Big Data bases and applications

D 3.3 Forest trafficability maps – data sources and methods

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1. EFFORTE project objectives

EFFORTE is a research and innovation project providing the European forestry sector with new knowledge and knowhow that will significantly improve the possibilities of forest enterprises to assemble and adopt novel technologies and procedures.

The project aims at enhancing the efficiency of silviculture and harvesting operations; increasing wood mobilization and annual forest growth; increasing forest operations' output while minimizing environmental impacts; and reducing fuel consumption in the forest harvesting process by at least 15%.

The project is based on three key elements of technology and knowhow:

1) Basic understanding of fundamentals of **soil mechanics and terrain trafficability** is a crucial starting point to avoid soil disturbances, accelerate machine mobility and assess persistence of soil compaction and rutting. The key findings and recommendations of trafficability related to EFFORTE can immediately be adapted in all European countries.

2) Due to decreasing Cost-competitiveness of manual work and maturity of technology it is now perfect time to realize the potential of **mechanization in silvicultural operations**. EFFORTE pursues for higher productivity and efficiency in silvicultural operations such as tree planting and young stand cleaning operations.

3) 'Big Data' (geospatial as well as data from forestry processes and common information e.g. weather data) provides a huge opportunity to increase the efficiency of forest operations. In addition it adds new possibilities to connect knowledge of basic conditions (e.g. trafficabillity), efficient silviculture and harvesting actions with demand and expectations from forest industries and the society. Accurate spatial information makes it possible for forestry to move from classic stand-wise management to precision forestry, i.e. micro stand level, grid cell level or tree-by-tree management. EFFORTE aims at achieving substantial influence to the **implementation and improved use of Big Data within Forestry** and through this increase Cost-efficiency and boost new business opportunities to small and medium size enterprises (SME) in the bioeconomy.

EFFORTE researchers will develop and pilot precision forestry applications that, according to the industrial project partners, show the greatest potential for getting implemented immediately after the project.

2. Forest trafficability maps – data sources and methods

Introduction

This report (D3.3) includes a description of Big Data used to produce forest trafficability maps and the methods under development in the EFFORTE project. The utilization of forest trafficability maps are reported in a separate document, "*Planning for precision forestry by means of trafficability maps"* (D3.4).

Background

Heavy traffic connected to harvesting and to other forestry operations may cause damage to the soil surface, interfering the stand growth and inducing leaching of nutrients and mercury to water courses. Depending on the terrain characteristics, weather conditions and machinery used the disturbance on soil will vary a lot. To have less harmful impact on forest soil, it is important to know the terrain characteristics and understand soil behaviour in chancing weather. With the aid of best data sources and methods as precision forestry applications it is possible to improve environmentally sound forest operations by influencing on e.g. machine selection, working techniques, timing of operations as well as site selection and definition.

In the last decade researchers has worked intensely in collaboration with academia and operational forestry on a national as well as an international base to evaluate and develop new technique and improved methods to avoid damages to soil and water in forestry. Examples of new technique such as longer and wider tracks on forwarders and harvesters, CTI (central tire inflation) on forwarders and softer hydraulic mechanics has been tested combined with methods for soft soils and sensitive areas including protecting the soil with tops and branches as well as protecting water through building tree bridges. To reach efficiency and success in "soft logging" techniques and methods should be combined with knowledge, information and planning tools.

One basic data source is the detailed digital elevation model already available in many European countries (or soon to be). It may be used to model water movements and indicate areas of increased risk for damage to soil and water.

To have more detailed information for modelling terrain trafficability following terrain characteristics should be taken into consideration: geomorphology, hydrology, land use and land coverage, soil types and man-made structures. On top of terrain features, weather condition and weather changes are crucial factors drastically influencing on soil conditions (hydrogeology) and therefore on terrain trafficability. Moreover, utilization of the data from machines can improve the estimations of trafficability by means of post-operation data of rutting at site.

Today a lot of terrain characteristic data are freely available and accessible in country wise as Big data. Some of the terrain characteristic data is accurate as regards to value and position, but some of the data is inaccurate, faulty and defective. For example, data of geomorphology (e.g. elevation, slope, land formation) is globally presentable in several accuracy levels, whereas soil type data (soil maps) are usually inaccurate for utilization purposes in operations at the forest site and the coverage of utilizable soil maps is only partial in some countries.

In the EFFORTE project three different forest trafficability maps are developed, refined and demonstrated. In Sweden, main efforts are put on the depth to water maps, while in Finland two methods for modelling terrain trafficability are under development process. The static forest trafficability map is a product developed by an EFFORTE project partner (Arbonaut) and further described in this report. The product has already been tested in larger scale and the first application version will be soon launched to be used for planning of forest operations. The SpatHy model is a dynamic trafficability map layer that has been developed in Luke. The SpatHy model takes weather into account in trafficability estimations.

3. Big Data sources

Depth to water maps

Depth to water map (DTW) is based on the detailed digital elevation model (DEM) in 2-meter resolution (Figure 1). Probably any resolution of 1-5 meter is possible to use while a lower resolution would miss important details in how water is flowing in the terrain. Based on the DEM, slope and flow direction/accumulation are calculated and utilised to produce depth to water maps.

Figure 1. Detailed digital elevation model. © Lantmäteriet

Static forest trafficability map

Main principle for big data sources used in trafficability maps has been the availability of open access data and availability to present trafficability maps in an extensive area (Figure 2). This has been the case in static trafficability map developed by Arbonaut Ltd. Static trafficability map product utilizes the 16x16 m raster format structure in map presentations.

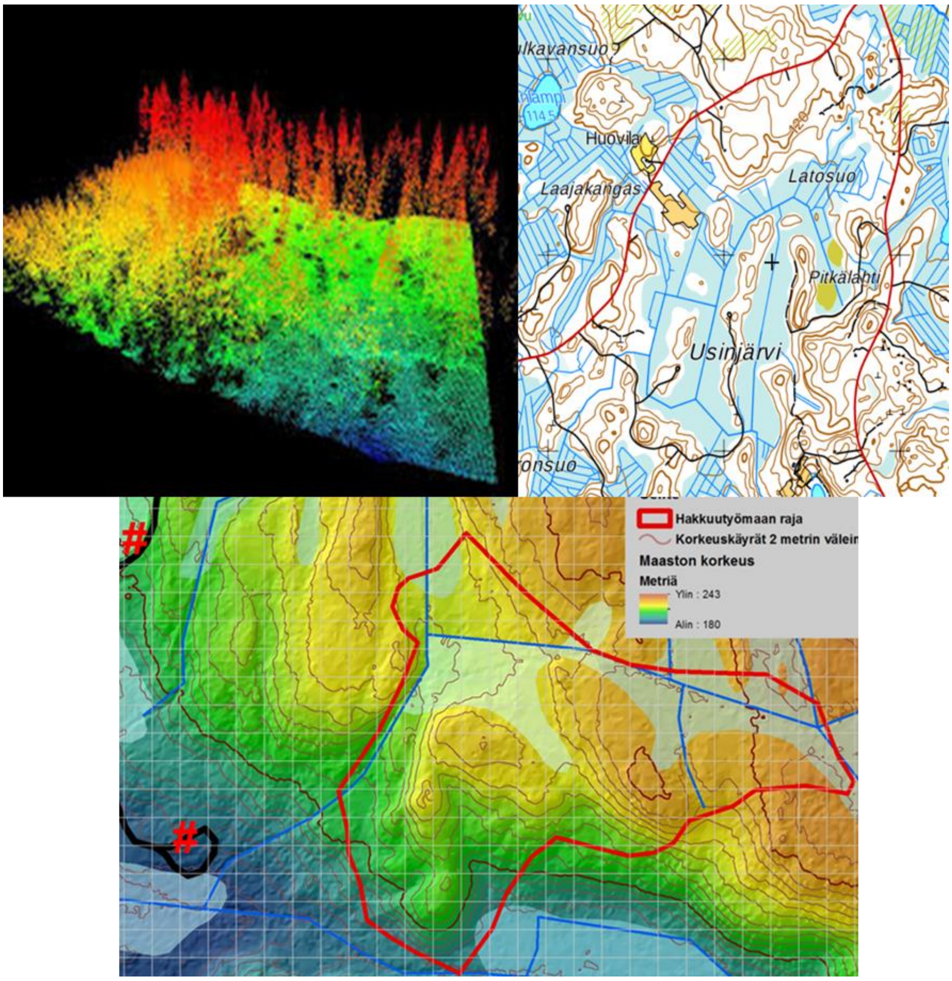

Figure 2. Data sources used in the static trafficability map product. Airborne lidar data, Base map (topographic database; peatland and ditches) and DEM.

Airborne laser scanning (ALS) point cloud data is the core data source for the static trafficability map. Digital terrain model (DTM) is processed from ALS data and by means of DTM topographic wetness index (TWI) is calculated. National Land Survey's topographic database is used for extracting peatlands and mineral soils as well as location of ditches and water bodies. Water bodies are classified in class "not classified". Ground water height for ditched areas is estimated by using ALS data and ditch locations. The analysis produces the average value of ditch depth or ground water height, depending on whether the ditch is dry or there is water in ditch. The analysis is calculated for the ditch parts and for further analysis it is generalized to 32 by 32 meter grid. For every grid cell in forest land the explanatory variables presented in table 1 are calculated.

Table 1. Explanatory variables and big data sources used in the static trafficability map product.

Explanatory variable	**Big data source(s)**
Peatland/mineral soil	Peatland mask from National Land Survey's topographic database
Average ditch depth/ground water height	ALS data and National Land Survey's topographic database
TWI	Digital terrain model (DTM)
estimate of amount of vegetation based on its height distribution	Processed ALS data

Dynamic forest trafficability maps - Predicting soil trafficability using GIS data and Spatial Hydrology Model (SpatHy)

The SpatHy-model is a dynamic trafficability map layer that uses GIS data, meteorological data and stream runoff data, which all are open data. Data from Multisource National Forest Inventory (MNFI), which is available throughout Finland in 16 m * 16 m grid, are used as an input value for the canopy model. That data consists of tree species, stand volume, basal area, height and leaf mass. From the Geological survey of Finland soil type data as gridded soil maps are acquired. Weather module requires daily air temperature, rainfall, relative humidity of air, and global radiation. In this application, weather information is available in 10 km * 10 km grid from the Finnish Meteorological Institute service.

4. Methods

Depth to water maps

The DTW model was first developed and used in Canada, University of New Brunswick[1]. It describes a wetness index which would enhance the process of detecting saturated regions around the flow channels.

The model creates an index of wetness were different index classes equals how far moving soil water is from the soil surface. The classes can be selected in the model but most often they are described as below (Figure 3).

- Dry soils (no color) > 1 m from ground water to the surface
- Common soils (light blue)) 0,5-1 m from ground water to the surface
- Moisty soils (middle blue)0,25- 0,5 m from ground water to the surface
- Wet soils (darker blue) 0-0,25 m from ground water to the surface
- Flow channel (dark blue) streams and wetland, water in the surface

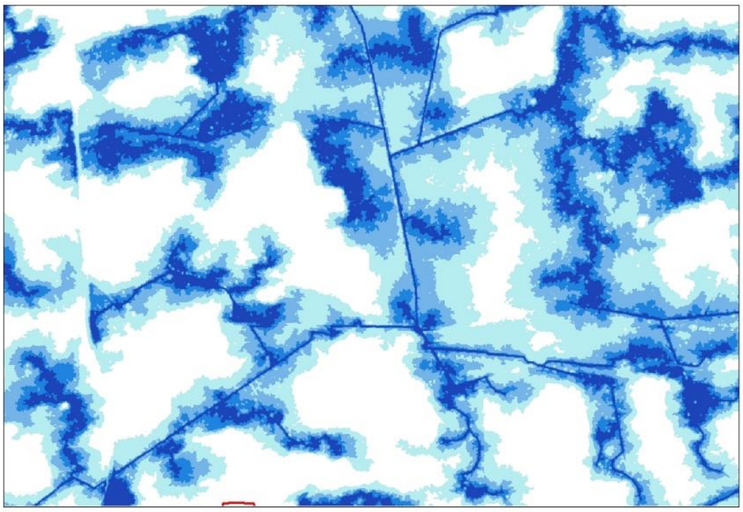

Figure 3. DTW model illustrating wetness index in different thematic classes

[1] Paul N.C. Murphy, Jae Ogilvie, Fan-Rui Meng, Barry White, Jagtar S. Bhatti, Paul A. Arp,. Modelling and mapping topographic variations in forest soils at high resolution: A case study. Ecological Modelling 222 (2011) 2314– 2332

The DTW index is derived using two grids: (i) a flow-channel grid based on 1 ha flow-initiation thresholds to signal the potential surface flow channels and (ii) the DEM-derived gradient grid. Grid (i) is based on the combination of "flow direction" and "flow accumulation" while the grid (ii) is the slope. An iterative function is used to determine the cumulative slope value associated with the least slope path from any cell in the landscape to the nearest surface water cell, e.g. the generated flow channels and other water bodies such as lakes, etc (DTW = 0). The cumulative slope value is multiplied by the grid cell size and is then assigned to the cell in the landscape.

The resulting DTW grid is formally obtained from:

$$\mathrm{DTW}\,(\mathrm{m}) = \left[\sum \frac{dz_i}{dx_i} a\right] x_c,$$

where dz/dx is the slope of a cell, i represents a cell along the path, a is 1 when the path crosses the cell parallel to the cell boundaries and 1.414214 when it crosses diagonally, with xc as cell size, in meter.

The developers evaluated the fit of the model with an inventory with 800 sample plots along sample lines in squares (Figure 4).

Each sample plot was measured concerning the soil wetness was measured and compared with the model. The result showed that in more than 70 % of the plots the soil wetness equalled between inventory and model. Different results in the plots were mostly due to ditches and roads and in more than 90 % of the unequal plots the model showed more wetness than the inventory. In conclusion, the model was a good tool and an informative map layer to estimate risk for wet areas in the forestry.

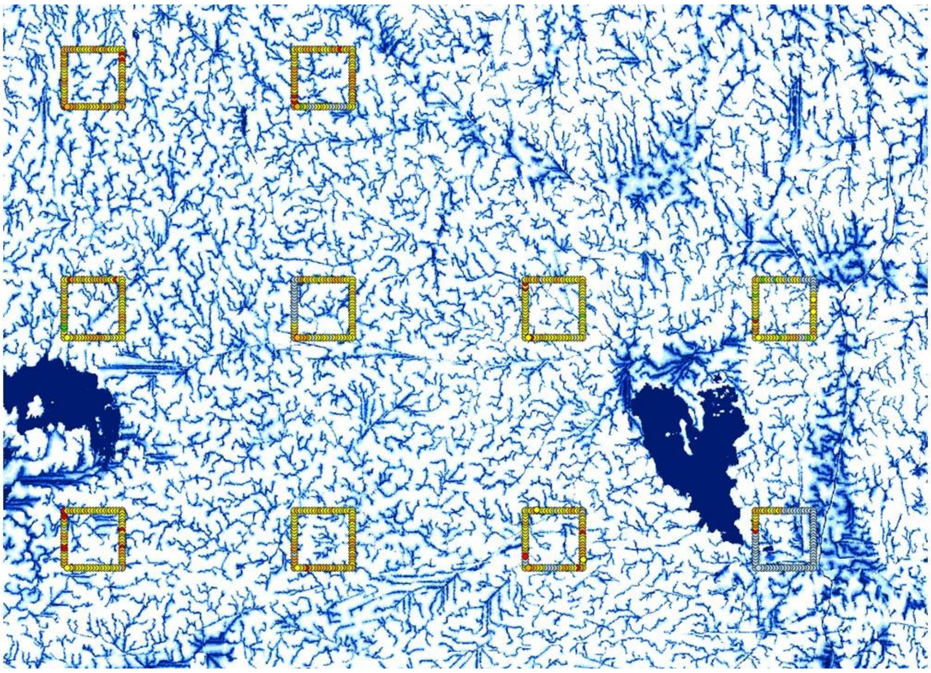

Figure 4. Design of field validation for DTW maps

Static forest trafficability map

Arbonaut Ltd has developed a trafficability map product that combines classic topographic wetness index – (TWI) and depth-to-water - DTW information to tree volume and soil type (peatland or mineral soil). The static forest trafficability map is a classification of every map pixel to class describing the season when the harvesting operations may take place without causing significant damages to soil using standard logging machinery (harvester, forwarder). The following classification is used:

1. Operations possible in any season
2. Operations possible in (normal) summer
3. Operations possible in summer during dry season
4. Operations possible only during frost or thick layer of snow
5. Not classified.

The pixel size is 16 by 16 meter and it is compatible with the standard Finnish forest resources inventory grid. This means that every inventory grid cell can have the forest trafficability attribute produced by the method. The classification is based on interpretation of airborne laser scanning (ALS) data and National Land Survey's topographic database. Both data sources are open access data in Finland and the coverages are extensive.

Field reference data collected by Finnish Forest Centre and by shareholders of Metsäteho from 5 study areas were used in method development. Field reference data included 296 field plots collected by Finnish Forest Centre (later FFC plots) and 856 point observations based on Metsäteho shareholders data (later Metsäteho points). FFC plots were sampled in area of 6 by 6 kilometer in each 4 study areas. Metsäteho points were from larger geographical area, roughly 300 000 hectares, in each 4 study areas. 4 of the 5 study areas were the same in both data sets. The location of field reference data is presented in Figure 5. FFC plots were from GNNS located circular field plots with an area of few hundred square meters whereas Metsäteho points were subjective point observations from representative points inside stands marked for cutting.

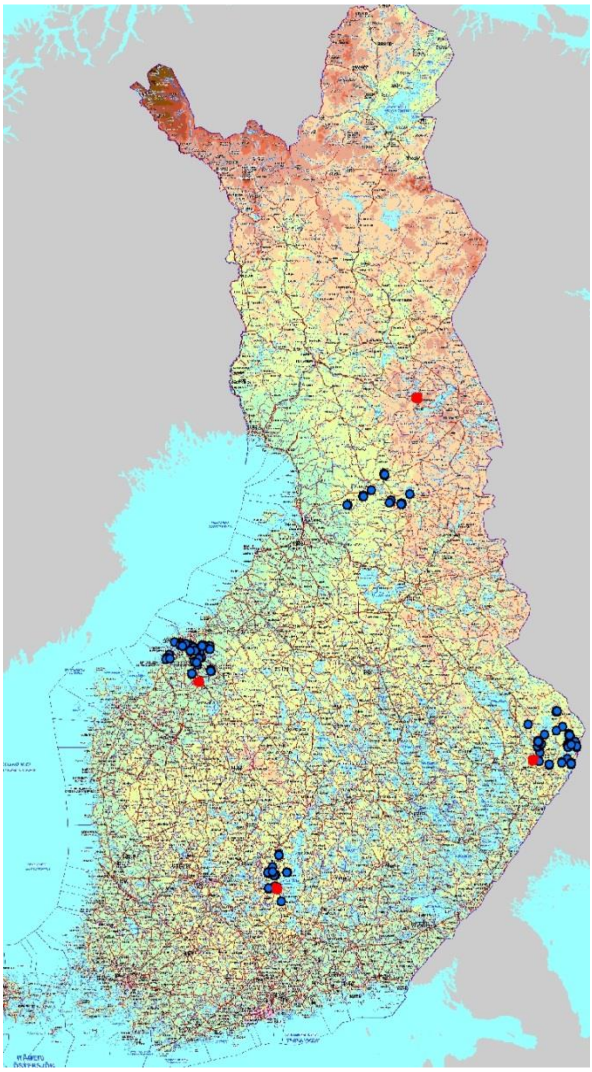

Figure 5. Location of field reference data. Red dots data collected by Finnish Forest Centre and blue dots data collected by shareholders of Metsäteho. Background map National Land Survey of Finland.

For every grid cell in forest land the following explanatory variables are calculated:

- Peatland/mineral soil
- Average ditch depth/ground water height
- TWI
- Estimate of amount of vegetation based on ALS height distribution

The estimation is done separately for peatland and mineral soil pixels. For both classes, the base level estimate is based on TWI, for which the thresholds values is estimated with the logistic regression technique from the field reference data. After that the base level estimate is adjusted to better or poorer class based on the amount of vegetation (in mineral soils) and amount of vegetation and average ditch depth/ground water height (in peatland). More vegetation and higher ditch depth/lower ground water height increases the trafficability. The threshold values are estimated from the field reference data. Each grid cell is considered individually not depending on the values of neighbour cells. The dynamic factors like precipitation, evaporation or ground frost do not effect on the static classification, only on usage of the classification. The classification flowchart is presented in figure 6.

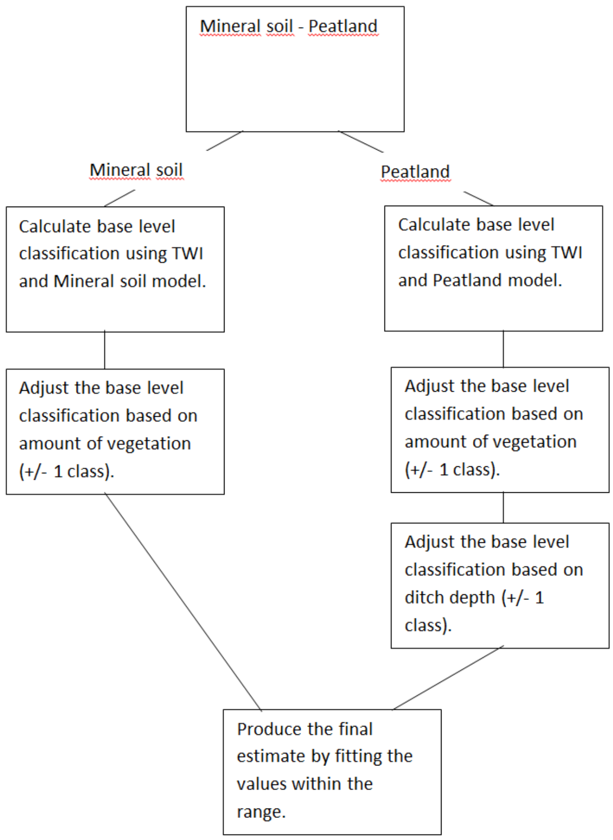

Figure 6. Flowchart of the classification in forest land.

During summer 2016, the classification accuracy of the static trafficability maps were studied in four separate areas around Finland. One third of totally 115 test sites (631 ha) were on peatlands. Accuracy was tested just on-site level. In addition, point/pixel -specific data was collected only for development purposes, because samples were presumed to bias towards mismatched points.

On mineral soils, more than 90 % of sites were classified correctly. On peatlands accuracy was a bit lower resulting in correct trafficability class on two sites out of three. Peatlands suitable only for winter-time logging were recognized promptly but almost half of summer-time accessible peatlands got winter-tag classification. Altogether, model predicting trafficability class was a bit conservative. Static trafficability model was found to be accurate enough and suitable for planning purposes. It compensates lack of local knowledge and is very helpful on allocating bigger peatland clusters potential for summer operations.

According to the test results, minor changes and adjustments were made to the model and its classification algorithm. New version of the static trafficability map is now in commercial use and further studied in the EFFORTE project. It is estimated that the coverage of trafficability map will be more than 3 million hectares until the end of 2017 in Finland.

The layer can be used in wood procurement for finding forest areas to be harvested in needed season. For example, peatland areas that can be harvested during summer are important for levelling seasonal variation in harvesting operations in Finland. The layer can be utilized at some degree in planning harvesting operations, too. The stock of marked stands can be sorted from best trafficability to the worst trafficability and optimized for the current harvesting season and dynamic factors. The accuracy and static nature of the results layer does not necessarily provide accurate enough information for planning actual harvesting operations. In EFFORTE project the method is tested and further refined in a new study site in Central Finland.

Dynamic forest trafficability map - Predicting soil trafficability using GIS data and Spatial Hydrology Model (SpatHy)

Heavy traffic connected to harvesting and to other forestry operations may damage the soil surface interfering the stand growth and inducing leaching of nutrients and mercury to water courses. Fine textured mineral soils are vulnerable to rutting especially during the wet and frost-free season. Preventing the damage requires restricting traffic during times when the rutting is most likely to occur. This requires dynamic forecasts and spatiotemporal prediction of soil trafficability.

Daily topsoil water content is computed using a simple spatially distributed hydrologic model combined with a conceptual ground water model (SpatHy). SpatHy is composed of a gridded above-ground hydrology model, bucket-type topsoil hydrology model and of topographic-based conceptual groundwater model. The model is parameterized open GIS data, run using open meteorological data, and calibrated using open stream runoff data.

The canopy model describes water and snow fluxes (rain fall, through fall, snow melting, infiltration, evapotranspiration) and storages (interception in canopy, and ground vegetation, snow pack) above the soil surface using daily time step. Tree species, stand volume, basal area, height and leaf mass are given as input grid for the canopy model. In the current application data from Multisource National Forest Inventory (MNFI) are used, which is available throughout Finland in 16 m * 16 m grid. The bucket-type soil hydrology model describes soil water storage in the topsoil according to soil porosity, field capacity and wilting point, which are derived from the soil type information available in the Geological Survey of Finland gridded soil maps. The water content in topsoil is increased by infiltration and decreased by evapotranspiration (both computed in the canopy model). The water storage in the bucket that exceeds the field capacity is percolated into the deep soil layers and the conceptual ground water model Topmodel. Topmodel accounts for lateral flows in saturated zone assuming that the ground water flow lines parallel to local surface slope, and further assuming quasi-steady state balance between ground water recharge and lateral flow.

Weather input requires daily air temperature, rainfall, relative humidity of air, and global radiation. In this application, this information is available in 10 km * 10 km grid from the Finnish Meteorological Institute service.

The primary output of SpatHy is a dynamic, daily changing top soil moisture map in 16 m * 16 m grid over the area where the off-road traffic is planned (Figure 7).

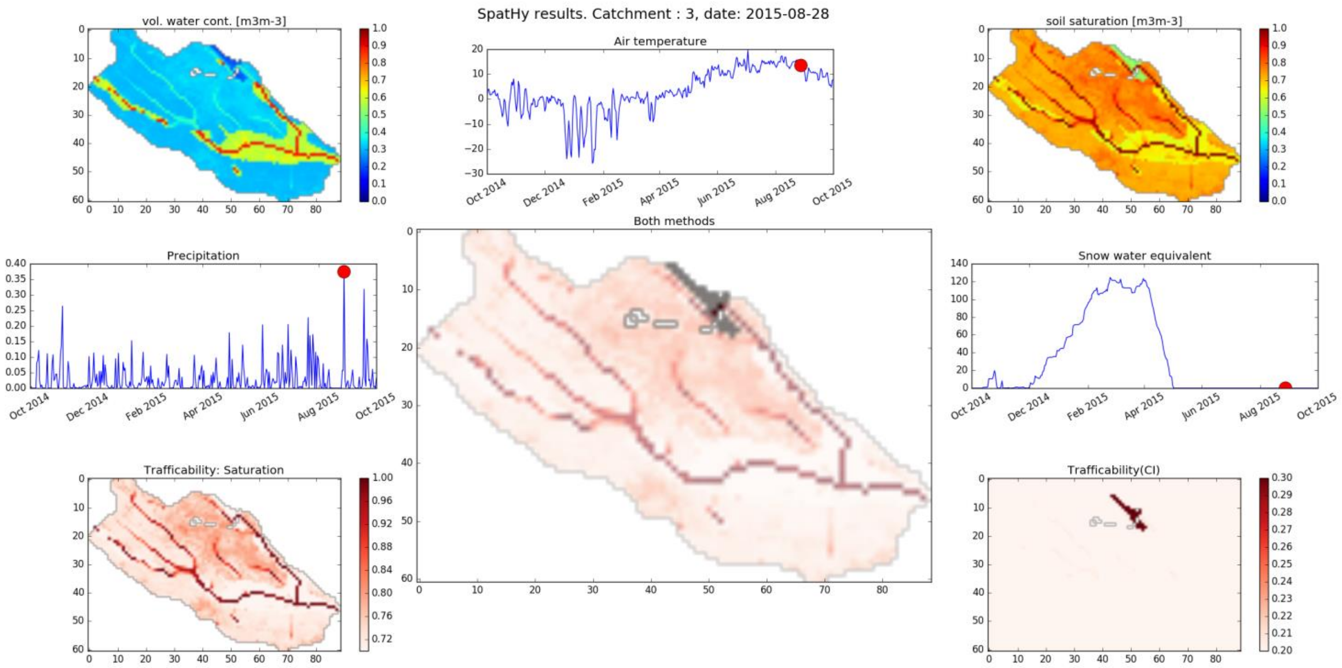

Figure 7. A map of soil water content, saturation and trafficability computed using SpatHy-model.

Soil trafficability is predicted using two parallel approaches: directly from topsoil water content and by a more mechanistic approach using topsoil water content, soil type, cone index, machinery details to predict the risk of rutting. Dynamic maps of rut formation risks were produced to study the spatiotemporal pattern of rut risk in the study area. The model can be run forwards in time by using weather forecast in order to support decision making (Figure 8). Next step in the development is to test the model performance against results of an independent traffic experiment.

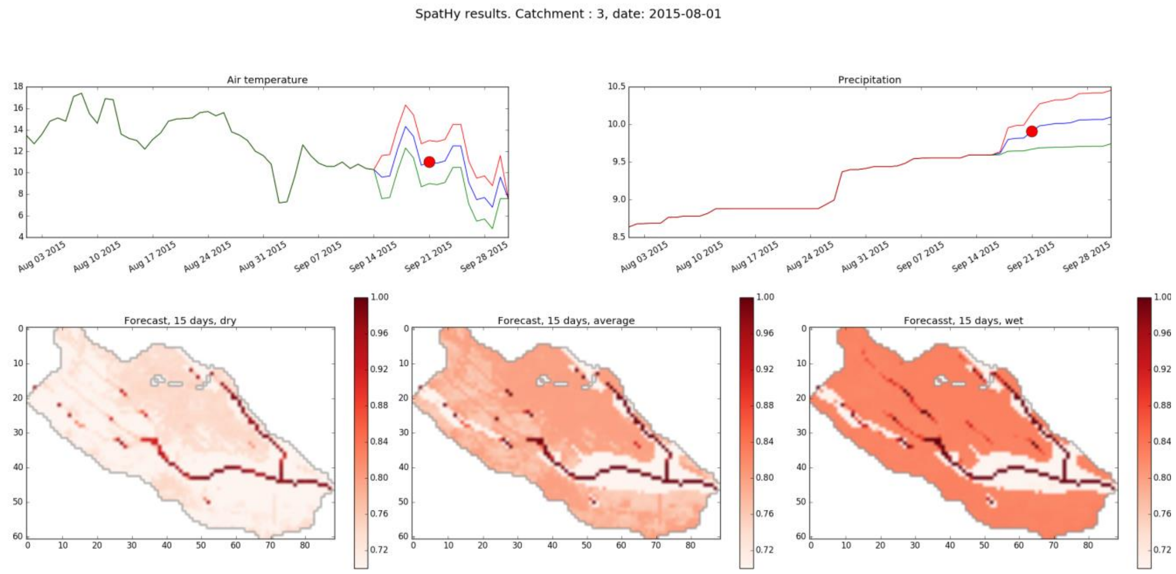

Figure 8. Trafficability computation with weather forecasts and the uncertainty in the weather forecasts. The model is run first until the present day and then forwards using different weather forecast scenarios.

5. Conclusions

The DTW maps are rather simple and robust and forms an excellent platform for introduction of trafficability maps in forest operations. Limitations include very flat terrain where all trafficability maps using only DTM information have limited information content.

The static trafficability map layers have been tested in 2015 and 2016 in several forest areas by forest companies and contractors. While the experiences have been very encouraging, a new program of trafficability map will be launched in Finland to adopt the method as a part of the Metsaan.fi –portal run by the Finnish Forest Centre, which runs the campaign for inventorying forest resources data on privately owned forests. The inventory data is produced by the combination of ALS, aerial photography and field work. After the last areas are inventoried in 2019, comprehensive forest resources data will be ready in 2020 covering the surface area of privately owned forests (14 milj. ha). Meantime, Metsähallitus (state forests) and other big forest owners (e.g. forest industry companies) run their own inventory programs with similar methods. This means that the static trafficability map layer may be basically extended to all forest areas in Finland.

The Spathy model brings the dynamic component into account in trafficability mapping. It includes more weather data and shows interesting results to be further developed and evaluated during the EFFORTE project.

All three trafficability maps have the potential to be used in all European countries. The more complicated is the data structure of the model, the more effort is needed to make country wise adaptations. A detailed DEM based on Lidar is getting available in all EFFORTE countries which makes it possible to compile TWI or DTW map layers. The hydrological models certainly require some national refinements when included in trafficability maps as they vary according to national and regional conditions.