

# NORTH STATE

## Enabling Intelligent GMES Services

### Final Report

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## Abbreviations

CROBAS	Tree growth and CROwn BASE from carbon balance
DI	Disturbance Index
DVM	Dynamic Vegetation Model
EO	Earth Observation
ET	Evapotranspiration
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
GHG	Greenhouse Gas
GIP	GMES Initial Operations
GPP	Gross Primary Production
GSE	GMES Service Element
ICA	Independent Component Analysis
IPCC	Intergovernmental Panel on Climate Change
IR-MAD	Iteratively Reweighted Multivariate Alteration Detection
LAI	Leaf Area Index
LPJ-WM	Lund-Potsdam-Jena Wetlands Methane
MAI	Mean Annual Increment
NDVI	Normalized Difference Vegetation Index
NEE	Net Ecosystem Exchange
NFI	National Forest Inventory
NPP	Net Primary Production
PFT	Plant Functional Type
PRELES	PREdict Light-use efficiency, Evapotranspiration and Soil water
SAR	Synthetic Aperture Radar
SRS	Simple Random Sample

SVM	Support Vector Machine
TanDEM-X	TerraSAR-X Add-On for Digital Elevation Measurement
UAV	Unmanned Aerial Vehicle
VH	Vertical Polarisation Transmitted/Horizontal Polarisation Received
VHR	Very High Resolution
VV	Vertical Polarisation Transmitted/ Vertical Polarisation Received
YASSO	Yet Another Simulator of Soil Organic matter

## 1 Project context and objectives

The boreal forest, with an area of 11.35 Mkm<sup>2</sup>, is the largest terrestrial biome, and stores about 270 Pg C (32% of the world's forest C stock) (Pan *et al.*, 2011). Europe contains 25% of the world's boreal forests and has a global lead in forest industry and forest management expertise. Climate warming is predicted to be strongest at high latitudes (IPCC 2007) and can therefore dramatically affect the European economy through its impacts on boreal ecosystems (forests and peat lands) as sources of wood and other products.

One of the greatest sources of uncertainty in climate predictions is the feedback between climate and changes in land surface processes (IPCC 2007), with northern high latitudes being particularly important because of the vast store of carbon in northern forests and peat lands. Such feedbacks occur through a range of inter-linked processes, including the following key land processes:

1. Modifications in the spatial and seasonal patterns of vegetation, snow and albedo alter the associated radiative and biogeochemical balances and have major land surface and atmospheric feedbacks. Increased vegetation activity absorbs more carbon dioxide but also reduces albedo acting as both a positive and negative feedback.
2. Disturbances, particularly fire and clear felling, contribute to the inter-annual variations in atmospheric carbon dioxide in the Northern Hemisphere.

Knowledge on the carbon and water balances and their effects on GHG fluxes is crucial to understanding these feedbacks. Current estimates of flux rates, based on national forest inventories, are highly uncertain and lack spatial resolution. For instance, Russian forest resources information is largely outdated and the development trend of forest biomass is poorly known. There is therefore an apparent need to develop a system to monitor high latitude changes and to assess their consequences. The key objective of North State was therefore:

**To develop innovative data analysis methods that exploit the new generation of multi-source data from Sentinels and other satellites in an intelligent framework that interfaces state-of-the-art carbon and water flux models with a view monitoring of these fluxes over boreal Europe with the aim of reducing their current large uncertainties. This will provide a paradigm for the development of products for future Copernicus services that will be applicable far beyond its specific application to the boreal zone.**

The general logic of North State approach was that land cover and a number of structural forest variables were predicted from Sentinel, and other satellite imagery with the help of reference data. The accuracy of the assessment was evaluated. The predictions were input as raster images as parameters to carbon flux models. Using the models, the carbon balance variables were computed also in raster image format. Two model chains were applied: the Lund-Potsdam-Jena Wetlands Methane (LPJ-WM) Dynamic Vegetation Model (DVM) and three semi-empirical models of University of Helsinki: PREdict Light-use efficiency, Evapotranspiration and Soil water (PRELES), Tree growth and CROwn BASE from carbon balance (CROBAS), and Yet Another Simulator of Soil Organic matter (YASSO).

The variables, predicted from satellite data were land cover type, plant functional type or main tree species, logging events, tree height, stem basal area, site fertility type, and stem diameter. The growing stock volume could also be used in the Helsinki models if reference data for height and basal area were not available. Similarly, if some other forest variables were not available, they could be estimated with the help of the existing variable predictions. The Leaf Area Index (LAI) or alternatively fraction of Absorbed Photosynthetic Active Radiation (fAPAR) were additional key model parameters.

The LPJ-WM Dynamic vegetation model considered all land cover classes whereas the Helsinki models were applicable in forest area only. Furthermore, the LPJ-WM model operated at coarse scales, and was mainly driven by climatic and land cover variables and fAPAR. The Helsinki models utilized all the above-listed forest variables and additionally the climatic variables. It was applicable up to the 10-meter full resolution of Sentinel-2. The computed carbon flux variables were Gross Primary Production (GPP) and Net Primary Production (NPP). The Net Ecosystem Exchange (NEE), evapotranspiration (ET) and forest stem volume increment (MAI) were additionally computed with the Helsinki model. The results could be compared with the carbon flux values of the measurement towers that were located within in the Finnish sites. The estimate of stem volume increment for Finland was compared with the national forest inventory data.

Four sites of approximately 150 km by 150 km (Figure 1) were defined for the method development and demonstration. These sites were located in eastern Iceland in subarctic forest and shrubland, in southern Finland (Hyytiälä), and Komi oblast in boreal forest, and in Finnish north boreal forest (Sodankylä). The fluxes were also computed for the European boreal zone up to the Ural Mountains.



Figure 1. Approximate locations of the four test sites and boreal forest site in North State. (Hallormsstadur, Iceland; Sodankylä, Finland; Hyytiälä, Finland; and Pechora-Ilych nature reserve, Komi republic, Russia.

The main satellite data used were from Sentinel-2, Sentinel-1, Landsat-8, and Suomi NPP. Hyperion imagery from EO-1 satellite and UAV imagery were collected to study the potential of narrow-band data compared to Sentinel-2. Sentinel-2 was the principal high-resolution data source. Sentinel-1 was used to compute the forest mask and to study applicability of C-band SAR data for the mapping of clear cuttings.

A statistical sample of very high-resolution satellite imagery served as the data source for the accuracy assessment of the European boreal forest classifications. In Finland, the accuracy of forest variable predictions was tested with the help of stand data from Metsähallitus, the State Forest Enterprise.

A high number of image analysis methods to estimate static variables and change from the imagery were further developed and tested. These methods included also advanced image pre-processing approaches. First steps were also taken for the development of automatic and self-learning image analysis methods.

The study brought together leading European experts in forestry remote sensing and carbon flux modeling which made it possible to develop novel approaches for carbon balance monitoring. The coordinator of the project, VTT Technical Research Centre of Finland Ltd. focused on the optical and radar satellite image analysis and preprocessing. Norut from Norway specialized to radar and UAV based hyperspectral image interpretation and Institute of Biology of Komi to optical satellite data analysis. University of Iceland investigated advanced image analysis approaches for optical mono- and multi-temporal data. University of Sheffield was a specialist of the dynamic vegetation models and University of Helsinki of the semi-empirical models.

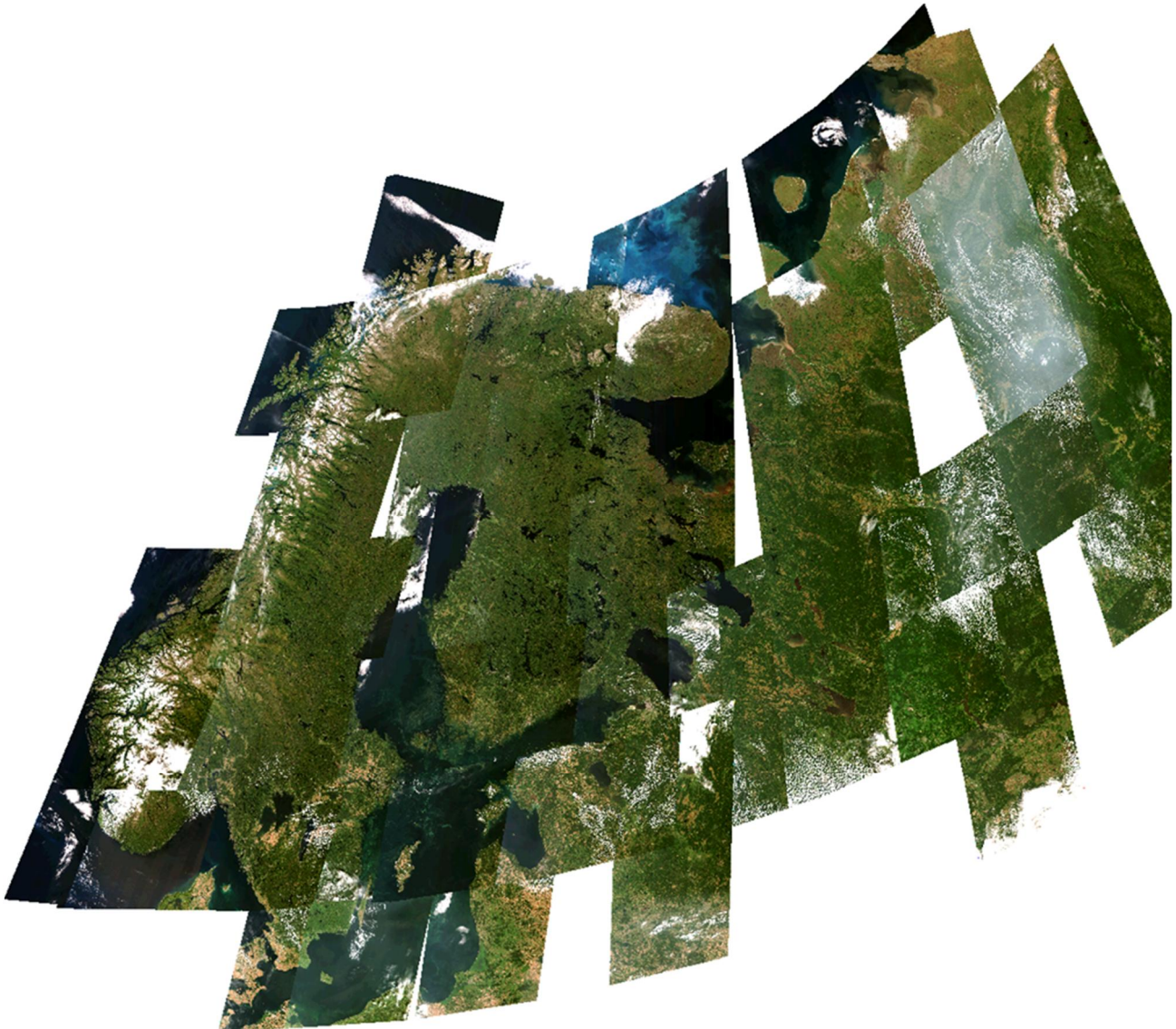
## **2 Main scientific and technical results**

### **2.1 Methods for forest area and forest variable prediction using EO data**

Image analysis methods were developed and applied to provide forest parameters for carbon and water balance models. The method development and selection was based on type and updating frequency of the parameters that are required by the models. Methods were developed for pre-processing and analysis of mono and multi-temporal optical and SAR space borne data and hyperspectral airborne and space borne data. The main results were related to processing of large data sets, land cover classification and change detection methods.

#### **2.1.1 Processing of large data sets**

79 Sentinel-2 images (Figure 2) were downloaded and pre-processed for the pan-boreal site. 3521 Sentinel-1 images were downloaded and pre-processed for Finland and a mosaic of multitemporal features was computed.



**Figure 2. Downloaded Sentinel-2 data.**

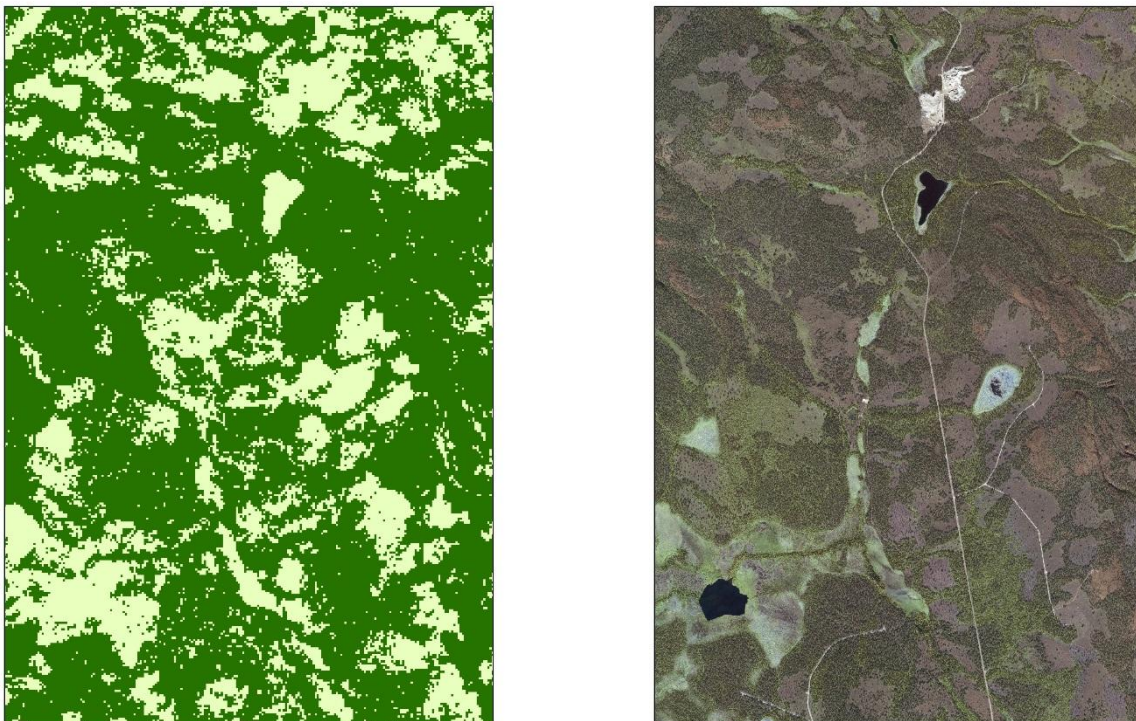
For analysis of large data sets an approach that applies a systematic geographic grid was developed. EO data values, reference data values and optional other data such as digital elevation model values are written in their original resolution in the grid-points defined by the grid-cell size. The data in the grid database represents thus a systematic sample of the original EO data/reference data in a fixed, pre-determined geographic grid. Raster images with coordinate information can be output from the grid database and these images can be used like any other raster image in image analysis.

#### 2.1.2 Land cover classification and forest parameter estimation

North State produced land cover classification and estimation methods for forest parameters. In addition, a framework for a self-learning automatic approach that can be applied with many of the new and existing methods was developed, implemented as software and tested.

The baseline method to predict the forest area and continuous forest variables was the Probability in house method (Häme et al. 2001) which has already been widely. It was used in the demonstrations over wide areas for optical satellite data.

A method was developed to forest-non-forest classification using Sentinel-1 data (Figure 3). Mosaics were generated per orbit repeat period (12 days) separately for Sentinel-1A and 1B. Seasonal composites were generated for wintertime data (October to May) and summer time data (June to September). For each seasonal composite, temporal variation and average backscatter was computed for both VH and VV bands. A forest index was defined as the average VH backscatter divided by the sum of VV and VH temporal variations. An average of the forest index was computed over all seasonal composites. Thresholding the average forest index was used to map forest areas. Urban areas and other high backscatter areas were excluded based on the average VV backscatter.



**Figure 3. Subarea of Sentinel-1 forest mask in Sodankylä and the corresponding area in VHR data.**

Two additional approaches were developed for land cover classification using SAR: supervised maximum likelihood classification on multi-temporal SAR features and a rule based semi-automatic system incorporating all available SAR data without any pre-screening. Forest parameter estimation methods e.g. Gaussian process regression estimation for growing stock volume and SAR interferometry with TanDEM-X satellite data to estimate tree height were developed. Tree height obtained from SAR data was further combined with optical data to predict growing stock volume.

The effect of different hyperspectral bands on land cover and tree species classification was investigated using Rikola airborne 15-band hyperspectral imagery with different band combinations and supervised classification. A preliminary tree counting and tree delineation algorithm was developed using the NDVI (Normalized Difference Vegetation Index)

orthomosaic. For hyperspectral satellite data, a novel methodology that exploits both spectral and contextual information was developed. The method was tested on Hyperion data from the EO-1 satellite acquired over the Sodankylä test site aiming at estimating land cover and plant functional types.

### 2.1.3 Change detection

Change detection methods applying both optical and SAR satellite data were developed. The logic of the algorithm of the existing Autochange change detection method (Häme et al. 1998) and software was modified. The method uses a hierarchical clustering approach, considers the land cover type and detects change types and magnitudes. Unlike in the earlier version the images before and after the change do not have to be mutually calibrated. In fact, the modified approach is applicable even to completely different data types such as optical and radar images. Autochange was applied in the larger area demonstrations of North State.

Another novel approach to change detection based on the analysis of both spectral and contextual information was developed aiming at identifying disturbances in forest. The contextual information improves the detection of changed areas that have, as in case of logging events, quite clear boundaries. The method exploits IR-MAD (iteratively reweighted multivariate alteration detection) as pre-processing to obtain relatively radiometric corrected channels. A region multi-scale decomposition was then performed in order to model the change at different scale of abstraction. This allowed identification of homogenous changed regions without losing geometrical detail.

A Sentinel-1 data based method was developed and implemented for clear-cut mapping (Figure 4, Figure 5). This method computes a ratio and difference of Sentinel-1 images from before and after the change and compares them with pre-defined threshold values from training data. Clear-cut areas appear as decreased back-scattering values. In addition, forest mask is computed from Sentinel-1 data as a separate process. The method was applicable particular for winter images that had been acquired in frozen conditions, which provided high contrast between forest and open areas.

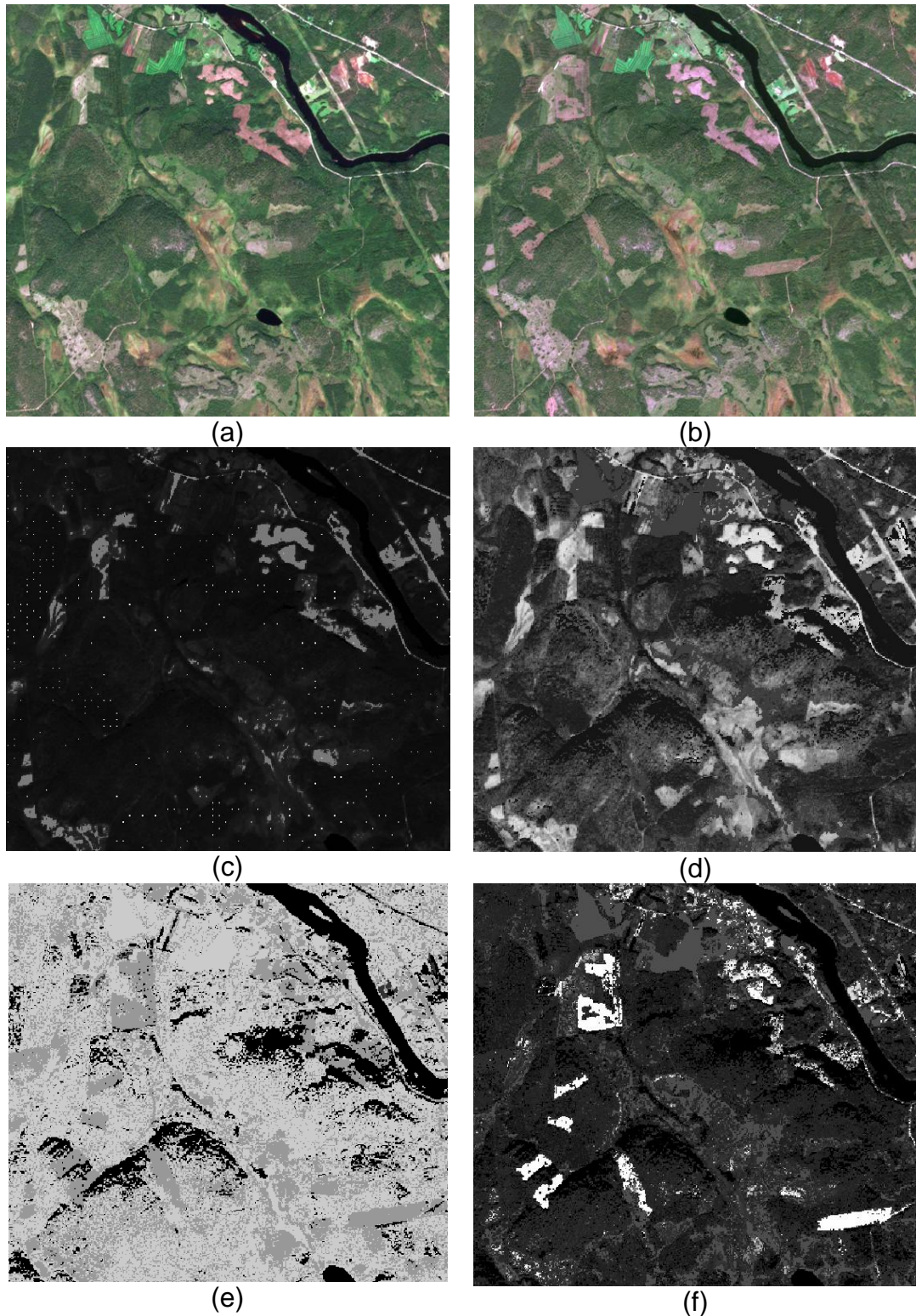


Figure 4. Output of AutoChange to two Sentinel-2 10 m resolution images from summer 2015 and 2016. Detail of 3.6 by 4.1 km<sup>2</sup> Sodankylä site: (a) Sentinel-2A 2015, (b) Sentinel-2A 2016, (c) observations selected for clustering as white dots, (d) primary clusters from earlier image sorted by increasing red band reflectance, (e) change type, (f) change magnitude.

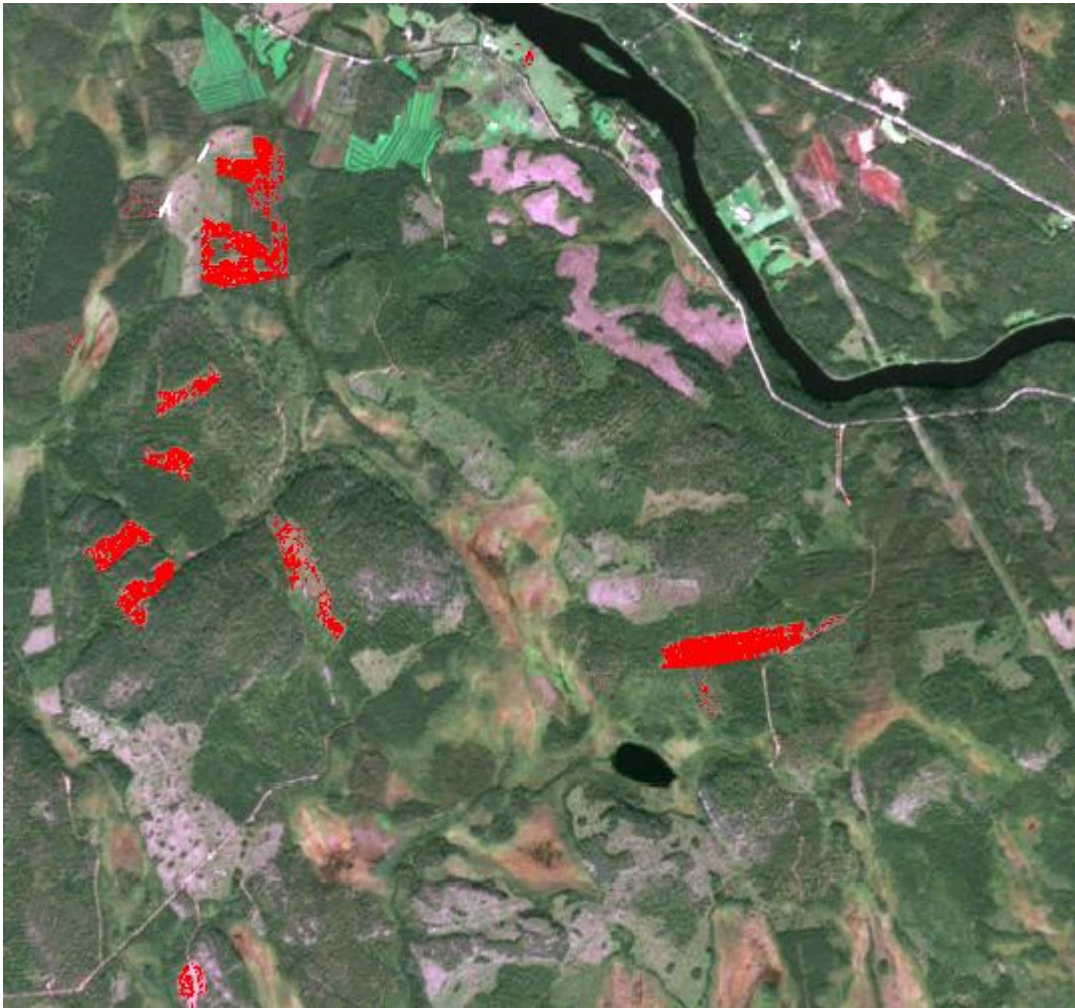


Figure 5. Final forest cutting map on Sentinel 2016 image. Same site as in Figure 4.

## 2.2 Approach to primary productivity and flux variable prediction

Two types of carbon and water models (Figure 6) were further developed and applied: forest models driven by forest structure information and climate data, and dynamic vegetation models (DVM) driven by climate data only.

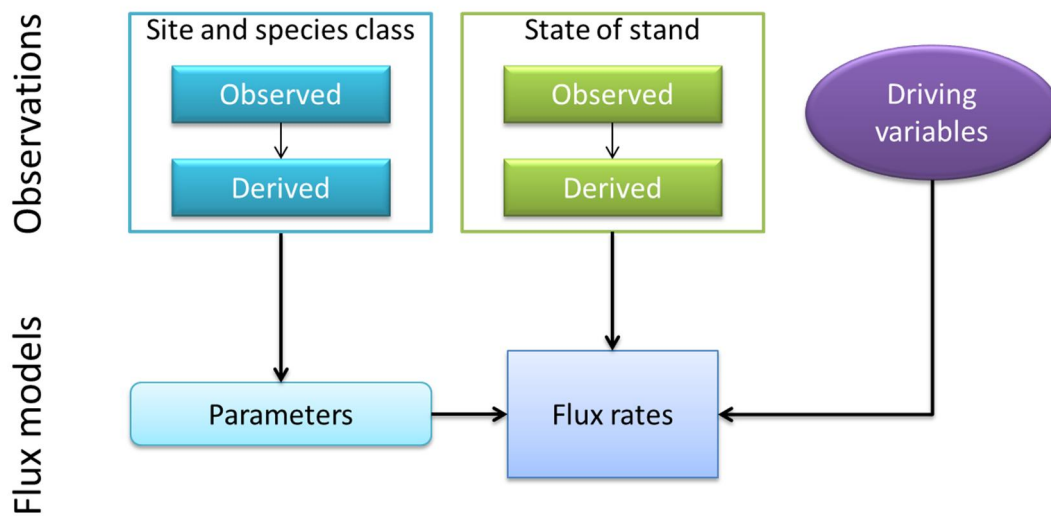


Figure 6. Monitoring carbon and water fluxes with a combination of EO data and models.

### 2.2.1 Dynamic Vegetation Model, LPJ-WM

LPJ-WM (Wania et al., 2009a; Wania et al., 2009b) is a global Dynamic Vegetation Model (DVM), which simulates land surface carbon and water fluxes by mechanistically describing a host of relevant processes such as photosynthesis, transpiration, and plant and soil respiration. As most DVMs are suited for global simulations and are computationally expensive, they are usually driven by gridded, low-resolution (0.25°-0.5°) climate data, which determines the grid-cell size. However, they can use finer scale information on land cover since each grid-cell is represented as a mixture of Plant Functional Types (PFTs). The fractional PFT occupation of each grid-cell can be calculated internally by the model (so-called natural vegetation) or provided by available land cover products, which are typically derived from remote sensing data. DVMs are often used to evaluate the direction of the carbon balance of the Earth system by running future scenarios of climate and carbon emissions coupled to global circulation models. Here we adapted LPJ-WM to the needs of the project by allowing it to be driven by weather station data and high-resolution land cover Earth Observation (EO) products provided by the consortium partners.

### 2.2.2 Forest models, PRELES + CROBAS + YASSO

PRELES is a semi-empirical model of canopy photosynthesis and evapotranspiration, which are computed daily from meteorological weather variables (Peltoniemi et al. 2015, Minunno et al. 2016). It is coupled with a stand growth model, CROBAS, which allocates the photosynthates to tree growth and respiration (Mäkelä 1977, Valentine and Mäkelä 2005). It also computes the carbon flux to the soil in the form of different types of tree litter. Litter decomposition and the related respiration flux to the atmosphere is computed with YASSO07, a soil carbon balance model (Liski et al. 1995, Tuomi et al. 2009). The models are called semi-empirical because their structure is based on our ecological understanding but model parameters have been empirically calibrated to produce results that are consistent with measurements. To run the models for a given site, initial values of leaf area index, stand basal area, mean height, crown ratio and diameter are required. These data are typically

provided on a hectare basis in forestry applications, but the models can benefit from higher spatial resolution, such as that provided by the earth observation data in this study. Subsequently, the model system simulates forest management actions, including thinning, clear-cut and regeneration. Actual change information can be input to the model when available. The relatively simple structure of the model combinations allows their application at a large regional extents. This enables simulations of carbon and water fluxes that are both climate and management sensitive.

## 2.3 Demonstration

### 2.3.1 EO methods

#### Hyytiälä

In the Hyytiälä study site in total 20 EO maps were produced. Land cover maps were compiled using Landsat 8, ALOS PALSAR, Envisat ASAR, Sentinel-1 and Sentinel-2 data. In addition forest parameter maps and change maps were compiled with Landsat 8 and Sentinel-2 data. The main reference data were stand data from Metsähallitus. The main tools for compilation of the maps were VTT's Probability and AutoChange software and Norut's GSAR software and maximum likelihood classification (Figure 7). Leaf Area Index was estimated using formulae from Heiskanen et al (2011).

Accuracy assessment data for forest parameter estimates were collected by extracting values from a separate test set of Metsähallitus stand data in a regular grid. The relative root mean square error of the for forest stem volume prediction was 47% for the test set using Landsat-8 data and 44% for Sentinel- 2 data. The figures for basal area and tree height were 38% and 32% and 42% and 32%, respectively.

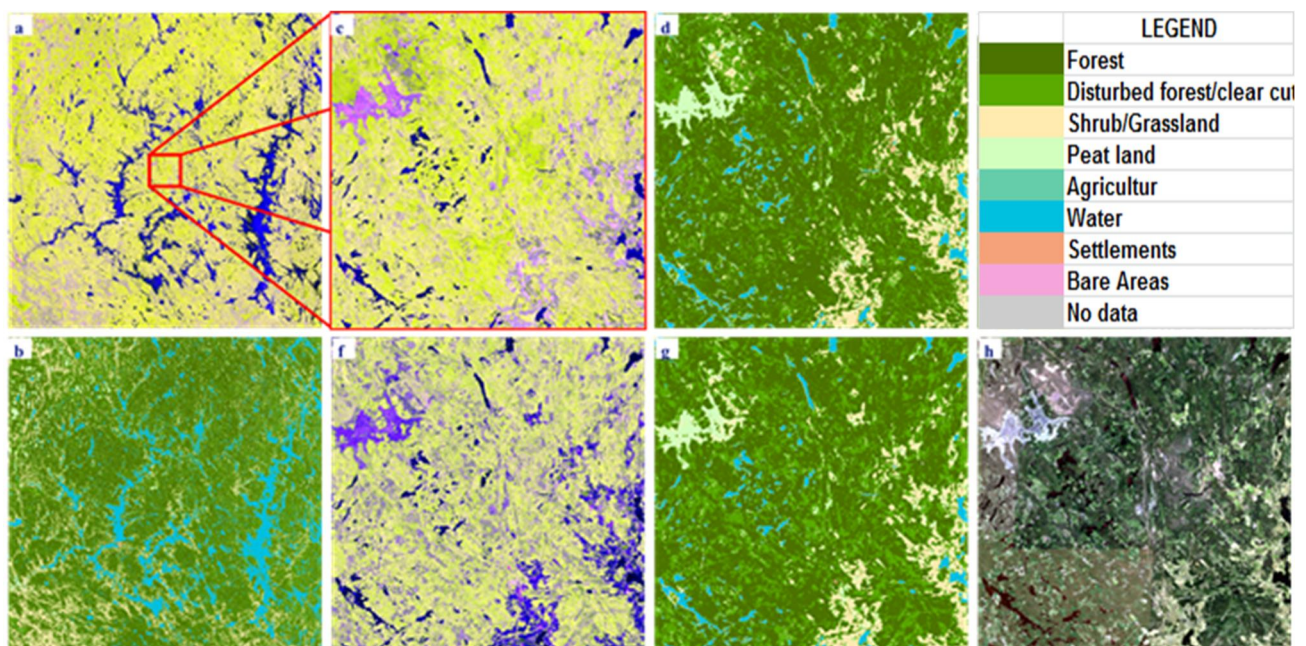


Figure 7. Hyytiälä test site: (a) Temporal averaged Sentinel-1 backscatter mosaics (RGB = [VV,VH,NDI]) using all Sentinel-1 A data until September 2015 and (b) Norut's derived maximum likelihood land cover classification of the full 200x200 km<sup>2</sup> test site. 20x20 km<sup>2</sup> zoom of the center location around Hyytiälä Field Station (c) and (d), (f & g) Norut's MLH classification based on ALOS PALSAR data from 2010 and (h) a GoogleMaps extracted optical overview as reference.

### Sodankylä

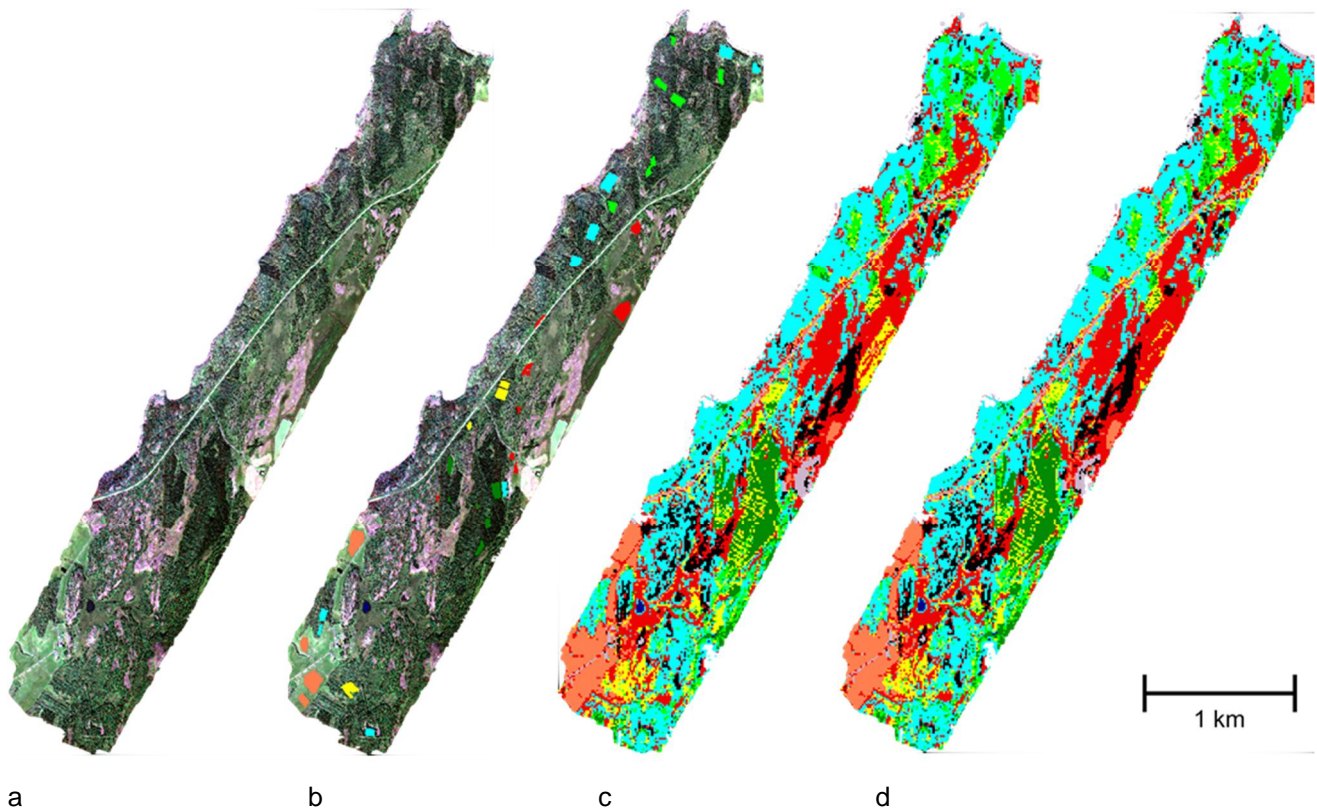
For the Sodankylä study site 17 land cover, change and forest parameter maps were produced using Landsat 8, Sentinel-1 and Sentinel-2 data. Additionally land cover map were compiled using EO-1 Hyperion and with a partial coverage of ALOS PALSAR data. The main reference data were stand data from Metsähallitus. The main tools that were used for the compilation of optical EO products were VTT's AutoChange and Probability software and Norut's GSAR software and maximum likelihood classification. The Hyperion land-cover map was obtained using a Random Forest classifier. Leaf Area Index was estimated using formulae from Heiskanen et al (2011).

Accuracy assessment data for forest parameters and land cover were collected by extracting values for points from a separate test set from the Metsähallitus stand data.

The relative root mean square error of the for forest stem volume prediction was 48% for the test set using Landsat-8 data and 55% for Sentinel- 2 data. The figures for basal area and tree height were 46% and 50% and 45% and 58%, respectively. For the Hyperion land cover classification for five classes (Scots pine, birch, shrub, grassland and water) the overall accuracy was 76%.

### Iceland

For the study site in Iceland land cover maps were produced using hyperspectral airborne and radar satellite data (ALOS PALSAR, Envisat ASAR and Sentinel-1). Training data for radar data classification were extracted from Google Earth. A maximum likelihood classifier was applied to produce the land cover classification, from which the forest/non-forest product was derived by combining the corresponding classes. The hyper-spectral 15-band orthomosaic from the Rikola imaging spectrometer was classified using the SVM (Support Vector Machine) classifier (Figure 8). The effective Leaf Area Index was estimated based on the NDVI using an equation derived by Stenberg et al. (2008) and tree count was estimated from the NDVI orthomosaic using Gaussian filtering and blob detection using a Mixture-of-Gaussian algorithm



**Figure 8. (a) Rikola data at 0.25 m resolution, bands 645nm, 560 nm, and 502nm, (b) training polygons used, (c) classification results with all 15 bands, (d) classification results with only S-2 bands. Colours: yellow: birch, light green: spruce, dark green: pine, light blue: larch, orange: cultivated grass, red: natural grass, grey: road, black: rock, blue: water.**

Accuracy assessment for the radar products was done with a stratified sampling approach considering forest and non-forest classes, and using visual interpretation of very high resolution aerial mosaics. Accuracy assessment for the hyperspectral study was performed using detailed ground truth data on the planted forest stands provided by the Icelandic Forestry Commission. The land cover classification resulting from use of all 15 bands was compared with classifications based on just the bands that also exist in Sentinel-2 data (with and without red-edge bands).

The accuracies for land cover maps using radar data varied between 44% for Envisat ASAR to 71% for Sentinel-1. For forest/non-forest classification, the corresponding figures were 65% and 90%). For hyperspectral data there was an insignificant difference in the classification accuracy when using all 15 spectral bands or only S2 equivalent spectral bands (76% overall accuracy for 15 bands, 75% for Sentinel-2 bands). However, the accuracies were clearly lower (overall accuracy 70%) when the red edge spectral bands were excluded, indicating that the red edge spectral bands do improve the classification.

### Komi

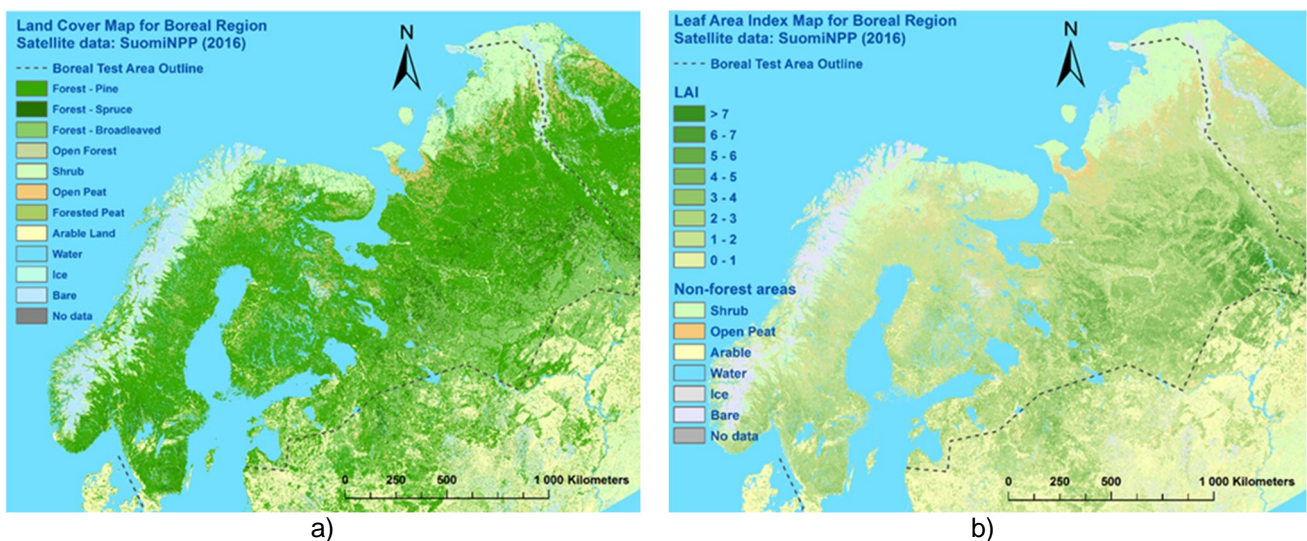
For the Komi site land cover, change and forest parameter maps were produced using Landsat 8, Sentinel-2 and ALOS PALSAR data. The main reference data were forest inventory data from the Up-Pechora and Jakshinskii forestry units of the Komi Republic. Land

cover, bud burst and forest variables were predicted using supervised classification and multivariate linear regression. Change monitoring in Komi included burned area mapping and clear cut detection. The main method for change detection was application of the Disturbance Index, DI (Healey et.al. 2005).

Accuracy assessment for the Landsat land cover classification was performed using forest inventory data. Overall accuracy for six classes was 78%.

### Boreal site

For the pan-boreal site, eight land cover and forest variable maps were produced using Suomi NPP image mosaic (Figure 9). Additionally seven maps were compiled with Sentinel-2 data for the whole of Finland and two using Proba Vegetation. Thematic maps available from the Natural Resources Institute Finland (Luke) for Finland were used as reference data. The main analysis tool was the Probability chain of VTT. The grid approach that was developed in North State was used to reduce the amount of data when the models for forest parameters estimation with Sentinel-2 data were computed. Images were resampled to a grid with 600 m x 600 m sampling. The models were computed on the shrunken images written from the database and then applied to the original Sentinel-2 data image by image. Leaf Area Index was estimated using formulae from Heiskanen et al (2011).



**Figure 9. (a) Land cover map and (b) Leaf area index map using Suomi NPP – Boreal site**

The accuracy of forest area estimation of Suomi NPP maps was assessed using a simple random sampling of 43 VHR images from the European boreal region. A regular square grid of 64 (= 8 x 8) plots with 600 m separation was generated within each VHR image area, thus covering the total area of 4200 m x 4200 m. The area of each plot was 60 m x 60 m, and the plots were interpreted visually. In addition to the forest area, also the structural variable values were interpreted experimentally. The land cover statistics for the boreal region were computed from the Suomi NPP maps and the VHR sample, which enabled also computation of the statistical confidence intervals.

From the VHR plots the proportion of forest was 70.7% (with 95% confidence interval 61.5% to 79.9%) or (2 090 766 km<sup>2</sup>). For Suomi NPP based land cover map the estimated forest proportion was 70.4% (2 080 035 km<sup>2</sup>). Thus, the difference of the VHR plot based estimate to the forest area and Suomi NPP map proportions was 0.3% (10 731 km<sup>2</sup>). The total growing stock volume predicted from the VHR for the total area of interest was 29.9 billion m<sup>3</sup> (with 95% confidence interval 25.7 billion m<sup>3</sup> to 34.1 billion m<sup>3</sup>). This represented the average growing stock volume of 143.8 m<sup>3</sup>/ha (with 95% confidence interval 123.6 m<sup>3</sup>/ha to 164.0 m<sup>3</sup>/ha). In Suomi NPP prediction the average growing stock volume of the three forest classes was 100.8 m<sup>3</sup>/ha and the predicted total growing stock volume 21.0 billion m<sup>3</sup>, respectively. The difference between the Suomi NPP map and the expected value of the VHR plot-based total growing stock volume prediction was -8.9 billion m<sup>3</sup> or 29.9%. The difference to the lower limit of the 95% confidence interval of the VHR plot results was -4.7 billion m<sup>3</sup>. The volume estimation from the visually interpreted VHR plots could have been positively biased, *i.e.* systematic overestimation.

The accuracy of the Sentinel-2 maps of Finland was assessed by the Natural Resources Institute Finland with 13249 Finnish national forest inventory plots from the 12<sup>th</sup> national forest inventory. The inventory is a systematic cluster sampling in which the plot distance is 300 m within a cluster. In addition, the forest area predictions of Suomi NPP and Sentinel-2 data were compared to national forest inventory data by the thirteen forest districts in Finland and to the reference data from Finnish Statistical Yearbook of Forestry 2012.

The overall accuracy of the land cover classification for the whole of Finland using the national forest inventory plots was 76% for seven classes. The accuracy was higher in Northern Finland than in the south where the landscape is more fragmented. In the forest statistics, the forest proportion for the whole of Finland was 76%. By comparison, forest area was overestimated in both Suomi NPP (81%) and Sentinel-2 maps (84%). In Finnish forestry, the so-called forestry land is divided into forest land, poorly productive forest land and unproductive land. The 76% forest proportion was the sum of the forest land and poorly productive forest land. The proportion of forestry land in Finland is 86%.

### 2.3.2 Flux computation

#### Predictions for Hyytiälä and Sodankylä test sites

Forest variables derived from Sentinel 2 and Landsat 8 data were used in the University of Helsinki semi-empirical forest model to simulate the carbon and water fluxes at Hyytiälä (Figure 10). To run the model, forest cover, site type, average height of the stand, average diameter at breast height and basal area were needed at the start of the simulation. These were obtained at grid cells of size 10 m x 10 m, covering an area of 100 x 100 km. The produced flux products were annual gross primary production (GPP), annual net primary production (NPP), mean annual increment (MAI), annual evapotranspiration (ET) and annual net ecosystem exchange (NEE).

The Hyytiälä and Sodankylä scenes covered an area of 100 km<sup>2</sup> centered at the flux towers. For the Hyytiälä scene the annual GPP of the forested areas was estimated as 64x10<sup>3</sup> tC y<sup>-1</sup>; while the total GPP at Sodankylä was 23x10<sup>3</sup> tC y<sup>-1</sup>. GPP was higher at Hyytiälä because the forests had higher photosynthetic capacity, thanks to the climatic conditions, and because

forests covered about 90% of the area at Hyytiälä, while at Sodankylä forest cover was around 65%.

At Hyytiälä the forest carbon uptake ranged between 300 and 1000 tC m<sup>-2</sup> y<sup>-1</sup>. The distribution of gross carbon uptake over the scene was bimodal due to the properties of the forest cover as derived from EO products. At Sodankylä the gross carbon uptake varied between 0 and 550 tC m<sup>-2</sup> y<sup>-1</sup>. Net primary production was 40x10<sup>3</sup> tC y<sup>-1</sup> and 15 x10<sup>3</sup> tC y<sup>-1</sup>; at Hyytiälä and Sodankylä respectively.

Flux computations with the LPJ-WM DVM were performed for Hyytiälä and Sodankylä at a much larger area covering 3600 km<sup>2</sup> but at a lower resolution of 800m (Figure 11). For the Hyytiälä scene the mean annual Gross Primary Production was estimated at 2.71x10<sup>6</sup> tC/year while for Sodankylä at 1.61x10<sup>6</sup> tC/year. The higher carbon uptake through Gross Primary Production for Hyytiälä meant that the Net Ecosystem Exchange was simulated at -0.65x10<sup>6</sup> tC/year, a land sink of carbon, while Sodankylä was simulated as a land source of carbon with a mean annual Net Ecosystem Exchange of 0.20x10<sup>6</sup> tC/year.

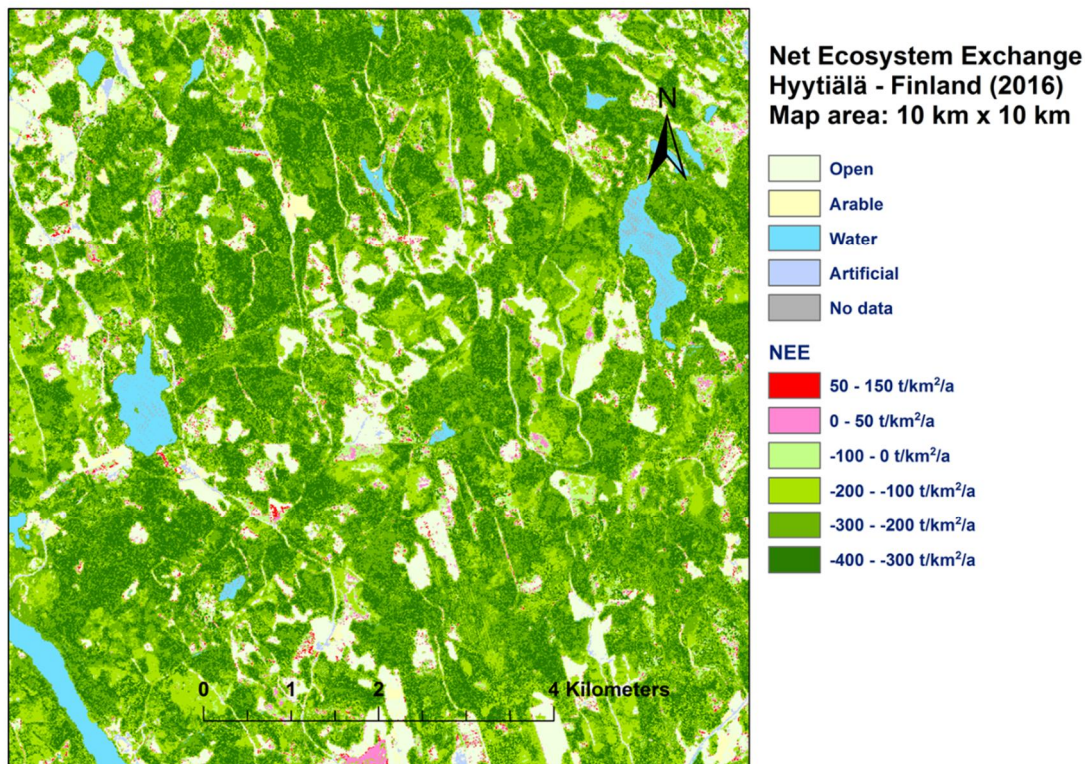
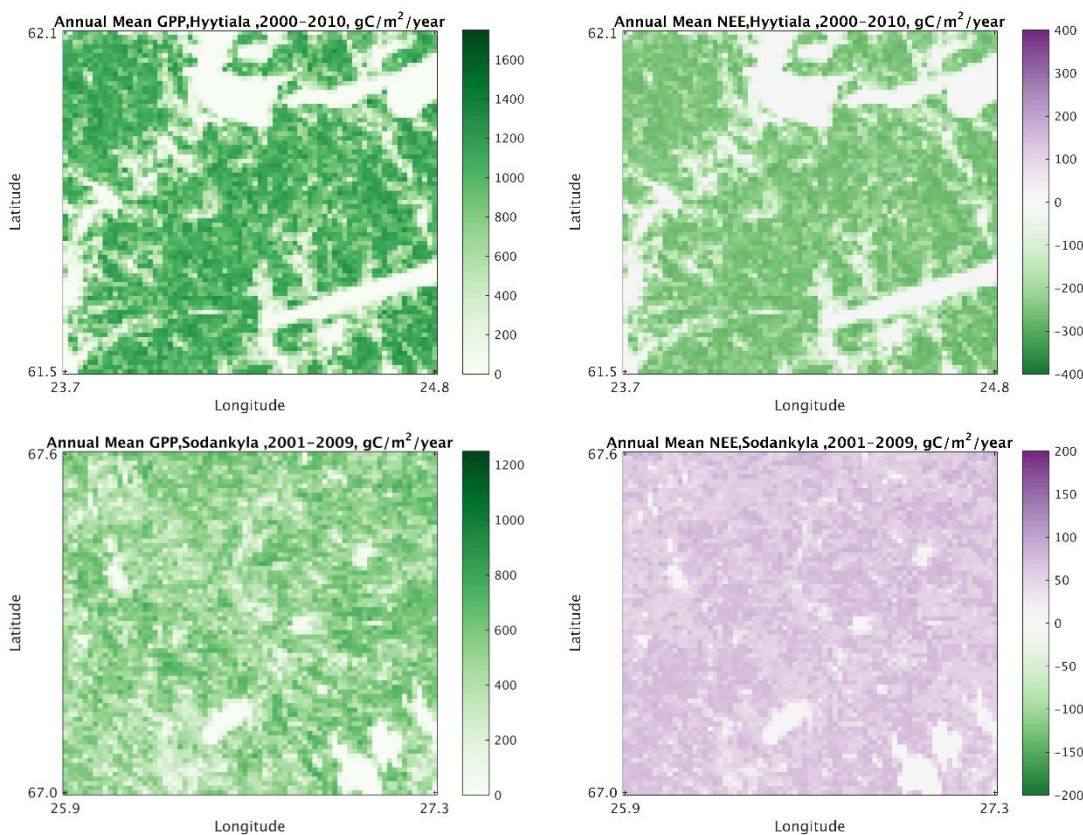


Figure 10. Annual net ecosystem exchange in Hyytiälä site - Sentinel-2 data.



**Figure 11. Simulations of annual mean (left) Gross Primary Production (gC/m<sup>2</sup>/year) and (right) Net Ecosystem Exchange (gC/m<sup>2</sup>/year) for the Hyytialä (top) and Sodankylä (bottom) scene obtained from LPJ-WM. Negative values of NEE depict a carbon sink.**

### Predictions for the pan-Boreal region

For the European pan-Boreal (EpB) scene run, LPJ-WM was driven with a downscaled Leaf Area Index and land cover EO product at 50km resolution. The annual mean Gross Primary Production for the EpB run ranged from 1.53 GtC/year to 0.96 GtC/year with an average of 1.22 GtC/year while the Net Primary Production from 0.60 GtC/year to 0.41 GtC/year with an average of 0.50 GtC/year. For the European pan-Boreal scene, Gross Primary Production of 1.22 GtC/year accounts for approximately 1% of global Gross Primary Production estimates (Beer et al., 2010).

The Helsinki semi-empirical models were used for simulations utilising the new EO products. We used the Suomi NPP products at 500 m resolution to provide the initial state of the forest to the model. The climate data for Finland came from the Finnish Meteorological Institute, whereas the pan-Boreal climate data was an output from weather simulators from the University of Sheffield. The EO products used were the forest cover of pine, spruce and deciduous species, site type, stand average height, basal area and stand average diameter at breast height. The models produced estimates of gross primary production (GPP), net primary production (NPP, Figure 12), current annual increment (CAI), evapotranspiration (ET) and net ecosystem exchange (NEE, Figure 13).

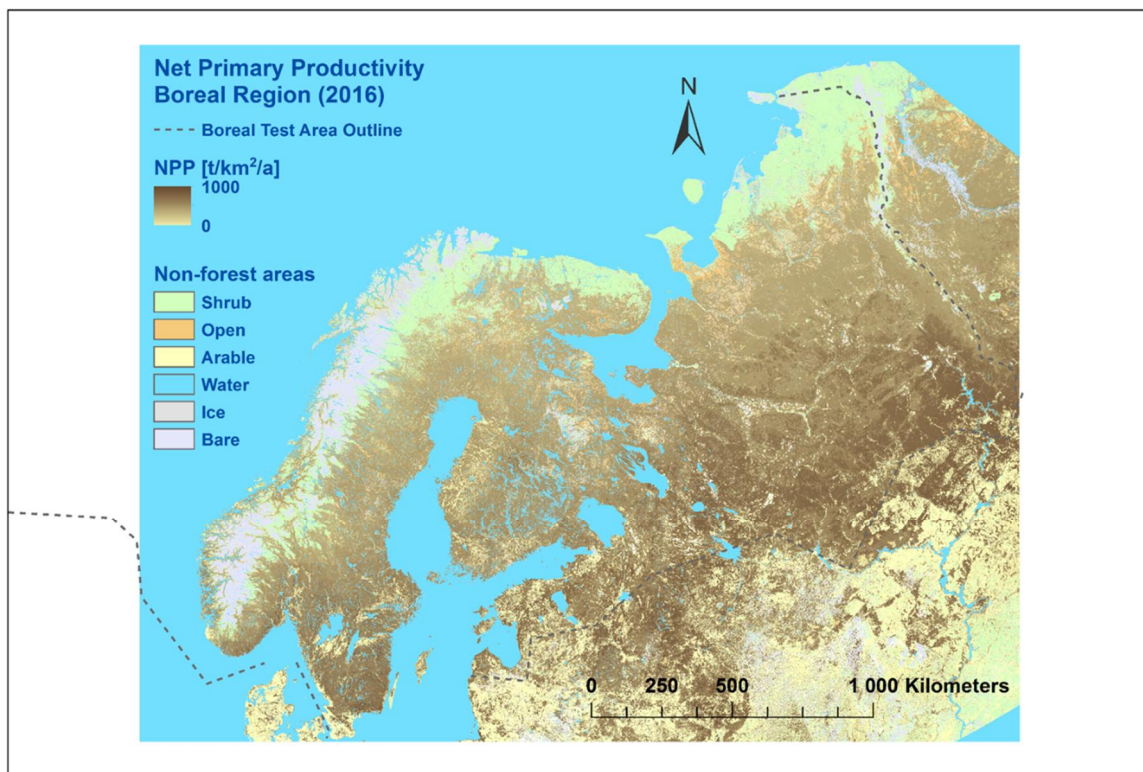


Figure 12. Net primary production in the pan-boreal site - Suomi NPP data.

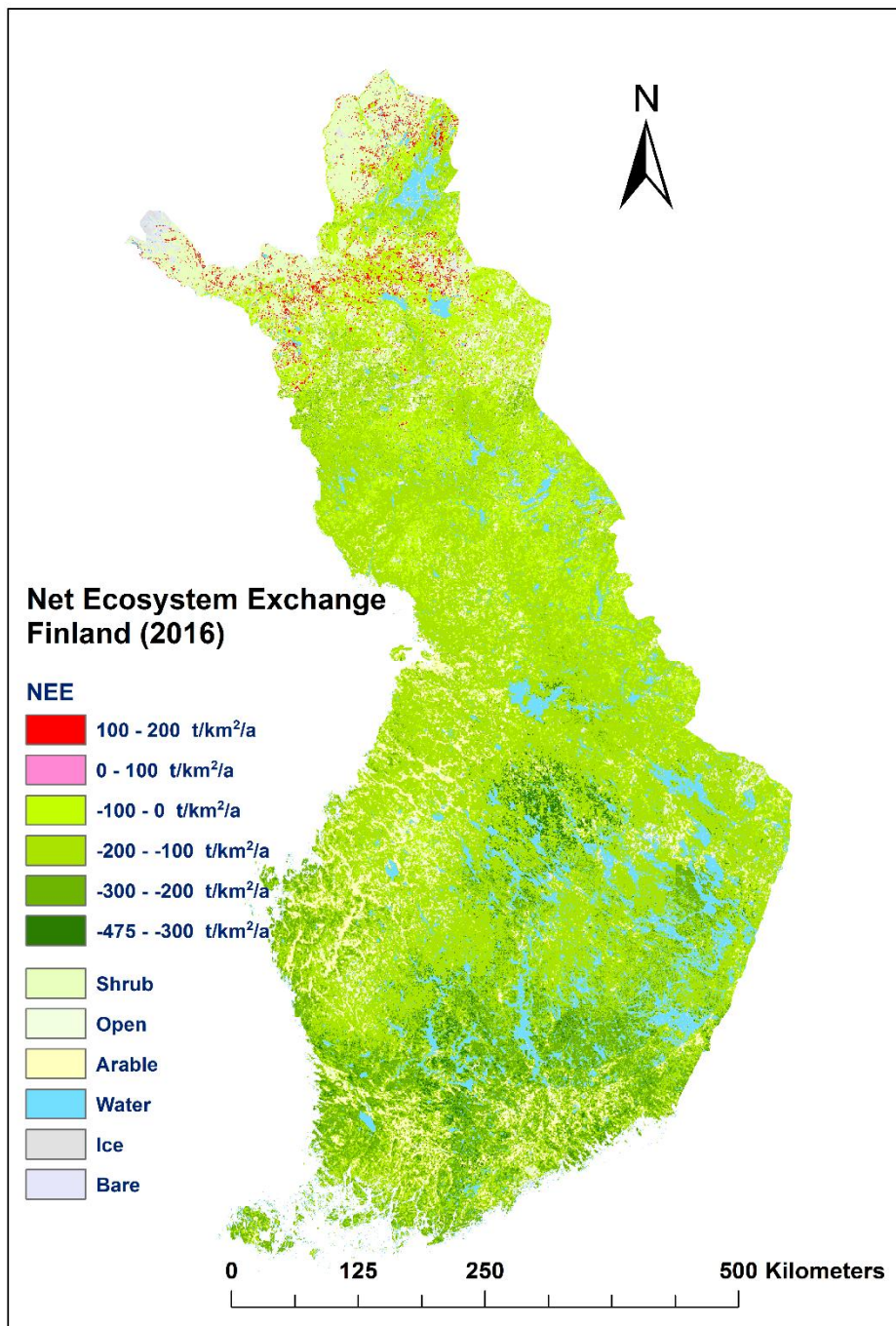


Figure 13. Annual net ecosystem exchange in Finland – Suomi NPP.

The annual GPP across Finland varied between about 150 and 1150 gC m<sup>-2</sup> y<sup>-1</sup>. The most productive areas were located in the southern part of the country thanks to more favorable climatic conditions. GPP was quite high also in the central part of Finland; in this case, the higher GPP values were due to the structure of the stands as derived by the EO products.

The estimate of NPP across Finland followed the same pattern as GPP, with the most productive areas located in the South. The total annual NPP was 62% of the annual GPP at

country level. The mean annual increment of timber volume ranged between 0.5 and 13 m<sup>3</sup> ha<sup>-1</sup> y<sup>-1</sup>. The total annual volume increment of the country was 125 x 10<sup>6</sup> m<sup>3</sup>.

**Table 1. Summary statistics of annual gross primary production for Finland. The values in the columns correspond to the mean, the 5<sup>th</sup> and the 95<sup>th</sup> percentiles and the total GPP.**

GPP	Mean (gC m <sup>-2</sup> y <sup>-1</sup> )	5% (gC m <sup>-2</sup> y <sup>-1</sup> )	95% (gC m <sup>-2</sup> y <sup>-1</sup> )	Total (MtC y <sup>-1</sup> )
Finland	537.8551	310.2163	758.2301	144.255

## 2.4 Conclusions

### 2.4.1 Do hyperspectral data provide utility compared to broader band instruments

This question is difficult to answer based on the data available in this project. In general, based on published research, hyperspectral data can greatly enhance the ability to obtain specific vegetation parameters, such as leaf nitrogen concentration. However, in this project the focus was on land cover, broad tree species mapping and LAI. The Rikola hyperspectral camera can collect numerous narrow spectral bands between 500-900 nm when driven through an attached computer. However, when used as a stand-alone instrument, e.g. when mounted in a UAS, the Rikola camera can only record a maximum of 15 spectral bands. The difference between the land cover/ tree species classifications using all 15 bands and only those 8 bands that correspond to S-2 bands in the 500-900 nm range was minimal. Thus the additional 7 narrow spectral bands did not significantly improve the classification.

### 2.4.2 Potential of Sentinel data vs. other satellite missions

Forest variable predictions from Landsat 8 and Sentinel-2 were compared at two intensive study sites in Finland using the Probability method. The results indicated similar accuracies as expected. At the Hyytiälä site the Sentinel-2 based predictions indicated somewhat higher accuracies than Landsat, but at Sodankylä Landsat gave greater accuracy. The Sentinel-2 based classification for Sodankylä were extracted from the national-wide predictions whereas the Landsat classification was made specifically. The ground reference data represented for the most part year 2014 which matched better with Landsat than with Sentinel-2 data. The Sodankylä land cover model that was combined with the continuous variable predictions for Sentinel-2 was computed by using several Sentinel-2 images. The model was thus a compromise considering the residual radiometric differences of the images. This led to high growing stock volume estimates on open bogs. Moreover, particularly in Sodankylä the proportion of clear cuts was high. Although we attempted to take cut areas into consideration in the testing, they obviously increased the RMSE values.

Another test was done on the Hyytiälä site to predict the cubic root of total growing stock volume separately with Landsat-8 and Sentinel-2 spectral bands with Metsähallitus stand data using linear regression analysis. The band that gave the highest R<sup>2</sup> value was first selected, then the two best bands and so on. In both cases, the R<sup>2</sup> did not significantly increase after three input bands. The Landsat model included the red, blue and 1500 nm SWIR bands. In the Sentinel-2 model the bands represented the red edge (B6), green (B3),

and near infrared (B8A). Hence, the models included different spectral bands. This could be accidental since the bands are strongly correlated and the first selected band affects the selection of the other bands. The RMSE's were computed from the actual volume. For Landsat data the RMSE was 39% of the mean and for Sentinel-2 44%, respectively.

On the basis of several tests we conclude that from the statistical viewpoint Landsat-8 and Sentinel-2 data have similar performance in forest variable prediction. Earlier studies conducted by VTT indicated very fine resolution data or Rapideye only slightly improved the growing stock volume or land cover estimates in a similar test when compared to Landsat. So, the benefit of Sentinel-2 compared to Landsat comes from better mapping and edge detection accuracy, higher acquisition frequency, and large image size. Investigation of edge detection accuracy was beyond the scope of North State. Both satellites can provide information for carbon flux prediction. They can also be used together in the same model as was shown in the change detection demonstrations for Hyytiälä and Sodankylä.

The separation of forest from other land cover classes with Sentinel-1 appeared to be feasible when a very high number of images was used. With the lower frequency ALOS PALSAR similar performance can be achieved using fewer images. SAR-based forest area prediction tends to overestimate forest area which could be seen in PALSAR based predictions. For the Sentinel-1 based data set overestimation was not apparent and the bias could be reduced by introducing Sentinel-1 data.

Sentinel-3 data were not available for the project but based on the experiences with Proba-V and Suomi NPP data, there is a good reason to assume that Sentinel-3 has high potential for regional forest mapping and for providing input parameters for carbon flux models. As in the case of Suomi NPP, use of a large number of individual images improves the quality of the results. The test results with Suomi NPP were surprisingly good.

As a conclusion, the Sentinels are important as data sources for flux modeling, but they may not revolutionize the accuracy compared to what is achievable with other sensors. Their special asset is provision of data for operational applications including flux computation for decades to come.

#### 2.4.3 Degree of operationality of the processing chains after North State

We conclude that the study reached the targeted technology readiness levels 6-7. The satellite image predictions could be computed for the whole boreal region using 238 Suomi NPP images. In Finland more than 3000 Sentinel-3 images and 11 Sentinel-2 full size images at 10 m resolution were analyzed. Nationwide forest variable prediction with Sentinel-2 data would have been unfeasible without the grid based system developed as part of model development. In addition, nearly 80 Sentinel-2 images were pre-processed. Application of models for forest variable prediction started but the work, not included in the DoW, was not completed before project end, though will still continue.

The carbon flux models were applied over the boreal region with coarser resolution satellite image predictions and locally using 10 m estimates from Sentinel-2. The processing chain from satellite intensity data to carbon flux predictions required several manual steps and transferring data sets from one actor of the project to another.

The operational phase of the chain at the time of project completion enables project type application of the flux prediction chain also for operational users. A fully operational smooth flux service requires another development activity as was planned in the DoW. The huge data volumes particularly from Sentinel-2 have to be considered in future development.

#### 2.4.4 Applicability of earth observation data in flux modeling

The essential motivation of North State was to amalgamate carbon and water balance models with new EO data streams, to allow continual monitoring of the carbon stocks and fluxes and water status of the boreal forest. This has also provided a template for more general application of EO-derived variables in estimating the state and evolution of land surface processes represented in models.

The key tasks to achieve the goal were (1) retrieving relevant information from the EO data at appropriate spatial scale, (2) adequate calibration of models for all relevant regions and species, and (3) scaling up to appropriate regions with estimates of uncertainty.

In the DoW, we proposed to develop a system that produces flux rates based on (1) climatic driving variables, (2) EO data on state of the stand, and (3) EO or mapped data per site and species class. The latter type of data is used as class parameters in the flux models, whereas the data on state of the stand are used as input to dynamic calculation of component fluxes. The Helsinki forest models follow this logic, utilizing EO inputs on the two data categories. In addition, climate data are required, which in this project were provided by meteorological data networks (Finland) and climate models (pan-European region). The methods developed are novel, with the advantage of being able to utilize observed satellite data for estimating current fluxes with uncertainty ranges.

The fine resolution of Sentinel offered new prospects for making the larger-scale estimates more accurate, as each grid-cell can be assumed to represent a homogeneous patch of forest with well-defined inputs. However, it is not feasible to calculate results for each grid cell for vast regions. We reduced the number of actual calculations by classifying the forest grid cells within each climate grid cell. This also allowed us to utilize efficient statistical tools in the estimation of uncertainty of the regional stocks and fluxes.

One of our findings was that the DVMs were not fully able to utilize the fine scale of the Sentinel data, because the spatial resolution of DVMs is largely determined by that of the climate inputs. Contrary to our expectation in the proposal, it was difficult to apply a finer resolution for DVMs, because the models are based on simulating an equilibrium state of vegetation essentially from the climate inputs. Using a finer resolution and forcing the vegetation cover to vary at a higher resolution than the climate would lead to internal inconsistencies in the models. A finer resolution in climate data would likely not solve the problem because the spatial variability of climate is inherently lower than that of the vegetation cover, which varies because of soil type, land use and management. On the other hand, information about disturbance, such as fires and clear cuts, could be included in DVMs in the same way as forest cover types.

The spatial resolution in the Helsinki forest models is essentially given by the resolution of the forest inputs, although the climate resolution is the same as in DVMs. As noted above, the spatial gradient in climate (especially as annual mean values) is much weaker than that of the actual vegetation cover. The forest models benefit from the high resolution because it allows them to simulate the observed vegetation. The models can use the different

resolutions provided by the satellites, although the computation time becomes rather large if the finest resolution is used over large areas. However, introducing aggregation (e.g. *k-nn* nearest neighbors) techniques would allow us to speed up the computations while still utilizing the finer resolution.

The main constraints of the vegetation and forest models are related to the generalisation of the results both in space and time. The DVMs are meant to be generic, i.e., the parameter sets are general and any variability should be described by input variability and how that reflects in the outputs. However, this project revealed that reparameterising the LPJ-WM model using flux tower data and Markov Chain Monte Carlo calibration, while producing accurate site-wise predictions, also led to different parameter solutions at different sites. These differences in process parameters may partly compensate for the differences in predicted and actual vegetation cover. How to generalise these differences in model predictions over wider areas was not entirely clear, other than considering it as inherent uncertainty of model predictions. On the other hand, DVMs remain well suited for long-term predictions of climate change impacts on potential vegetation.

The Helsinki forest models used generic parameterisations with specified uncertainties for all parameters. These parameter sets were obtained using different data sets depending on the sub-model (PRELES, CROBAS, YASSO), but usually the data sets did not contain data from the larger pan-boreal region. This may cause uncertainties and inaccuracies when making predictions, especially for species that are not present in the calibration data set. We did not consider peatland areas separately either, which tends to overestimate growth in CROBAS. The soil model for peatlands should be different from that used here. As regards temporal extrapolation, the fluxes will be strongly dependent on forest management and the related changes in forest structure. For long-term predictions, it is possible to use different management models based on past management and national recommendations, although this becomes more and more uncertain with increasing time. However, for monitoring purposes the EO-based information about changes in forest variables will be invaluable in future applications.

#### 2.4.5 Future research needs

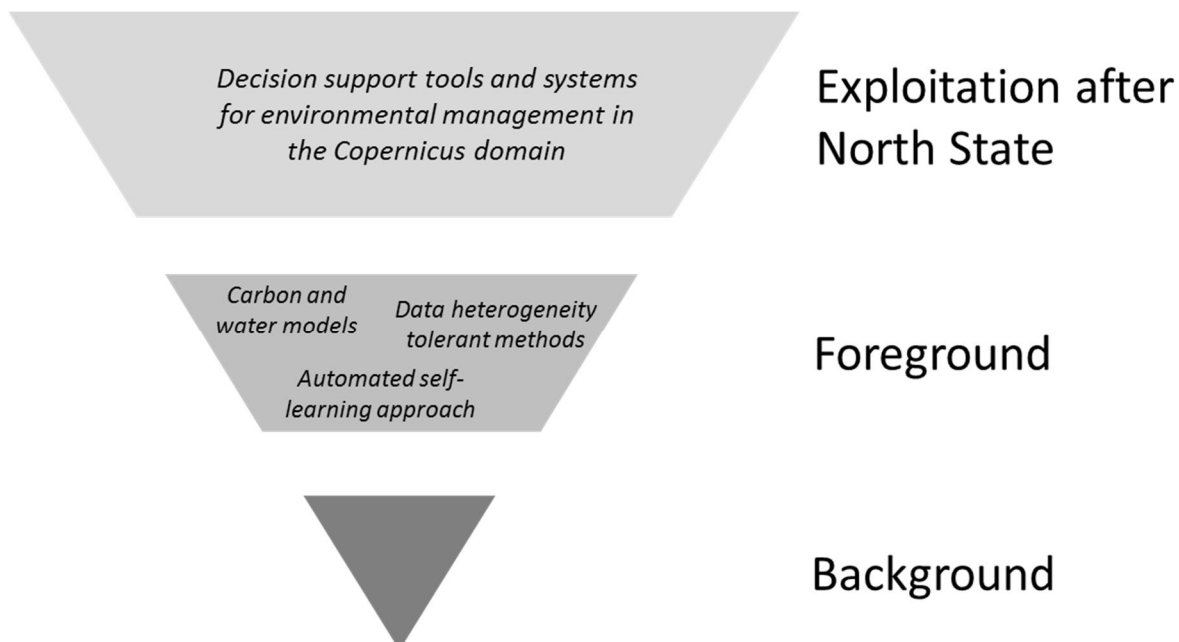
In addition to operationalization of the processing chain a number of more research-oriented actions should be taken. Peatlands, which are important actors in carbon fluxes and abundant in the boreal forest region could not be taken fully into consideration. In particular, tree-covered peatlands could not be separated from mineral soil forests. Wet open bogs could give erroneous high growing stock volume estimates. Furthermore, the flux models cannot presently consider peatland soils adequately, which influences especially the NEE estimation.

Accuracy assessment with a statistical sample of VHR imagery and visual interpretation worked very well for those land cover variables it was aimed at. Experimental interpretation of the other forest variables indicated correlations with the true values but also likely systematic errors. The assessment system should be further developed in which the visual interpretation is calibrated with a sparser sample of real ground measurements. It may be possible to use crowdsourcing and terrestrial photography for this purpose. The accuracy assessment of changes that cover a small proportion of the total area should also be further investigated and developed.

The Helsinki model, which was able to benefit greatly from the satellite image predictions, has been developed for boreal conditions especially focusing on tree species found in Finland. An important research task is to make it applicable in any global location by widening the species coverage of the growth model.

### 3 Potential impact

The overall idea for exploitation can be seen as an inverted pyramid (Figure 14). The results of North State will strongly contribute to building operational Copernicus services. As a parallel development, the results can improve the accuracy and cost-effectiveness of forest management planning by updating the results of forest growth models, for instance. Such a service has a direct commercial interest.



**Figure 14. Technology readiness level evolution. The exploitation in the future aims to develop the technology through both research and services to higher technology readiness levels. The exploitation aims also for wider reach and adoption of the remote sensing based services and solutions**

One project party, *i.e.* Simosol Oy (SME), has developed decision support tools for the environment sector. The company indicated an interest in introducing the foreground of the project in its decision support service. In addition, the other parties of the project have direct contacts with the forest industry and other commercial user sector. The Copernicus services and network are also well known since the lead project party participated in the GIO services for production of the first forest high-resolution layers and the corresponding GSE services of ESA.

The algorithms developed for predicting the input variables of the carbon and water balance models can be taken immediately to operational use (*e.g.* forest biomass estimation). The carbon and water balance models were already run in an operational extent during this

project, which means that the present consortium would be able to provide such services from the project after a short activity to develop the production chain. The main part of this activity is further streamlining of image interpretation process but most importantly application of the carbon flux models with large EO-based input data volumes.

The variety of variables on forest structure (height, basal area, volume) at a high spatial resolution has not been available in the past to forest models. While this is useful for forest mensuration purposes, in this project we also used it as input to forest models (UHM) and in validation of DVMs (LPJ-WM). Combined with UHM it allowed us to estimate carbon and water fluxes, including stemwood growth, as a function of the current measured state of the forest. If these data were available on a long-term basis a system could be constructed for monitoring the trends of these fluxes, possibly in relation to events such as clear-cuts or large scale damages (storm, fire).

It is stressed, however, that building of an automatic, self-learning and adaptive analysis system will be a continuous process. The foundation of such system was built in North State. The amount of manual work can be gradually decreased as soon as the accuracy of the results allows rationalization steps to be taken.

The commercial market in EO-based forest variable estimation and mapping is already existing and is growing but the market for carbon flux predictions on a commercial basis is just developing. Carbon balance estimation is considered more an academic research than a business activity. However, the situation could evolve rapidly once the reliability of the carbon flux computation can be consolidated and communicated. The market in this sector can be significant due to climate treaties and the obligations of the countries to report their carbon balances. Also, computation of forest growing stock volume increment could change in future and be based on utilization of semi-empirical models as demonstrated in this study. The geographic applicability of the growth models will greatly improve if reliable prediction of forest increment can be based on the new approach.

The North State project strengthened European leadership in the provision of EO-based services for the analysis of northern forest-dominated ecosystems. The method reached, as planned, the technology readiness levels from 5 to 6 which is the foundation for operational and commercial service development after the project.

## 4 Dissemination activities

Table 2 list the scientific publications of North State project and Table 3 lists the main public dissemination activities.

**Table 2. The scientific publications of the North State starting from the most recent ones.**

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers (if available)	Is/Will open access provided to this publication?
1	<i>Calibration and validation of a semi-empirical flux ecosystem model for coniferous forests in the Boreal region</i>	Minunno, F	Ecological Modelling	341	Elsevier	Netherlands	2016	37-52	DOI: 10.1016/j.ecolmodel.2016.09.020	No
2	<i>Remote Sensing Image Classification Using Attribute Filters Defined over the Inclusion Tree Representation</i>	G. Cavallaro	IEEE Transaction on Geoscience and Remote Sensing	54:7	IEEE	United States	2016	3899-3911	DOI: 10.1109/TGRS.2016.2530690	No
3	<i>Spectral and Spatial Classification of Hyperspectral Images Based on ICA and Reduced Morphological Attribute Profiles</i>	N. Falco	IEEE Transactions on Geoscience and Remote Sensing	53:11	IEEE	United States	2015	6223 - 6240	DOI: 10.1109/TGRS.2015.2436335	No
4	<i>On Understanding Big Data Impacts in Remotely Sensed Image Classification using Support Vector Machine Methods</i>	G. Cavallaro	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, J-STARS	8:10	IEEE	United States	2015	4634-4646	DOI: 10.1109/JSTA RS.2015.2458855	No
5	<i>Extended Self-Dual Attribute Profiles for the Classification of Hyperspectral Images</i>	G. Cavallaro	IEEE Geoscience and Remote Sensing Letters	8:12	IEEE	United States	2015	1690-1694	DOI: 10.1109/LGRS.2015.2419629	No

6	<i>GPU Implementation of Iterative Constrained Endmember Extraction from Remotely Sensed Hyperspectral Images</i>	E. M. Sigurdsson	IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, J-STARS	8:6	IEEE	United States	2015	2939 - 2949	DOI: 10.1109/JSTARS.2015.2441699	No
7	<i>A simplified gross primary production and evapotranspiration model for Boreal coniferous forests – is a generic calibration sufficient?</i>	F. Minunno	Geoscientific Model Development (GMD) journal	8	Copernicus GmbH on behalf of the European Geosciences Union (EGU)	Germany	2015	5089-5137	DOI: 10.5194/gmdd-8-5089-2015	Yes
8	<i>Satellite methods for the analysis of changes of lichen cover at vegetation communities of natural reserve «Pasvik»</i>	V.V. Elsakov	Current problems of remote sensing of the Earth from space	12:3	Space Research Institute Russian Academy of Sciences	Russia	2015	87-97		
9	<i>Ecological and Landscape Research in the National Park «Yugyd Va» (Komi Republic)</i>	E.I. Shubnitsina	Russian Journal of Ecotourism	8		Russia	2014	12-16		
10	<i>Land cover and soil type mapping from spaceborne PolSAR data at L-band with probabilistic neural network</i>	O. Antropov	IEEE Transactions on Geoscience and Remote Sensing	52:9	IEEE	United States	2014	5256-5270	DOI: 10.1109/TGRS.2013.2287712	No

**Table 3. The public dissemination activities of the North State project.**

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
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1	Conference presentation	Elsakov V	Effects of climate fluctuation to subpolar Ural and subarctic forest changes . The 13th International Circumpolar Remote Sensing Symposium	Sep 10, 2014	Reykjavik, Island	Scientific Community		International
2	Conference presentation	Cavallaro G	Parallel SVM for the analysis of hyperspectral data, In EGU General Assembly	April 29, 2014	Vienna, Austria	Scientific Community	12437	
3	Conference	Cavallaro G	A comparison of self-dual attribute profiles based on different filter rules for classification. IGARSS 2014.	July 15, 2014	Québec, Canada	Scientific Community	1800	International
4	Conference presentation	Cavallaro G	Smart data analytics methods for remote sensing applications. In IGARSS 2014	July 15, 2014	Québec, Canada	Scientific Community	1800	International
5	Conference presentation	Falco N	An ICA based approach to hyperspectral image feature reduction. In IGARSS 2014	July 17, 2014	Québec, Canada	Scientific Community	1800	International
6	Conference presentation	Astola H	Forest Stem Volume and Storm Damage Mapping in Finland and Russia. In IGARSS 2014	July 16, 2014	Québec, Canada	Scientific Community	1800	International
7	Conference presentation	Mäkelä A	Projections of forest productivity under climate change: uncertainties related to C and N limitation In 17th International Boreal Forest Research Association Conference	May 25, 2015	Rovaniemi, Finland	Scientific Community		International
8	Conference presentation	Borovlev A.J	Satellites images for analysis of canopy parameters of Pechora submountains forests In Forest ecosystems in the conditions of climate change: biological productivity and remote monitoring	Oct 14, 2015	Yoshkar-Ola. Povoljskii State University	Scientific Community		International
9	Conference presentation	Elsakov V	Impact of climate fluctuations on Subpolar regions of European Russia: Results from international collaborative research In Celebrating ten years of Northern Eurasia Earth Science Partnership Initiative Research: Synthesis and Future Plans	April 11, 2015	Prague, Czech Republic	Scientific Community		International
10	Conference presentation	Cavallaro G	Automatic morphological attribute profiles. In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 29, 2015	Milan, Italy	Scientific Community	2106	International
11	Conference presentation	Cavallaro G	Scalable developments for big data analytics in remote sensing . In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 28, 2015	Milan, Italy	Scientific Community	2106	International
12	Conference presentation	Cavallaro G	Automatic Threshold Selection for Profiles of Attribute Filters Based on Granulometric Characteristic Functions . Proc. of 12th International Symposium on Mathematical Morphology (ISMM 2015)	May 28, 2015	Reykjavik, Iceland	Scientific Community		International
13	Conference presentation	Antropov O	TanDEM-X InSAR time series data in forest cover mapping in boreal zone . In 9th International Workshop	March 25, 2015	Frascati, Italy	Scientific Community		International

			<i>Fringe 2015 Advances in the Science and Applications of SAR Interferometry and Sentinel-1 InSAR Workshop</i>					
14	Conference presentation	Antropov O	Combining TanDEM-X and Landsat 8 data for improved mapping of forest biomass . In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 30, 2015	Milan, Italy	Scientific Community	2106	International
15	Conference presentation	Antropov O	Selective logging of tropical forests observed using L- and C-band SAR satellite data . In IEEE International Geoscience and Remote Sensing Symposium(IGARSS)	July 30, 2015	Milan, Italy	Scientific Community	2106	International
16	Conference presentation	Mäkelä A	Uncertainty about future nitrogen availability dominates boreal forest growth projections, In EGU General Assembly	April 14, 2015	Vienna, Austria	Scientific Community	11837	International
17	Poster	Häme T	North State - Enabling Intelligent GMES Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems, In EGU General Assembly	April 17, 2015	Vienna, Austria	Scientific Community	11837	International
18	Poster	Häme T	North State - Enabling Intelligent GMES Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems, In 36th International Symposium on Remote Sensing of Environment (ISRSE)	May 12, 2015	Berlin, Germany	Scientific Community	743	International
19	Poster	Häme T	North State - Enabling Intelligent GMES Services for Carbon and Water Balance Modeling of Northern Forest Ecosystems, In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 28, 2015	Milan, Italy	Scientific Community	2106	International
20	Conference presentation	Antropov O	Mapping forest disturbance using long time series of Sentinel-1 data: Case studies over boreal and tropical forests, In IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 13, 2016	Beijing, China	Scientific Community		International
21	Conference presentation, conference proceedings	Davids, C	Simulation of Sentinel-2A red edge bands with RPAS based multispectral data, European Space Agency, (Special Publication) ESA SP-740, Proc. ESA Living Planet Symp. 2016	May 9-13, 2016	Prague, Czech Republic	Scientific Community	3000	European
22	Conference presentation, conference proceedings	N. Falco	"Unsupervised change detection analysis to multi-channel scenario based on morphological contextual analysis," in IEEE International Geoscience and Remote Sensing Symposium (IGARSS)	July 13, 2016	Beijing, China	Scientific Community		International
23	Conference presentation, conference proceedings	Haarpaintner, J	Boreal forest land cover mapping in Iceland and Finland using Sentinel-1a, European Space Agency, (Special Publication) ESA SP-740, Proc. ESA Living Planet Symp. 2016	May 10, 2016	Prague, Czech Republic	Scientific Community	3000	European

24	Conference presentation, conference proceedings	Rauste Y	On clear-cut mapping with time-series of Sentinel-1 data in boreal forest, European Space Agency, (Special Publication) ESA SP-740, Proc. ESA Living Planet Symp. 2016	May 12, 2016	Prague, Czech Republic	Scientific Community	3000	European
25	Poster	Sirro L.	Predicting essential forest variables using Landsat-8 and Sentinel-1 data for carbon assimilation models of boreal forest in ESA Living Planet Symp. 2016	May 10, 2016	Prague, Czech Republic	Scientific Community	3000	European
26	Poster	Minunno F	Assessing the carbon and water balance of Boreal forests using a process-based model driven by satellite images In ForestSAT2016	Nov 14-18, 2016	Santiago, Chile	Scientific Community		International

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