of terrestrial vegetation for habitat characterization and mapping on the North Slope of Alaska**

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**Presentation type:** Oral

**Abstract:** Integration of quantitative, ground-based vegetation data with the analysis of remote sensing imagery informs habitat mapping and evaluation in support of sustainable development of natural resources. Detailed vegetation composition and structure measurements were collected using a line point-intercept sampling approach over a variety of tundra vegetation types on the North Slope of Alaska during summer 2012. We compared ground vegetation characteristics to remote sensing metrics at multiple scales. Handheld spectrometer measurements and vertical ground photographs were collected concurrently with the vegetation sampling. We also obtained high-resolution satellite imagery (GeoEye-1 and WorldView-2) that was collected over our sites during the peak of the summer growing season. Finally, Landsat imagery and image composites were compiled for the study area. Atmospheric correction was performed for Landsat and high-resolution satellite imagery and results were compared, including comparisons to the handheld spectrometer data. We then compared spectral indices derived from the spectral data and satellite imagery to vegetation cover and structure summaries with the objective of scaling up vegetation properties based on the satellite spectral information. Across all vegetation types, a strong linear relationship ($R^2$ = 0.73) was found between total live cover at the top of the canopy and midsummer Landsat NDVI. This comparison of Landsat NDVI and vegetation cover provides a quantitative understanding is one example demonstrating how NDVI relates to vegetation conditions on the ground.

**Vegetation and ecosystem transformation on Finnmarksvidda, Northern Norway, due to reindeer grazing pressure**

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**Presentation Type:** Oral

**Abstract:** Reindeer herding in northern Scandinavia is associated exclusively with the Sámi people and the herding can be traced back to the historical hunting of wild reindeer. During the 15th century, entire herds were domesticated and part of the Saami people became reindeer-herding nomads. This way of life has been preserved for parts of the herding communities until today. During the past decades considerable changes have occurred in the herder's society. Since the 1960's reindeer management has been rapidly modernising followed by general socio-economical processes. The changes in the herders society is also reflected in an increased pressure on the reindeer ranges. During the past decades the lichen ground has been severely depleted. The unfortunate situation has been documented in many scientific studies. Modern technology expressed through remote sensing has made it possible to perform mapping and monitoring of the changes going on.

In 2005 the authors published a survey paper describing the changes in the lichen cover for the period 1973-2000. In this presentation the recent development of the changes will be presented. New Landsat images for the years 2006, 2009 (Landsat 5/TM) and 2013 (Landsat 8) are processed and added to the earlier presented time series. By this the oscillation of the lichen cover can be traced for a time period of forty years. Until 1980 Finnmarksvidda plateau was regarded as one of the most favourable lichen region in entire Scandinavia, where lichen communities represented more than one third of the entire landscape. In 1987 this amount was reduced to 19 percent for the winter ranges with a further decrease in 1996 (8,4 %) and 2000 (5,6 %). In 2006 a minor increase in the lichen cover (6,7 %) was recorded, with an approximate equal situation in 2009 (6,1 %). The last step of this time series shows a new degradation of the lichen cover in 2013, representing 4,0 percent of the winter region.

The dramatic increase in the reindeer population, especially during the 1980's, is regarded as one of the main explanation of the problems faced today. In 1976 the reindeer

number in Finnmark was estimated to 90 000 animals. In 1988 the stock of herds had increased to 210 000. During the same period the vegetation types rich in lichen were considerably reduced compared to one decade before. Damages to the vegetation surface, visible as erosion flats or erosion ridges, were reported at several localities within the spring and fall areas. Concerning current data on reindeer body-weights, reproduction rates, and mortality describes an even more discouraging picture of the today´s herding. Much of a similar situation is reported from other herding areas, both in Finland and Sweden.

**Arctic Land Cover Change Index**

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**Abstract:** The Conservation of Arctic Flora and Fauna (CAFF, http://www.caff.is/) is working to produce a set of satellite-based remote sensing products with a geographic focus on the pan-artic. This will consist of three components: (1) Existing Moderate Resolution Imaging Spectroradiometer (MODIS) satellite standard products of relevance to arctic processes will be leveraged and converted to a more arctic-friendly projection facilitating a top-of-the-world analysis perspective. The satellite products will be developed for use by different stakeholder groups i.e. GeoTiffs, PDF maps, and animated gifs will be provided to accommodate to a wide audience with different analysis and visualization needs; and products will be organized by terrestrial, marine, coastal, and freshwater disciplines. (2) Landsat images will be used to generate additional remote sensing products at fine scale (30 meter). (3) A remote sensing needs assessment workshop will be conducted at the December 2014 CAFF Arctic Biodiversity Congress (http://www.arcticbiodiversity.is/about-the-congress?id=109). At a minimum the following products are expected from this project: normalized difference vegetation index (NDVI), land surface temperature, land cover change, albedo, sea surface temperature (SST), primary productivity, sea ice concentration, sea ice concentration change, ice dynamics, ice type (age), surface water mapping and large lake (>4 $km^2$) chlorophyll.

**Modeling Soil-Surface Organic Layers in Alaska's Arctic Foothills using a Digital Terrain Model and Vegetation Indices**

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**Presentation type:** Poster

**Abstract:** Accumulated organic matter at the ground surface plays important roles in arctic ecosystems. These soil-surface organic layers (SSOLs) influence temperature, moisture, and chemistry in the underlying mineral soil and, on a global basis, comprise enormous stores of labile carbon. Understanding the dynamics of SSOLs is a prerequisite for modeling the responses of arctic ecosystems to changing climate. Here we investigate what physical and environmental factors control the distribution of SSOLs and whether these variables can be used to model SSOL distribution. Using field measurments, a digital terrain model, and remotely sensed imagery, we analyzed the relationship between topography, normalized vegetation difference index (NDVI) and the corresponding thickness of SSOLs one a point by point basis within a 47 $km^2$ study area in the central Arctic Foothills. Results show the best physical predictor of SSOL thickness and distribution is a combination of duration of direct sunlight during the growing-season, upslope-drainage-area, slope gradient, and elevation. This produced an overall adjusted R-squared of 0.55. Using these new estimates of SSOL thickness and distribution, we estimate that SSOLs in the Arctic Foothills typically contain 6.6 ± 0.8 kg C $m^{-2}$ and that our 47 $km^2$ study area contained approximately 1.9 ± 0.52 teragrams (Tg) of carbon (± = 95% c.i.). NDVI values will be included in further analysis with the expectation of improved correlations, mapping ability and carbon stock estimates.

**Regional patterns of ice-wedge degradation since the mid-20th century across northern Alaska**

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**Abstract**: Ice-wedge polygons are abundant in the continuous permafrost zone of Alaska's North Slope, creating complex microtopography and strong, meter-scale contrasts in hydrologic regime, vegetation, and ground ice conditions. Recent studies indicate that abrupt and dramatic landscape changes have occurred in recent decades in the coastal plain of the eastern North Slope due to thawing of the uppermost portions of ice wedges. Thaw of the wedges results in subsidence (thermokarst) and the formation of flooded pits along the polygon margins. Secondary impacts, including thermal degradation of permafrost and spatially variable flooding and drainage of polygon centers, affect areas well beyond the thermokarst pits themselves. Archives of historical (1948, 1971, and 1977–1985) and modern high-resolution imagery support regional-scale detection of ice-wedge degradation across bioclimatic (north-south) and geomorphic (east-west) gradients spanning the North Slope.

To characterize the timing and extent of ice-wedge degradation, we delineated small waterbodies in historical and modern imagery for a network of ten 43 $km^2$ study areas spanning the North Slope, including sites where we collected field data in 2010–2012. We conducted spatial analyses of imagery to delineate waterbodies in color-infrared aerial photography (1979–1985), and modern high-resolution satellite imagery (2009–2012), using an iterative process by which we set a threshold near-infrared reflectance value and then assessed the extent to which pixels with reflectance values beneath this threshold corresponded to water or land. Spatial analysis of surface water extent indicated increases in the total area occupied by flooded thermokarst pits at 7 of 10 landscapes since circa 1980 (median +10.6%; maximum 77.8%). The 3 landscapes that lacked appreciable change are located in the western North Slope; photography from 1948 indicates similar surface water distribution to that present today. Increases in the

extent of flooded thermokarst pits were evident across a broad range of soil landscapes with divergent surficial geomorphology (e.g., alluvio-marine, eolian sand sheet, yedoma) and climate regime (e.g., coastal to continental). Because the ice wedges underlying the North Slope have developed over millennial timescales, the large increase in surface water at most sites suggests that the observed changes represent an episodic event. Our results also indicate an intriguing regional pattern of ice-wedge degradation, in that thermokarst pit development appears to have occurred much earlier in western parts of the North Slope. Future work involves remote-sensing and field-based approaches to identify drivers of the changes and regional patterns observed since the mid-20$^{th}$ century.

**Treeline Structure and Changes in Nenets Autonomous Region**

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**Presentation type:** Poster

**Abstract:** Russian Arctic treeline, i.e. the tundra-taiga ecotone, remains largely understudied despite the urgent need for understanding the climate related changes in vegetation distribution and tree growth that have been predicted for the Arctic regions, and have already begun to occur at some parts of Arctic treeline.

In remote Arctic areas it is almost a prerequisite to use remote sensing methods. We studied the current treeline structure in the previously unexamined area in the north-western European Russia, the Nenets Autonomous Region (67°15′ and 67°18′ N and 49°52′ and 49°57′ S). By comparing two satellite images of the area acquired at different years, we aimed at defining whether changes in NDVI and related biomass changes have been occurring in the area between the years 1989-2009. These changes would also indicate the change in treeline forest structure and location. We applied radiometric corrections and used COST technique when performing atmospheric corrections on the compared images before gaining NDVI values that we further converted into above ground biomass values to study the possible shifts in vegetation.

We analyzed the climate data of the area aiming at identifying possible climate trends that may have occurred during the past decades. Our aim was also to describe the area within forest stands, at the forest border, and in the nearby tundra. We studied several properties of local tree species (Picea obovata and Betula pubescensenrh.) at the site level. In addition, we produced a ground cover classification map that we further used for predicting the possible future distribution of vegetation into tundra sites. The accuracy of the performed land cover classification was tested based on field observations and field records that were made for the support of satellite images, as well as based on the aerial photographs that were obtained during the helicopter rides to and from the study area. In addition, we managed to acquire old Russian field maps that contain accurate data on different types vegetation distribution and other land cover types.

Our results show that no significant changes in vegetation have been occurring at our study site during the years 1989-2009. Our climate data supports the results, with no significant trends in temperature or precipitation trends during the years 1959-2009. At different parts of the treeline, there were statistically significant differences between some of the field layer vegetation characteristic components, such as the occurrence of lichen, mosses, herbs, B. nana and Ledum. The ground cover vegetation groups characterize well the differences between different site types. We find the used methodologies suitable for such studies and suggest that they provide effective, fast and non-costly ways of studying vegetation changes in remote Arctic areas.

**Unmanned Aircraft Systems**

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**Presentation Type:** Poster

**Abstract:** The goal of the U.S. Geological Survey's (USGS) National Unmanned Aircraft Systems (UAS) Project Office is to support the integration of UAS technology into the process employed by USGS scientists to support informed decision making across the Department of the Interior. This integration will directly benefit the nation by creating the opportunity for USGS and our partners to gain access to an increased level of persistent monitoring of earth surface processes (forest health conditions, monitoring wildfires, earthquake zones, invasive species, etc.) in areas that have been difficult or nearly impossible to obtain information before. Each of the Bureaus in the Department is eagerly investing in the investigation of UAS to support their mandated missions. The USGS is working closely with partners from NOAA, DoD, DHS, NASA and academia to apply UAS technology in support of our specific and overlapping missions. The Dept. of the Interior has acquired Raven and T-Hawk small UAS systems to conduct proof-of-concept projects; initiate UAS operator training; and submit numerous Certificate of Authorization (COA) requests to the Federal Aviation Administration. The USGS UAS Project Office staff is recognized as subject matter experts not only for DOI but also internationally. More information can be found at http://uas.usgs.gov/. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

**Nytjaland: Land Cover Classification for Iceland**

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**Presentation Type:** Poster

**Abstract:** The Agricultural University of Iceland has classified the land cover in Iceland. The classification is based on Landsat 7 and Spot 5 satellite images. Vegetation in Iceland differs in many ways from what is found at other cold Boreal to Low Arctic areas of the world. A large part of the country is characterized by barren black volcanic areas and biological crust and moss surfaces. Classification is made challenging by a complex land cover mosaic.

Land cover was separated into 12 units, with 10 representing land in addition to water and snow/glaciers. The 10 units for land are: 1 cultivated land/hayfields, 2 shrubs and forests, 3 grasslands, 4 saturated wetlands, 5 damp wetlands, 6 rich heathlands, 7 poor heathlands, 8 moss land, 9 poorly vegetated land, and 10 half vegetated land.

The separation of land cover classes was based on unsupervised classification. The images were grouped into 200-250 classes initially for each image with further classification into the 12 final classes based on 10,000 control points. The classification was subsequently verified in the field with a total of 9000 ground truth points placed on the images by stratified random sampling, easily accessed by roads.

The Nytjaland land cover map was not fully completed due to financial constraints, but a more simplified classification was made for the remainder of the country (about 30%). The simplification was done by merging classes. Vegetated land was reclassified into one class. Wetlands and damp wetlands were also reclassified into one class. The Nytjaland land cover database is therefore a mixture of two different classifications, with two map editions.

Error Matrix was used to measure the maps accuracy. Error Matrix compares the relationship between the result of classification and ground truth data showing which classes intermix with each other. Several descriptive measures can be obtained from the error Matrix, such as “Overall accuracy”. The “Overall accuracy” factor is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. “Producer´s accuracy” indicates how well training set pixels of given category type are classified. The

Producer factor is computed by dividing the number of correctly classified pixels in each category by the number of training set pixels for each class.

The Overall accuracy for the 12 classes map is 65% and 73% for the 8 classes map. The Producer´s accuracies range from 59% (saturated wetlands) to 85% (damp wetlands), for the 12 classes map. The Producer´s accuracies for the 8 classes map range from 50% (shrubs and forests) to 79% (vegetated dry land).

The two classes with the lowest accuracy are those which were merged in to the classified map (shrubs/ forests and cultivated land/hayfields). The error matrix shows that "grassland" and "hayfields" intermix. Classes that intermix with each other are primarily those that do not have clear boundaries (gradient), such as "rich"- and "poor heathlands", "poor heathlands" and "moss land", and "damp wetlands" and "rich heathlands".

# Detection of potential arable land with remote sensing and GIS: A Case Study for Kjósarhreppur

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**Presentation Type:** Poster

**Abstract:** Arable land is a valuable natural resource. In 2010 the Farmers Association of Iceland concluded that there was a need for a standard for evaluating potential arable land, which could be used in planning and strategic planning for land use. In the Planning Act from 2011 municipalities are required to define both arable and potential arable land.

Arable land is well defined but it is not as straightforward to define potential arable land. The current definition of arable land includes areas below 200 m a.s.l, with slope less than 10º, not in protected areas nor in wetlands larger than 3ha and with minimum continuous size of 3 ha.

The aim of this study was to use this definition to develop a digital method to define and locate potential arable land that would be possible to use in strategy planning and planning work for land use. The municipality of Kjósarhreppur was used as a case study.

The following sources were used for the analysis: satellite image data, aerial photographs, the Nytjaland Land cover map, Icelandic Geographical Land Use Database, contour lines, elevation points, and roads, lakes and rivers from the municipality of Kjósarhreppur.

SPOT-5 and Quickbird images were used for the classification, both supervised and unsupervised classification were used to define arable and potential arable land. Supervised classification gave better results than unsupervised. Subsequently, attempts were made to identify potential arable land using normalized difference vegetation indices. This method was found to be easier to use and gave better results than the image classification method.

According to the current analysis, assuming a minimum continuous size of 3 ha, potential arable land in Kjósarhreppur municipality is 2,483 ha including 220 ha of wetlands. If the requirement of the continuous size is reduced to 2 ha or 1 ha the potential arable land would increase to 2,530 ha and 2,575 ha respectively.

**Assessing the uncertainty in permafrost lake margin detection from varying spatial resolution Synthetic Aperture Radar (SAR)**

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**Presentation Type:** Oral

**Abstract:** Arctic and sub-Arctic freshwater ecosystems play a significant role in the carbon cycle. This leads to a necessity to quantify these remote inland waters on the landscape-scale. Synthetic aperture radar (SAR) is suitable for monitoring hydrological properties including permafrost thaw lakes, which are a typical landscape unit in tundra environments.

However, the accuracy of detecting lake margins remains to be addressed. Quantifying uncertainties in lake extent with respect to spatial and spectral resolution is crucial, since such data are used to monitor (often subtle) changes in land surface hydrology associated with permafrost conditions. This study discusses the advantages and disadvantages of different frequencies with respect to spatial resolutions for TerraSAR-X, ALOS PALSAR (L-band) and ENVISAT ASAR (C-Band) data for a site on the Yamal Peninsula in the North of West Siberia. Furthermore, lake size-frequency distributions and the apparent scale issues are investigated.

This study contributes to the COLD Yamal (Combining remote sensing and field studies for assessment of Landform Dynamics and permafrost state on Yamal), a Joint Russian-Austrian project.

**Assessment of photogrammetry Structure-from-Motion compared to terrestrial LiDAR scanning for generating Digital Elevation Models. Example in a polar basin, Spitsbergen 79°N**

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**Presentation Type:** Oral

**Abstract:** Digital Elevation Model (DEM) is a key tool for modelling spatially dependent processes including water flow, altitudinal dependent precipitations or, in the case of glaciers, assessing mass balance. Thus, observation at the most accurate spatio-temporal scale of elevations is needed to better understand some key processes. DEMs are classically generated from satellite imagery (sparse temporal datasets), aerial photography, airborne and ground-based LiDAR, and GPS surveys. In order to allow for periodic DEM acquisition with lower logistics requirements than the afore mentioned techniques, we assess the resolution and quality of ground based, oblique view pictures as the source for generating elevation models using Structure from Motion (SfM) algorithms.

Using a commercial off the shelf digital camera, sets of pictures of a same structure – whether the slopes of a single mountain or a whole glacier basin – taken from various points of view are acquired. Selected features are identified on the images and allow for the reconstruction of the three-dimensional point cloud after identifying the camera positions and optical properties. Adding Ground Control Points allows for converting qualitative point clouds into DEMs. Operating in a snow covered environment might appear challenging due to the lack of relevant features but we observed that the SIFT algorithm was nevertheless able to grab enough reference points for 3D reconstruction. Furthermore, while the challenging climatic environment of an Arctic region (Ny Alesund area, 79°N) is not a problem for such a measurement technique, the low lying spring sun with its associated cast shadow appears as a significant limitation both due to the lack of relevant features in the shadow and lack of color dynamic in some of the low-grade digital camera we used.

To assess the quality of measurements, comparisons were made on different areas (cliff, slopes, ridges, snow accumulation) between SfM and LiDAR acquisition. Some examples of these comparisons and complement of these two methods of data sampling and processing, will be shown and explained in this presentation.

**High spatial and temporal resolution remote sensing of a rapidly eroding segment of arctic coastline**

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**Presentation Type:** Oral

**Abstract:** Eroding permafrost coasts in the Arctic are increasingly susceptible to the combined effects of declining sea ice extent, more frequent and effective storms, sea level rise, and warming permafrost. However, several observation sites have yet to firmly link changes in decadal-scale erosion rates with changing environmental conditions in the Arctic. This partially results from the broad temporal gaps in suitable remote sensing observations necessary to address the relative role of potential drivers of change on an annual and seasonal basis. Here we used high spatial resolution optical satellite imagery acquired at high temporal resolution between 2008 and 2013 to better understand recent patterns of erosion for a 9 km segment of permafrost coastline at Drew Point, Beaufort Sea Coast, Alaska. Mean annual erosion rates for the open water periods between 2008 and 2012 were 16.3 m/yr and in line with heightened erosion documented here between 2002 and 2007. Mean annual erosion ranged from 6.7 m in 2010 to 22.5 m in 2012, with 2008, 2009, and 2011 eroding between 16 and 19 m. In 2008 and 2011, ~70% of the annual erosion occurred in the early portion of the open-water season. In 2008, this was likely a result of two large early season westerly storm events and in 2011 this was likely a result of relatively warm near shore sea surface temperatures. Additional comparisons will be made between remotely sensed, near-shore sea ice free conditions relative to storm timing and other potential drivers for which data is available during the observation period. We will also highlight the potential role of high-spatial and temporal resolution spaceborne radar imagery in Arctic coastal erosion studies. This study shows how detailed observations of arctic coasts, now possible using high-spatial resolution satellite imagery,

provide an essential step forward in linking changes at the Arctic land-sea interface with those in the broader Arctic system.

**A Circumpolar ENVISAT ASAR GM map of backscatter statistics for utilisation of global soil moisture datasets**

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**Presentation Type:** Oral

**Abstract:** Soil moisture controls the partitioning of runoff and infiltration and is a driver of ecosystem respiration and carbon exchange with the atmosphere. In order to better understand biogeochemical cycles at high latitudes remotely-sensed soil moisture products need to be assimilated into land surface models. This study assesses the suitability of coarse resolution soil moisture products from global datasets for application in polar environments. The so called 'scaling layer' allows interpretation of the coarse resolution soil moisture product (Metop ASCAT 25 km grid) at local scale and is based on medium resolution SAR (ENVISAT ASAR GM 1km) according to the approach of temporal stability (Wagner et al. 2008). High correlations suggest that the coarse resolution measurements are applicable on local scale and good agreement with *in situ* measurements can be expected. It has been derived for the entire Arctic for the PAGE21 (Changing Permafrost in the Arctic and its Global Effects in the 21st Century) project (www.page21.org) funded by the European Commission FP7 framework. Approximately 14000 single GM datasets have been orthorectified, normalised, resampled to tiles which allow efficient spatial-temporal analyses of backscatter. Comparability is however also impacted by landscape heterogeneity specifically with respect to abundance of small lakes. A masking scheme for areas where higher spatial resolution C-Band SAR (ASAR WS 125m) is available has been developed (Sabel et al. 2012). The majority of GTN-P sites north of 55°N is characterised by $R^2 > 0.5$. This database is the key dataset for downscaling as well as upscaling of surface wetness.

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**The role of remote sensing in the study of changing northern high latitude ecosystems**

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**Abstract:** Northern high latitude terrestrial and aquatic ecosystems are undergoing unprecedented change in structure and function as a result of rapid climate warming. The response is manifest in myriad ways, including the melting of ice and the thawing of permafrost, and an increase in the frequency and severity of disturbances, as well as through changes in vegetation productivity, thermokarst dynamics, lake abundance and cover, runoff patterns, river and lake ice thickness and cover duration, snow cover timing extent and duration, and coastal erosion. Such changes have substantially altered energy, water and biogeochemical cycling in these regions, which has important global-scale consequences for climate and society. Recognizing the vulnerability of these ecosystems to change, scientists and decision-makers have identified a critical need for research that employs existing and new remote sensing technologies and methodologies to observe, monitor and understand changes in Arctic and Boreal ecosystems. Remote sensing offers repeat observations of dynamic land surface and biophysical properties from local to regional scales over multi-decadal time periods. The changes occurring across the northern high latitudes can be characterized and quantified using remote sensing techniques based on information from various sensors and platforms. Remote sensing can also play a critical role for scaling field measurements to landscape and regional scales, parameterizing and evaluating models, and testing hypothesis of key ecosystem processes.

The unique capabilities provided by remote sensing imagery and data products have allowed us novel views of ecosystems and their dynamics over multiple scales in time and space across all regions of the globe. Here we offer a synthetic discussion of the recent and emerging science focused on understanding the dynamic landscape processes in northern high latitude ecosystems using a variety of remotely-sensed information collected from passive and active

sensors on ground-, aircraft- and satellite- based platforms. To consider the evolution of these technologies, methods and applications over recent decades, we look at key examples from the scientific literature that range from the use of radar sensors for local-scale characterization of active layer dynamics to the circumpolar-scale assessment of changes in vegetation productivity using long-term records of optical satellite imagery. We then assess the current state of the science by surveying new and emerging research on remote sensing of changing Arctic and Boreal ecosystems based on our organization of both a scientific journal special issue and a scientific conference session focused on this topic. We use these examples to demonstrate the development of new techniques and data products, as well as to highlight the challenges of remote sensing in northern high latitudes regions. Finally, we discuss our involvement in planning and early research related to large-scale national and international research activities in Arctic and Boreal ecosystems (e.g., NGEE-Arctic, DUE-Permafrost, NASA-ABoVE). Going forward, remote sensing will continue to play an important and expanding role in these and other scientific programs for characterizing landscape dynamics, scaling process-level knowledge, driving and informing simulation models, and developing data products for decision support.