CASSIA Final Report

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with

REACH-U Ltd.

Project Title: „Customised Forest Assessment Service for Insurance“

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1. Introduction

The objectives of the application development project "Customised Forest Assessment Service for Insurance" were to develop forest value assessment and temporal forest change monitoring services for the insurance and reinsurance sectors.

Access to satellite data and a wide choice of satellite platforms has increased the interest in using space-based monitoring in both, governmental and private sector. Forest insurance industry sector represents a large market where operational remote sensing based applications have not yet fully emerged. The role of forest remote sensing in insurance industry has been insignificant and operational use cases are very difficult to find (Leeuw et al. Remote Sens. 2014, 6, 10888-10912). Despite that, it is an important market that will keep growing due to the increased wind and fire severity and frequency, climate change, increasingly unsustainable forest management and illegal logging due to the increasing demand for timber, paper and derivative products (WWF). The demand for protection products is expanding by the growing awareness of natural catastrophes while the levels of trust in the insurance sector have been among the lowest in any consumer industry (Ernst & Young, 2015 European insurance outlook). Remote sensing data could provide the critical support that is needed for risk assessment and pricing through the consistent and continuous data flow of information and a selection of reliable method to observe the changes around us. According to Leeuw et al. (2014), the benefits from remote sensing information in the insurance sector include; (1) making insurance affordable to low income households; (2) reducing fraud, moral hazard and adverse selection; (3) eliminating the burden of costly verification of claims on-the-ground and (4) enabling faster and cheaper pay-outs to the insured. In addition, it was also proposed that remotely sensed index insurance can provide insurance to forest owners in remote areas where conventional insurances cannot serve.

The proposed service would not just automate the industry's existing business processes but provide it with the opportunity to detect illegal activities or force majeure related damages in a very short time. Such effort would frequently add value to the industry and the customers by detecting the possible damage at an early stage. For example, reporting storm damage in a few days after the storm would benefit the client who can clear and sell the fallen timber before it loses its value. Monitoring forests from space can also increase the possibility to find out about illegal logging during the activity or shortly after it and help to track down the people responsible.

The main objectives of the proposed Copernicus forest Assessment Service for Insurance (CASSIA) service were to:

I. Produce a country-wide forest value map

II. Generate a weekly change map for forest disturbance detection

III. Assess regional forest loss rate and damage probability risk

IV. Provide data layers over a web service

The core of the proposed service lies in utilizing the Copernicus Programme's Sentinel-1 and Sentinel-2 satellite data where the two satellites will be applied for assessing forest value and detecting near real-time changes in forests.

2. Description of the Programme of Work

The whole project was divided into six work packages with two of them dealing with end-user and business related activities (WP1: User consultancies, mapping customer needs and feedback, WP2: Viability analysis and business model development), two of them with technical application and service development (WP3: Forest data layers generation with insurance requirements, WP4: Operational forest monitoring service platform development), one with sample datasets generation

(WP5: Forest change rate analysis and change probability assessment) and one with project management and reporting (WP6: Project management and reporting). For a sub work package level categorisation see Figure 1 below.

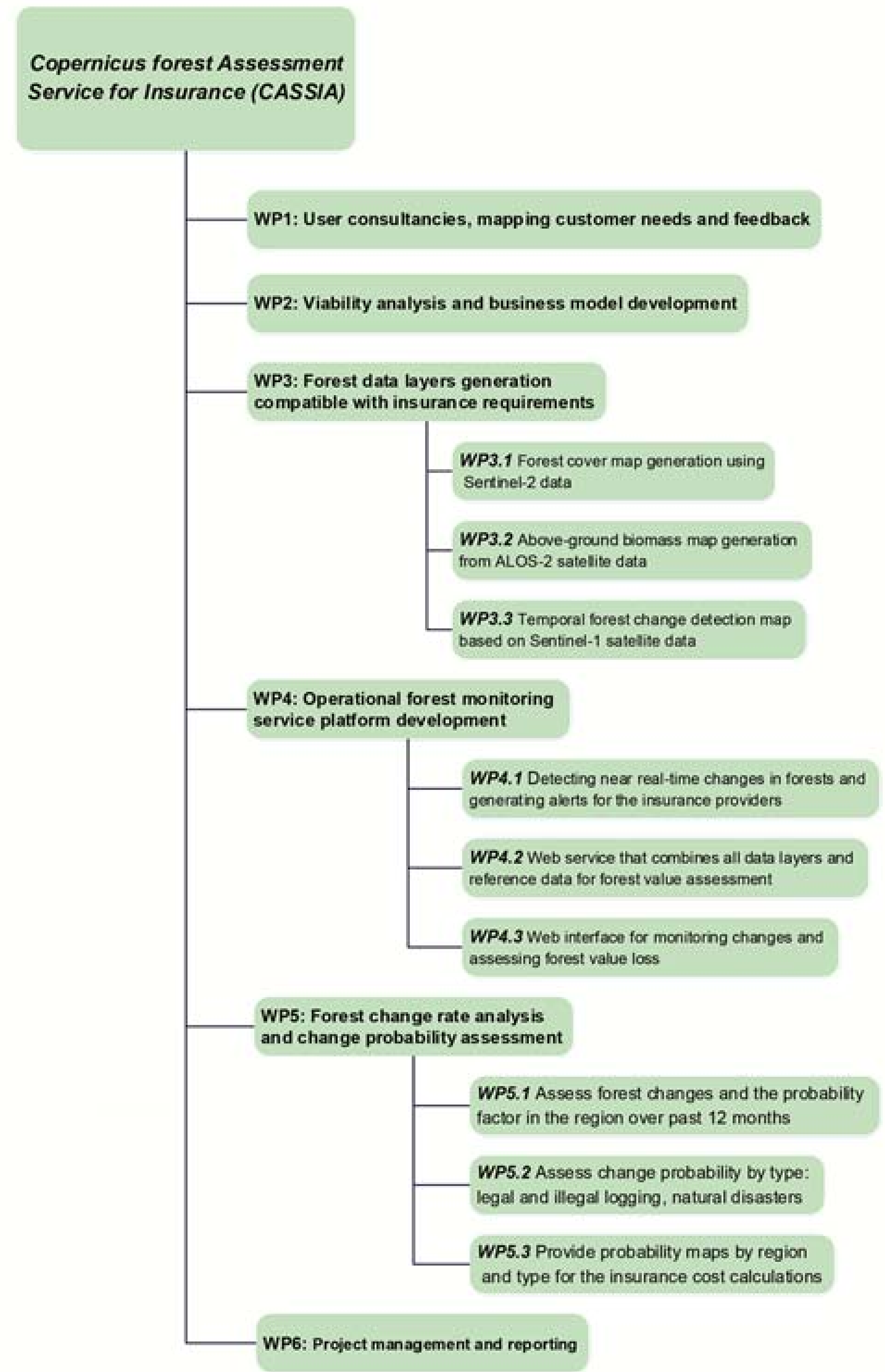


Figure 1. Work breakdown structure and work packages of the CASSIA project.

According to the project plan, the project was to start with user consultancies and mapping their needs under WP1 for gathering technical inputs for forestry products and algorithms development under WP3 and for business model development under WP2. These were to be followed by the operational forest monitoring service platform development and the generation of sample forest change products to be used for forest change analysis demonstration. Also see Figure 2 below.

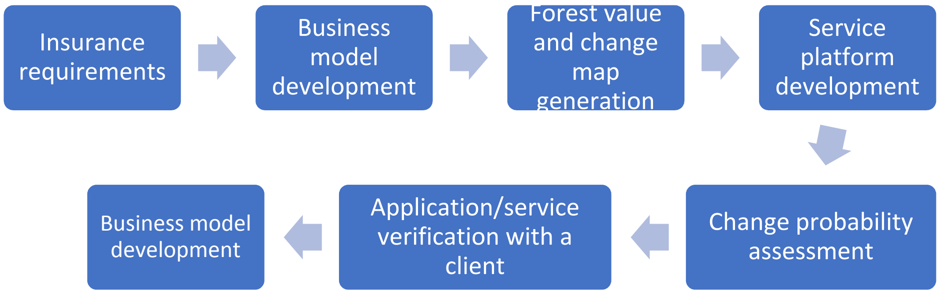


Figure 2. The main proposed workflow of the CASSIA project.

In general, on a work package level, there were no significant deviations from the original work plan. There were, however, changes at the sub work package level, in response to the identified user needs and end user feedback acquired during the project. These manifested themselves in reallocating resources between sub work packages to concentrate on those with business potential and of value to the end users. These are elaborated on in more detail later in this document where activities performed during the project are reported. All the changes have been communicated to and approved by ESA. Following are the reports on the activities performed and main results achieved under each work package.

3. Reports on the Activities Performed and Main Results Achieved

3.1 WP1: User consultancies, mapping customer needs and feedback

3.1.1 Activities performed

The bulk of activities in this WP were done during the first half of the project. The main goals were:

- To get in contact with the end users (Insurance, Reinsurance and forest companies buying insurance) and validate the use case ideas and confirm the needed forest data layers and their requirements.
- To get CASSIA introduction material to the Insurance companies inner circle to generate development and cooperation interest from within the insurance companies.
- To get technical persons within the insurance companies involved in the development and to pick 1-2 companies that would agree doing risk modelling tests with the data provided by Reach-U.
- To, on a rolling basis, interact with the end users (Insurance, Reinsurance and forest companies buying insurance) and validate the use case ideas and confirm the requirements to the forest data layers.

To achieve these, many meetings were set up and done with potential end users in the insurance sector and other relevant stakeholders. Mostly within the first half of the project, but also later. These can be found in Tables 1 (meetings with insurance players) and 2 (meetings with stakeholders) below.

Table 1. Meeting with possible end-users in the insurance sector.

Date	Location	Participants	Meeting summary
1 June 2016	Munich, Germany	Andreas Siebert – Munich RE	Introduction: Introduction to CASSIA project and possible roles were defined. Reach-U introduction was made to the customer. Plan of how to address

			use case validation and providing technical input to forest change detection algorithm development was agreed. Key findings: Next meeting was agreed with technical personnel and forest insurance department.
9. June 2016	Tallinn, Estonia	Jaanus Seppa, Laura Tõnise, Vienna Insurance Groupe	Introduction to CASSIA project and possible roles were defined. Reach-U introduction was made to the customer. Plan how to address use case validation and providing technical input to forest change detection algorithm development was agreed. Key findings: Reach-U will send sales material and list of activities where VIG can provide input to Reach-U. Based on this information next steps will be agreed
18 June 2016	Estonia, Tallinn	Gunnar Reinapu- Estonian private forest association	Key findings: • Currently using Landsat-8 • Main problem is with clouds • High interest to have more forest owners active in management • Possibility to have national budget subsidy for the annual service cost • High interest in forest "reforestation" detection in less than 30 year stands Price for the service should be 3-5 EUR per user per month
07.07.2016	Munich, Germany	Beverly Adams, David Marechal – Guy Carpenter	Introduction to CASSIA project and possible roles were defined. Reach-U introduction was made to the customer. Plan of how to address use case validation and providing technical input to forest change detection algorithm development was agreed. Key findings: Guy Carpenter technical team was impressed by the options that remote sensing can offer in the future to monitor changes. It was emphasized that more data is needed (5-10 years) in order to make customers analytical tools for estimating forest damage risk. Cuy Carpenter will organize next technical meeting to address the use-case and technical requirements part asked from Reach-U.

10 July 2016	Germany, Munich	Rudolf Seitz - Bavaria Forest Agency	Key findings:
			• About 700 000 forest owners in Bavaria
			• Most of owners would be interested to use the service if:
			    o Changes report in 3-4 days
			    o Beetle damage reported
			    o Privacy for data provided

			o Price not exceeding 10 EUR a month • Main owners group older people, conservative. • Average forest stand size 0,8 – 2 hectare (suitable for detection with Reach-U service) Not much cooperation between different German counties and forest management branches
10 July 2016	Munich, Germany	Petra Adler - Göttighen Forest Agency	Key findings: • Price for the service should be about 5-6 eur per customer; • Focus on privacy issues, data about forest is personal; • Same use-cases could be implemented as neighbouring counties. Update frequency 1 week to 2 weeks is sufficient.
1 July 2016	Belgium, Brussels	EU forest management DG Grow – 2-3 persons tbc.	Key findings: • Update frequency for forest change, storm damage is once per month • Sensor resolution for forests 10x10m is minimum parameter that could be used. Preferred resolution is 2-3m or less. • No global or EU coverage service is available in 2016. Many products currently available in the forest sector rely on large volumes of manual work.
14 July 2016	Sweden, Stockholm	Markus Steen - Södra (forest association)	Key findings: • More than 50 000 forest owners together under Södra • Full country coverage has high interest • Possibility not to be affected by clouds is highly valued. • Current input is 1 time per year SPOT5-SPOT6 and Landsat data. • Using Airborn platforms is already cost effective for forest monitoring but it is expensive to continue in coming years, alternative solutions are welcome Cost for forest change monitoring service should be less than 10 EUR per user. Input to the forest insurance premium is promising, but first the change detections should be proved to customer.
2 Aug 2016	Latvia, Riga	Juris Zarins, Latvias State Forest	Key findings: • Main interest in forest changes due to storms • LoI to be signed with Reach-U. Secondary objective is to have forest changes update for planning around 800 persons work

			weekly bases.
14 Aug 2016	Lithuania, Kaunas	Ina Bikuviene - Lithuanian Forest Inventory and Management Planning Institute	Key findings: • Lack of forest data is coming critical to handle/manage forests in Lithuania • Old methods can provide data in 5-10 year frequency and questionable coverage • Definitely possible to launch service in Lithuania Confirmation about quality of the service should be in focus.
12 September 2016	Tallinn, Estonia	Jaanus Seppa, Laura Tõnise, Compensa OÜ, VIG	Introduction: Looking over Compensa Interest creating new business opportunities and export potential in Poland and Romania. Key findings: Agreement to exchange information about other Vienna Insurance Group (VIG) companies and interested parties from Finland, Poland and Sweden.
27. September 2016	Munich, Germany	Dr. Tobias Hirzinger, Transiskus Sebastian, Mayer-Bosse Alexa, von Gravenreuth Wendelin, Schlüter-Mayr Sabine, Hartmann Rainer - Munich RE Dr. Tommy Klein Zurich-NR Emmanuel MONDON AdviceGEO	Introduction: Large scale introduction to Munich RE and associated partners about CASSIA and potential for forest assurance Negotiations to promote CASSIA documentation and use cases in Munich RE internal network. Key Findings: Agreement with Dr. Hirzinger that Munich RE will provide input for CASSIA regarding technical parameters needed for forest insurance, Agreement to have Munich RE input for potential use-cases regarding forest insurance. Clarification that in business model planning the focus for CASSIA should be to reduce the RISK of insurance payments back due to insurance event. From the 3 EUR insurance premium around 75% is going to insurance claims and only 25% remains for the maintenance. This 75% is where remote sensing techniques with the combination of insurance risk modelling should provide biggest impact.
18. October 2016	Tallinn, Estonia	Jaanus Seppa, Laura Tõnise, Vienna Insurance Groupe (VIG)	Introduction: Providing update on the forest change accuracy and samples. Discussion over pricing based on insurance premium of 3 EUR per hectare. Negotiations to promote CASSIA documentation and use cases in Vienna Insurance Groupe internal network. Key findings: It was agreed that VIG will provide technical input for the algorithm development in

			Q1 2017. Further work must be done in order Compensa (partner of VIG) could provide marketing and technical material to VIG inside network.
29.11.16	Lahti, Finland	Aki Hostikka, Esko Välimäki, Marko Keisala, Juha Inkilä – Metsäkeskus (Finnish state forest agency). Kauko Määtta - Eminko	Introduction to CASSIA project and Reach-U was made to the customer. Key findings: • Interest in storm damage data layers. • Quarterly reports on logging activities would be of use for forest management planning. Could also be delivered more frequently. • No interest regarding insurance.
15.03.17	Stockholm, Sweden	Olof Fält, Jacob Stafstedt, Robert Stenlund – Guy Carpenter	Introduction to CASSIA project and Reach-U was made to the customer. Key findings: • One use case for storm damages was identified. • Information of forest height and type would be of use as well. • Big storms in Sweden take place on average every 5-10 years.
02.06.17	Tallinn, Estonia	Jaanus Seppa, Lauri Tõnise – Compensa Ltd., VIG.	Previous activities and communications between Priit Anton from Reach-U (the previous CASSIA project manager and contact point with Compensa) and Compensa were discussed. Current state of the project was introduced to Compensa. Potential uses of EO data in insurance (forestry but also other sectors) were discussed. Writing of a White paper to introduce new EO products and capabilities for the insurance sector was discussed. Key points: • It was decided to work together on a White paper to be disseminated inside the VIG by Compensa. • Flooding detection could be of interest to insurance providers in agricultural and urban areas. • Compensa shared (confidentially) their findings about forest insurance from talks with foresters in Estonia.

04.08.17	Teleconference	Dr. Tobias Hirzinger, Sabine Schlüter-Mayr – Munich RE. Emmanuel Mondon – AdviceGEO.	Munich RE introduced their past activities in this year regarding forest insurance. Key points: • Munich RE has worked out wind and fire damage models for the US, now looking for models for other parts of the world. • Munich RE is interested in fire and storm damage events and alerts. • Munich RE is interested in fire and storm damage maps after the events and also historical data. • Munich RE is mainly interested in assessing damages and monitoring of plantations. • Munich RE is interested in knowing how many private forest owners are/were affected by damages. • Munich RE are interested in information regarding management practices in plantations. • Munich RE will provide detailed input to Reach-U in September about what information layers/products (and their tech. requirements) are needed for their assessments and models.

Table 2. Meetings with possible partners and stakeholders.

Date	Location	Participants	Meeting summary
20 June 2016	Estonia, Tartu	Mait Lang, Estonian University of Life Sciences	Introduction: Reach-U provided input information about difficulties how to evaluate what technical parameters could be agreed between insurance companies and Reach-U. There can be input provided from the University side how to address the forest modelling and input to change detection. There was specific focus in algorithm development for forest change detection. Key findings: • Forest clear-cut areas have been requested from University. • SAR is main source to provide EO based data about forests • Private forest data is not collected as should be done by the law. • Main problem is lack of resources

			to cover vast amount of labour work regarding accurate forest measurements EO data could be beneficial and forest owners are willing to by this info
20 Aug 2016	Lithuania, Kaunas	Gintautas Mozgeris - Aleksandras Stulginskis University	Meeting result was that there will be support provided for calibration of forest change detection in Taurage, Lithuania area.
27. October 2016	San Francisco, California, Planet Labs Partner Summit	Andy Wild (CRO) - Planet Labs	Introduction: Reach-U presented use-case scenarios and asked for update if any of Planet Labs partners has experience in the forest change detection and insurance area. Also negotiations took place to use Planet Labs data as an input for forest change classification and modelling the forest damage risks. Key findings: Planet Labs will provide Dove data (4m resolution) for research purposes free of charge to Reach-U. There was no knowledge about any of Planet Labs partners having same research as Reach-U CASSIA project is addressing.
22.11.16	Helsinki, Finland	Tuomas Häme - VTT	Possible cooperation between Reach-U and VTT regarding Forestry TEP was discussed. It was concluded that cooperation could be possible in terms of platform testing and data sharing.

Main meetings with key end users and stakeholders were: Munich Re, Guy Carpenter and Bayern National Forest Agency (LWF) in July 2016; Compensa in August 2016; Södra Sweden, Metsa Group Finland, Munich Re and MEAG in September 2016; Planet Labs and Metsäkeskus in November 2016, Guy Carpenter Stockholm in March 2017, Compensa in June 2017 and Munich Re in August 2017. During the meetings with insurance or reinsurance providers, 3-4 different experts were participating from various relevant departments, such as forest insurance, natural hazards prediction, risk modelling, weather analysts and marketing departments. Besides insurance companies there were consultancies with several big potential customers to the forest insurance companies mainly in the Scandinavia market.

3.1.2 Main results achieved

The summaries and key findings of all the meetings can be found in Tables 1 and 2.

There was a lot of interest from the end users' side in setting up the meetings of the first round. In general, it was confirmed that both insurances and forestry agencies were looking for and interested in forest data, products and services as their current solutions didn't meet all their various needs. During these or the follow-up meetings it was identified that mostly there was interest in forest change information - mostly storm damages but sometimes also clear-cuts. Depending on the use case and the client this information was said to be needed from every 2 weeks to about once in a quarter. There was no interest in the above-ground biomass product either because it wasn't needed in the first place, the retrieval accuracy wouldn't probably be sufficient and/or there were already satisfactory solutions for acquiring this information. The quality of the potential data products to be offered was stressed often and that this needed to be demonstrated well. The feedback from various forest agencies in Scandinavia, potential customers of forest insurance companies, was that reducing the price of forest insurance premium should be addressed, because the subsidy and support from the government side (both Finland and Sweden) to the forest insurance is under negotiations and could be changed in the coming years. It was agreed upon with insurance/reinsurance companies Munich Re, Cuy Carpenter and Compensa of the Vienna insurance Groupe to arrange new meetings and work on defining detailed use cases and needed technical specifications of the forest change products, both on our and their side.

In the following months Reach-U and Compensa researched possibilities of providing forest insurance in Estonia, in addition a white paper describing the new possibilities provided by EO data from the Copernicus programme and its potential applications in the insurance sector was written with them and distributed within their network (see Annex 1). The white paper focused on all the insurance sectors and not only forestry to have a wider potential effect. The main findings of Compensa were that forest insurance hasn't been a topic of discussion and much interest in the forestry sector in Estonia because large forest owners own enough forest that the damage cost incurred in an event is of the same scale than the insurance premiums for all the forest owned and as such they don't see any economic gain from it. Regarding insurance for small and medium (private) forest owners it was said that this hasn't been a topic of discussion and consideration within those circles in Estonia. It was commented that it could be of interest if the costs of the insurance are low, but even then, the concept should first be adopted on a state level for small private forest owners to be comfortable and confident enough to consider it.

Regarding Guy Carpenter there was a meeting with Guy Carpenter Stockholm as it's operating in the Scandinavian market and has experience with forestry and forest insurance. Unfortunately nothing new was achieved in that meeting and during the following contacts with them. Again, interest in detecting storm damages up to 2 weeks after the storm was shown but nothing more concrete came from the meeting nor from the contacts afterwards.

After the initial couple of meetings Munich Re started analysing their internal processes dealing with forest insurance to identify possible new and validate Reach-U's initially proposed use cases. Munich Re organised an internal workshop in May 2017 with the aim to analyse how various forest data layers could be used in their current work processes and what new work processes could be implemented having such datasets available and how much integration effort would be needed. As forest insurance isn't a well analysed topic then it was reported that further work and analyses needed to be done to provide feedback. In August 2017 a teleconference was arranged with Munich Re where they reported that they had, in partnership with some forestry plantation owners in the United States, worked out wind and fire damage assessment and prediction models for those areas and were now looking to do the same in Europe and other parts of the world. They reported that they were interested in wind and fire damage assessments after current, future and also historical events for building and validating risk models. It was agreed upon that Munich Re would provide detailed technical specification of the data they need at the beginning of September and that Reach-U would reply with a technical feasibility report within a few weeks. Unfortunately Munich Re never sent the technical specifications. In response to Reach-U's emails in September and the following months they commented that they were still working on their exact needs and in November they reported to have held another internal meeting, but that still more time would be needed to provide feedback. As of the writing of this report no input has been received from them, but this will be followed up on after then end of this project.

3.2 WP2: Viability analysis and business model development

3.2.1 Activities performed

The goals were:

- To identify 2-3 detailed and realistic use cases for viability analysis and business model development.
- To verify the viability analyses and business models with relevant stakeholders.

The activities here have been closely linked to those under WP1 as the end user meetings have been also used to gather information and to validate and get feedback on possible use cases and their viability. For more details refer to Table 1.

The initially proposed use-cases by Reach-U (forest value/above-ground biomass assessment, claims verification using EO data and forest changes/damages trend analysis) were either not seen as sufficiently important or detailed enough by the insurance actors as identified during the first round of meetings and so it was decided with a few companies (Guy Carpenter, Munich Re and Compensa) to work together on defining better ones. Due to the complexity of the insurance processes and the relatively small previous experience and knowledge about forest insurance in comparison to other insurance sectors (e.g. real-estate and life insurance) within the insurance companies, leading to more work to be done than initially estimated, the feedback from the partners was slow to come. This resulted in the activities and work done being limited in this work package due to not getting enough detailed, technical and timely feedback from the selected insurance or reinsurance companies regarding their data/service/use case needs and technical specifications.

3.2.2 Main results achieved

The key findings from WP1 relevant to business model development and viability analyses are:

- There is no to little interest in the above-ground biomass product as a proxy for forest value assessment.
- There is little interest in EO data use for claims verification as from the insurance premium per hectare about 75% is reserved/planned for back payments in case of an insurance case and so the economic gain would be low.
- As 75% from the insurance premium per hectare is reserved/planned for back payments in case of an insurance case, focus should be put on damage prediction modelling as better models would allow this percentage to be smaller, thus lowering the premium cost and potentially increasing the number of insurance companies' customers.
- For Reinsurance companies, the main interest is also forest damage probability modelling in order to decide what regions would have high potential to offer insurance.
- Windfall, fire and insect damages are of interest to insurances. Which most depends on the geographic area and which of those is the most prevalent form of damage there.
- For proper analysis and modelling of risks data from at least 5-10 years is needed.
- Clear-cut detection is of no interest to insurances.
- Large forest owners and forest associations are interested in clear-cut detection. The update frequency should be at least once in a quarter.
- The Estonian example is that large forest owners don't see the economic gain in buying insurance as they own enough forest that the damage cost incurred in an event is of the same scale than the insurance premiums for all the forest owned, unless a considerable decrease of premiums from the current levels occurs.
- In Estonian, regarding insurance for small and medium (private) forest owners, it was said that this hasn't been a topic of discussion and consideration within those circles. It was

commented that it could be of interest if the costs of the insurance are low(er), but even then, the concept should first be adopted on a state level for small private forest owners to be comfortable and confident enough to consider it.

- It was noted by the end users that the product from CASSIA should be geospatial services provided to company's internal system. The need for lowering the integration cost and finding solutions that could be used by customers' existing system was expressed in all the meetings.

3.3 WP3: Forest data layers generation with insurance requirements

The goals were:

- To develop algorithms for the production of sample forestry related data layers for and based on the needs of the insurance sector and for Reach-U's internal use, focusing on the following forest products (tied to the three sub work packages of WP3):
  - Forest cover
  - Above-ground biomass
  - Temporal forest change products (e.g. clear-cuts, windfall damages)
- To produce some sample products of these
- To identify the technical specifications and limitations of these and to compare these with the insurance sector requirements.

3.3.1 Activities performed

3.3.1.1 WP3.1: Forest cover map generation using Sentinel-2 data

Forest cover map was initially planned to be used as an ancillary dataset in the generation of the above-ground biomass product and the temporal change detection workflow and potentially be of use to insurance companies directly as well. As it was identified in WP1 that such a product has no significant value to the insurance actors then activities supporting Reach-U's other forest products' generation were focused on. In the end the activities done were in support of the change detection workflow development as at first the emphasis was put on the workflow needs because it was the product with the biggest practical and economical potential and later because its use in the above-ground biomass product development became superfluous. The goal became to identify the technical specifications of the forest mask product that would give the best change detection results and that could then be potentially generated with Sentinel 2 images as one of the inputs.

As there exists a forest cover dataset for Europe (from the Copernicus Land service) and also as it was decided to base the temporal change detection algorithm on determining changed forest cadastre polygons (which assumes the polygons are delivered by the client interested in change monitoring in effect giving us an extent-wise limited but otherwise correct forest mask layer), it was decided to first investigate what is the effect of using different forest masks (i.e. forest maps with different technical specifications) on our change detection algorithm results. This because some steps in the temporal change detection workflow use forested area (as determined by the forest mask) statistics for images temporal variability reduction. The goal was to get insight into (1) the sensitivity of the temporal change detection results on the forest mask used and (2) the characteristics of the forest mask best suited into the current temporal change detection workflow.

Three forest masks were selected for initial comparison:

- Forest cadastre based forest mask. Estonia's forest cadastre database was used to delineate between forest and non-forest. The data corresponded to the year 2015. The forest mask is a forest land use rather than a forest land cover mask.
- Copernicus Land Monitoring Service Pan-European HRL forest type dataset. The data corresponds to the year 2012. The forest type map is based on the tree cover density map filtered to conform to the FAO forest definition.
- Reach-U generated forest mask. One of our own generated forest masks. The data corresponds to the year 2011. The map was generated using supervised image classification results in combination with ancillary datasets from various public institutions.

After this, tests were made with forest masks describing forest land with varying minimum crown cover values in their definition. These layers were extracted from the Copernicus Land HR tree crown cover dataset and the 4 resulting forest masks that were tested were:

- mask, where forest cover >= 10%
- mask, where forest cover >= 30%
- mask, where forest cover >= 50%
- mask, where forest cover >= 70%

The effects of each of these different masks on the change detection results were investigated and it was analysed why the corresponding results were achieved.

3.3.1.2 WP3.2: Above-ground biomass map generations from ALOS-2 satellite data

The goal was to produce an above-ground biomass product as a proxy for forest value assessment by insurers and re-insurers. ALOS-2 images were processed and assessed over Järvselja test site. The backscatter images from different seasons were compared to the stem volume data in the national forest registry. It was found that the correlation of the above-ground biomass and SAR image backscatter was not with sufficient accuracy for being used in the forest value assessment process for the insurance companies. The accuracy could have been improved with ground truth data and measurements of the biomass, but this step was found to be superfluous as the reliability of the biomass measurements would still not have been sufficient and there was no interest in the product from the end users as identified in WP1. Thus, further investigations and the generation of a country wide product were cancelled and the remaining resource allocated to the change detection workflow development.

3.3.1.3 WP3.3: Temporal forest change detection map based on Sentinel-1 satellite data

The various activities done were in support of the following main goals:

- To improve the forest change detection algorithm and workflow. The core of the workflow and algorithm was developed within a previous project. In this project the core workflow and algorithm were further developed, tested and validated.
- To develop a results validation methodology and framework to assess the quality of the change algorithms and workflow

The results validation methodology development consisted of selecting various standard quality/change detection estimation statistical measures (e.g. false negative rate, precision) to be computed and analysed as well as the development of our own quality estimation measure based on the end user's/client's point of view.

Two clear-cut (Järvselja and South-Estonia) and one storm damage (Ziemelgauja) validation datasets were generated. The datasets were digitised using Sentinel 2 imagery from different dates as base maps.

A software module was developed for easy and automatic change detection results quality assessment. In addition, various supporting software tools were developed for results and image time series visualization and analysis. These were used to test different sets of the change algorithm's free parameters and workflow variations to guide the development of the algorithm and workflow and to identify the optimal values of the parameters. For context, the change detection workflow consists of various pre-processing, time series and spatial smoothing steps and a temporal change signal thresholding based algorithm.

3.3.2 Main results achieved

The results to note from the work package are related to the forest change detection algorithm and workflow development.

Concerning the forest masks, as a result of running the forest change detection workflow in the two clear-cut test areas for different change threshold values and using the different forest masks as inputs, it was concluded that the best results were achieved using the Estonian forest cadastres dataset, which is a land-use describing dataset, with swamp forests filtered out. As an example of the results the performance of the change detection workflow using the forest cadastres based forest mask and three other masks can be seen in Figure 3.

The forest change algorithm works on a forest stand level, as opposed to pixel level. Thus the quality assessment statistic, called the Client Retention Rate, that was worked out to estimate the quality of the change detection workflow also works on the stand level. It aims to capture the (dis)satisfaction of the client which is modelled using the amount of true positives, false positives and false negatives within a time period, like so:

- Each client receives a single assessment for each of his/her forest cadastre for every 3 months (i.e., did a clear-cut of at least 0.5 ha take place in that forest cadastre in a 3 month period)?
- After a 5-year period, customer assesses his/her satisfaction based on the number of true positives, false positives and false negatives received:
    - If the customer experienced only true positives and no errors, the satisfaction is 200% (i.e., the customer invites a friend to also use the service)
    - If the customer experienced only true negatives, the satisfaction is 90% (i.e., no clear-cuts happened during the period and the customer questions whether to continue using the service)
    - If the customer experiences false positives or false negatives:
        - each false positive reduces the satisfaction by 4 times
        - each false negative reduces the satisfaction by 3 times

Using this model, we use statistical calculations to derive the *average client retention rate*, taking into account the probability of each client receiving a given number of true positives, false negatives and false positives (based on the confusion matrix). As to what constitutes a false positive, false negative and true positive on a forest stand level analysis, et used to following set-up:

- If a given forest cadastre contains at least 0.5ha of clear-cut forest standings, then our algorithms must detect it and report it to client (i.e., not doing so constitutes a false negative)

- If a given forest cadastre contains between 0.2 ha and 0.5 ha of clear-cut forest standings, then our algorithms may or may not detect it and report it to client (i.e., in either case, it does not constitute an error)
- If a given forest cadastre contains less than 0.2 ha of clear-cut forest standings, then our algorithms must not detect it and report it to client (i.e., doing so constitutes a false positive).

We chose these categories because they seem to be reasonable from both technical and client's perspective.

While analysing the average client retention rate, we noticed the following tendencies:

- The maximum possible value of client retention rate (i.e., when the algorithm always agrees with ground truth data) depends strongly on the frequency of clear-cuts in the given region.
- If the frequency of clear-cuts is extremely low, then the "algorithm" *that never detects anything* produces results of mediocre "quality". On the other hand, if the frequency of clear-cuts is extremely high, then the same "algorithm" produces results of low quality.

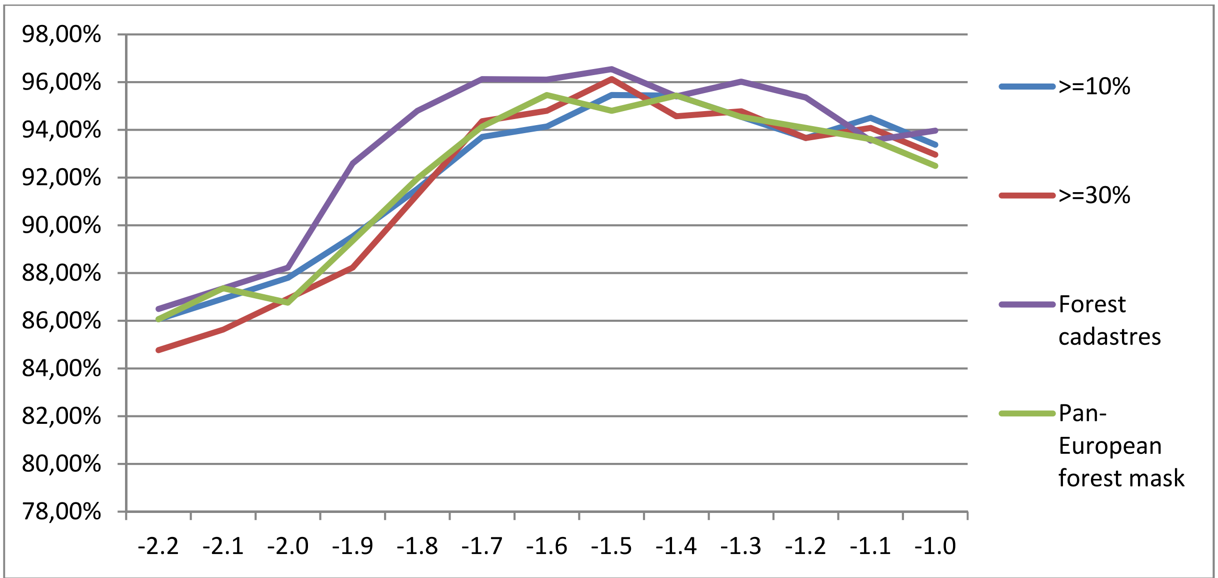


Figure 3. Comparison of performance for four forest masks. Average client retention rate (y-axis) for different change thresholds (x-axis) for the four forest masks.

The two clear-cut detection test areas both cover about 100 km^2 and the forest stands within were classified to the following three categories:

- TRUE - given forest cadastre contains clear-cut polygons of at least 0.5 ha
- EXCLUDED - various different possibilities:
  - forest cadastre intersects with cloud mask
  - intersection of AOI and forest cadastre is smaller than 0.5 ha
  - forest cadastre contains clear-cut polygons of area from 0.2 ha to 0.5 ha
- FALSE - given forest cadastre does not intersect with clear-cut polygons or intersection is less than 0.2 ha.

The amount of forest stands classified into these three categories for both validation sites can be found in Table 3 below and the Järvselja test area in Figure 4..

Table 3. Statistics of the two clear-cut validation sites.

Site Name	TRUE	EXCLUDED	FALSE
South-Estonia	52	12	2151
Järvselja	77	3	3887

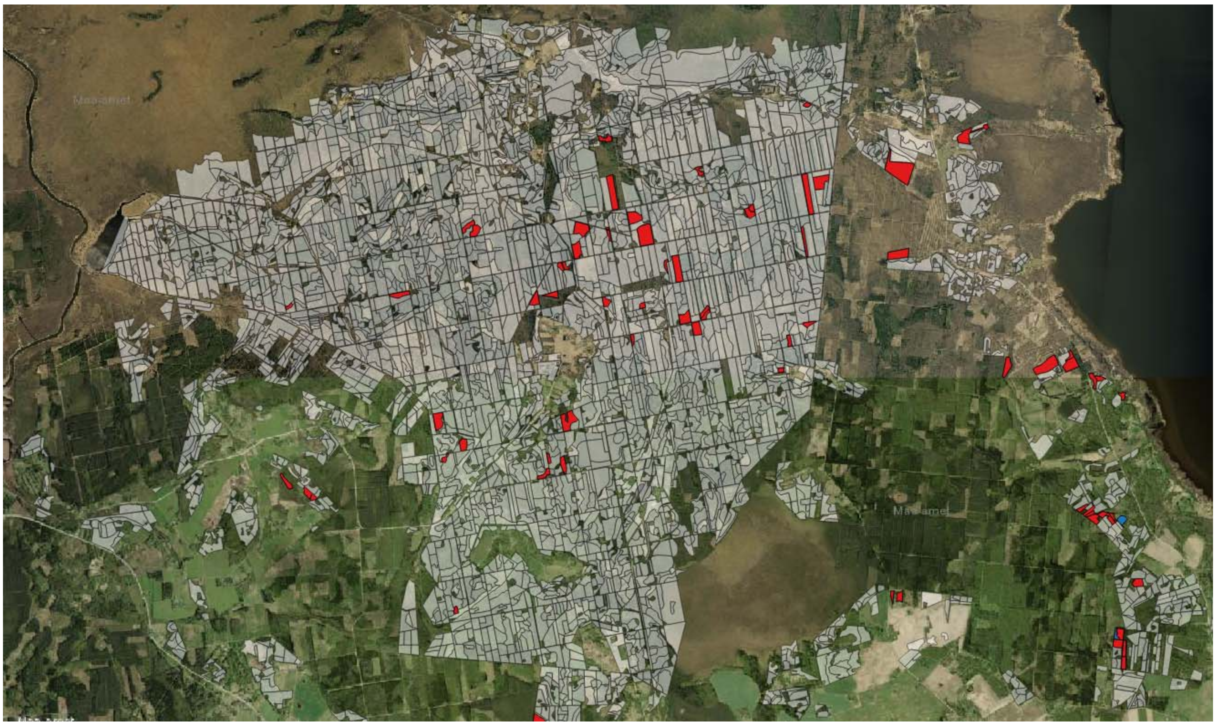


Figure 4. Red: clear-cut. Blue: excluded. Semi-transparent/grey: no clear-cut.

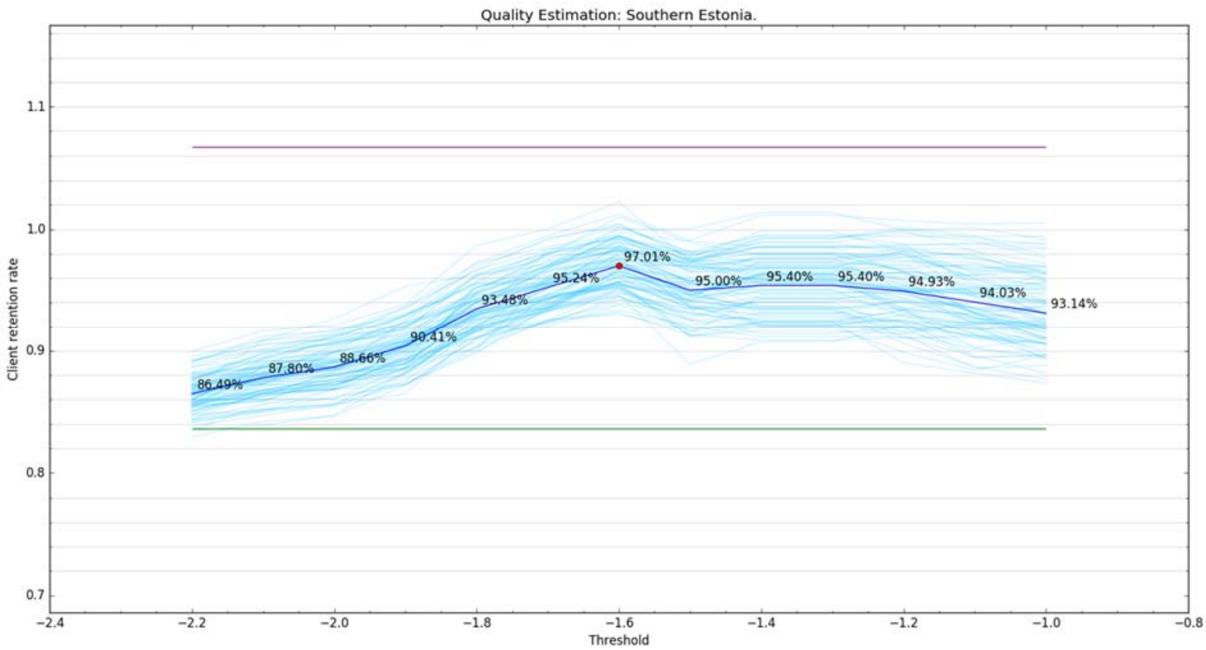


Figure 5. Client retention rate for various thresholds. The light blue lines are alternative client retention rate curves which were produced by random sampling with replacement from original data (i.e., bootstrapping). The green line corresponds to the algorithm which never detects anything. The purple line corresponds to a hypothetical algorithm which is always correct.

Table 4. Data for various threshold values. The threshold "-infinity" means an algorithm which never detects anything. The last line corresponds to a hypothetical algorithm which is always correct.

threshold	true_positive	false_negative	false_positive	true_negative	client_ret_rate	precision	true_positive_rate	false_positive_rate
-infinity	0	52	0	2151	83.62%		0	0
-2.2	8	44	1	2150	86.49%	0.888888889	0.153846154	0.0004649
-2.1	11	41	1	2150	87.80%	0.916666667	0.211538462	0.0004649
-2.0	13	39	1	2150	88.66%	0.928571429	0.25	0.0004649
-1.9	17	35	1	2150	90.41%	0.944444444	0.326923077	0.0004649
-1.8	24	28	1	2150	93.48%	0.96	0.461538462	0.0004649
-1.7	28	24	1	2150	95.24%	0.965517241	0.538461538	0.0004649
-1.6	32	20	1	2150	97.01%	0.96969697	0.615384615	0.0004649
-1.5	32	20	4	2147	95.00%	0.888888889	0.615384615	0.0018596
-1.4	36	16	6	2145	95.40%	0.857142857	0.692307692	0.0027894
-1.3	36	16	6	2145	95.40%	0.857142857	0.692307692	0.0027894
-1.2	38	14	8	2143	94.93%	0.826086957	0.730769231	0.0037192
-1.1	39	13	10	2141	94.03%	0.795918367	0.75	0.004649
-1.0	40	12	12	2139	93.14%	0.769230769	0.769230769	0.005578801
	52	0	0	2151	106.72 %	1	1	0

As mentioned, software modules were developed for algorithms results analysis, visual interpretation and quality assessment. Some examples of these or their outputs are Figure 5 and Table 4.

We'll briefly discuss next the main free parameters of the forest stand based change detection workflow that were analysed are explained. The most important parameter used by the per-pixel classification step is "clear_cut_threshold". It is the minimal change threshold, from which a pixel may be considered to be a part of a clear-cut. After that, a filtration is made. All pixels which do not form a sufficiently big connected area are thrown away. The parameter „min_area_ha" sets the minimal area for that filtration. If min_area_ha=0, then filtration is not done in this step. The forest cadastre classification step has two main parameters. First is "min_forest_cadastre_area_ha", which determines the minimal area of a forest cadastre for it to be included in the analysis. This is set to be 0.5ha in all runs and is not changed. The parameter "min_forest_cadastre_clearcut_detection_ha" determines the minimal area of a clear-cut to be covered with detected clear-cut pixels for it to be considered a "forest cadastre with a clear-cut".

Based on these results, we concluded that the optimal parameters (in the Järvselja region) were

- min_forest_cadastre_clearcut_detection_ha - 0.28 ha
- min_area_ha - 0.1 ha

The optimal threshold for this combination of parameters was -1.8.

Those parameters were tested in the Southern Estonian region and they remained near-optimal also in that area. The main difference was that the optimal threshold was located at -1.6, instead.

The analysis of the storm damaged areas was hindered by not having a forest cadastre dataset that covered the most severely affected areas (see Figure 6) and the unavailability of information regarding forest management activities and their timing. The latter to differentiate the storm damage signal from the sanitary clear-cut signal as the most severely damaged forest stands are clear-cut as quickly as possible after a storm to recover as much as possible of the economic value of the forest.

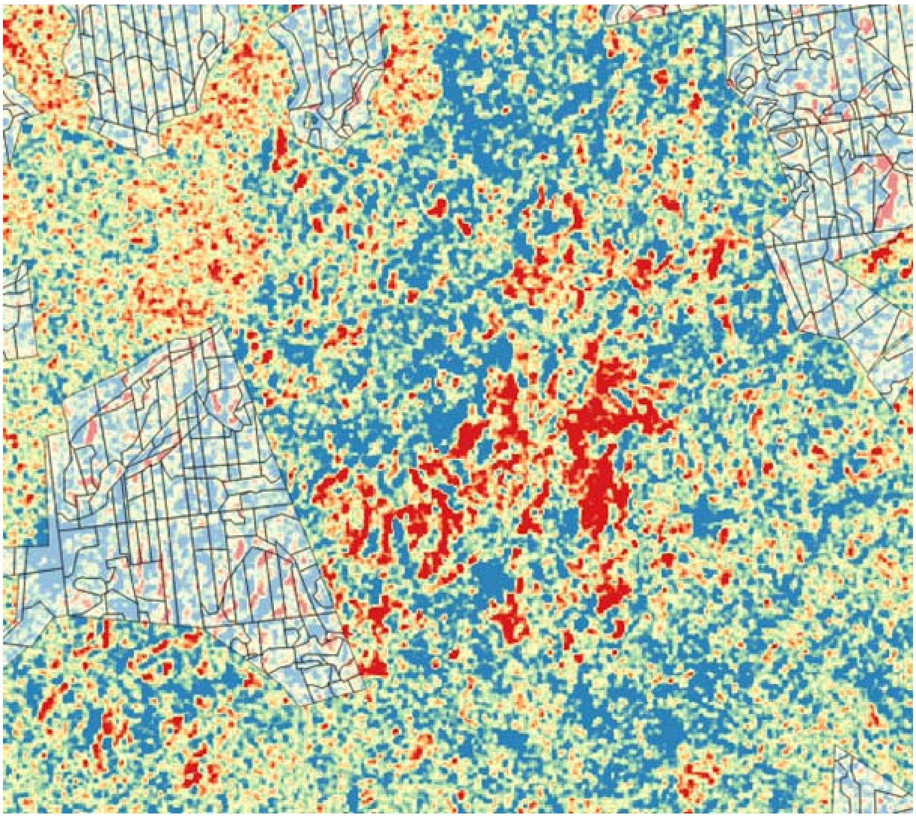


Figure 6. Detected storm damage. Orange and red areas correspond to detected storm damaged areas. LVM forest cadastres are drawn half transparently**.**

3.4 WP4: Operational forest monitoring service platform development

The goal was to develop an operational forest monitoring service platform with the backend development consisting of an automatic configurable data processing pipeline under WP4.1 and frontend developments according to user inputs under WP4.2 and WP4.3.

3.4.1 Activities performed

Due to the user consultancies and customer feedback gathered previously and the work done in WP3, work was mainly done under WP4.1. This also included, in addition to pure software development for the operational service, further investigations into our change detection workflow and algorithm to be able to meet the user requirements regarding detection times and accuracies for the near real-time forest change detection service.

3.4.1.1 WP4.1: Detecting near real-time changes in forests and generating alerts for the insurance providers

The goal of WP4.1 was the development of the backend of a forest monitoring/change detection service consisting of an automatic configurable data acquisition and processing pipeline. So the activities done were software development for such a system.

In addition, work was also done on the forest change workflow itself to be able to best meet various end user potential needs in terms of detection times and accuracy because in its prevailing state the live operational generation of weekly forest change layers was not practical due to the low quality of the results, although technically the layers could have been produced. Consequently, further research into the change detection workflow and algorithm was also done which consisted of investigating the individual forest stands' SAR signal time series and the effect of the following factors on them:

- Forest polygon shrinking amount: none, 5 m, 10 m, 15 m. This in order to eliminate possible shadows/over-exposure from the edges of changed areas and its neighbour polygons that are produced by the SAR signal processing characteristics and SAR instrument's viewing geometry.
- Subsets of Sentinel 1 relative orbits #7, #80, #160 used as a data source. This in order to investigate the option of making decision about forest changes from each orbit data separately and later combining these in a proper manner. The hypothesis was that the signal from one relative orbit would exhibit a somewhat more stable behaviour that would allow the changes to be better separated.

Focus was put on analysing:

- the stability of the individual forest polygons' time series before, during and after the change event with regard to various polygons based statistics;
- the distribution of the values of the individual forest stands polygons' statistics before, during and after the change event;
- the spread of the forest stands polygons' statistics over all the polygons over time.

The goal was to see whether a probabilistic change model based on some distributions for before and after the event signals could be developed instead of our current binary change/no change classification algorithm. For that histograms of pixels within individual forest stands and within different time periods were also analysed.

These analyses were done on output image time series of the following processing steps of the then current workflow *clearcut-detect*: *ToDecibels*, *HistogramMatching*, *SpatialEqualisation*. Data from the Järvselja test area was used in the analyses.

Various software modules were developed to aid and automate the analyses done.

3.4.1.2 WP4.2: Web service that combines all data layers and reference data for forest value assessment

As it was stated earlier in the report, the generation of forest mask and biomass layers was not done or done differently than originally planned due to lack on interest from the insurance companies, and these layers being inputs to forest value assessment and this sub work package, then no significant work was done here. This also because the end users have indicated that they would rather need data layers directly so that these can be integrated into their system rather than having them presented in an external system. The work hours planned here were put into WP4.1.

3.4.1.3 WP4.3: Web interface for monitoring changes and assessing forest value loss

As with WP4.2 limited work was done here and respectively more was done under WP4.1 for the same reasons as mentioned above for WP4.2. The changes of 2016 are presented on a web map (http://space.reach-u.com/eo under Forest logging -> Estonia -> Sentinel-1 (monthly)). A similar web map can easily be made for clients to show the identified changes, if they have a need for it.

3.4.2 Main results achieved

An automated system, live-service, that maintains a database of available Sentinel-1 images and their metadata, periodically updates it with the list of newly-added images, downloads the new images and ingests them for inclusion in the automatic change detection procedures was built. The ingestion consists of preprocessing to calibrate and orthorectify the images, then align them to a common grid and split them into tiles. Automatic forest change detection algorithm is run on each stack of ingested images to detect any new changes. We used the open-source Apache Airflow framework for a convenient way to construct processing chains and to monitor their status and running history, examples of which can be seen in Figure 7 on the next page.

Concerning the forest change workflow development, we present some visual outputs produced during the analyses. For the following example plots results from the *SpatialEqualisation* step and the Järvselja clear-cut ground truth dataset polygon #105 and its reference unchanged polygon are used. These kinds of plots were produced for all combinations of polygons shrinking sizes and relative orbits discussed earlier, a software tool *clearcut-stats* was developed for this purpose.

Comparison of time series

In the analysis, we concentrated on the following single-valued statistics of the signals over the whole polygon:

- mean;
- standard deviation (std);
- mean of 1st quartile (m1q).

Legend of plots (see Figure 8):

- horizontal axis: dates of images;
- vertical axis: signal change in dB;
- red curve: time series of statistic of *ground truth positive* polygon;
- green curve: time series of statistic of resp. *ground truth negative* polygon;
- blue vertical lines: beginning and end date of known execution date range of clear-cut.

a)

b)

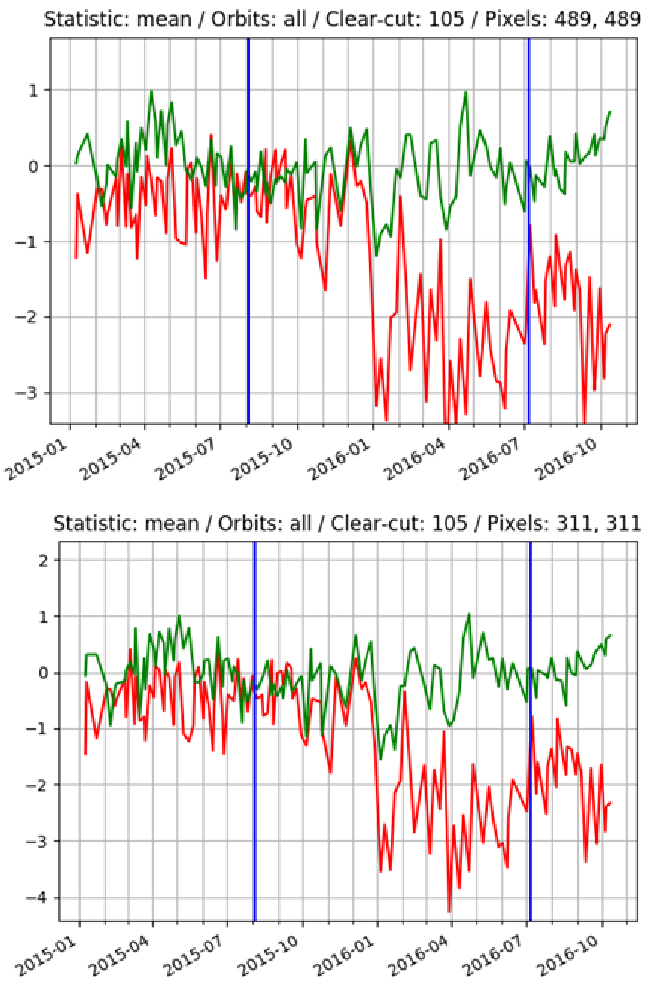
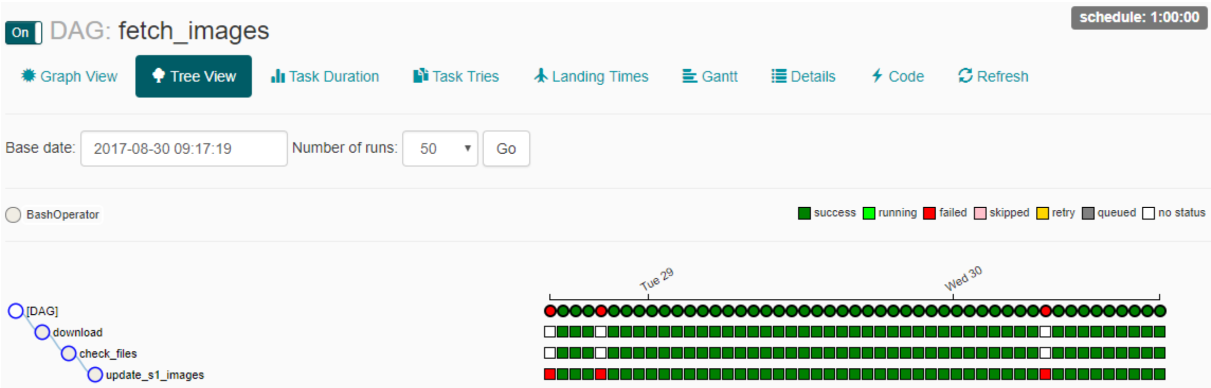
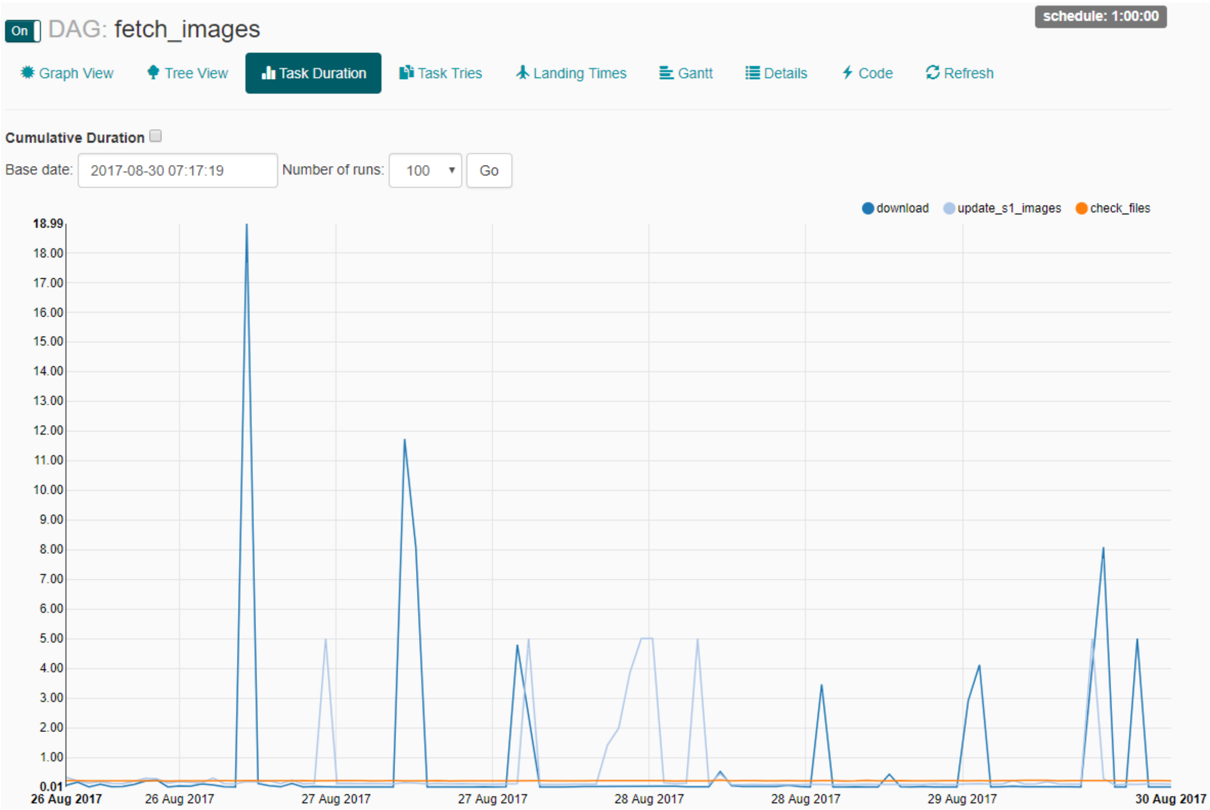


Figure 8. Time series for polygon pair #105: (a) original, (b) 15 m shrunk. Note that the vertical axis scaling is different for the two plots.

a)



b)



c)

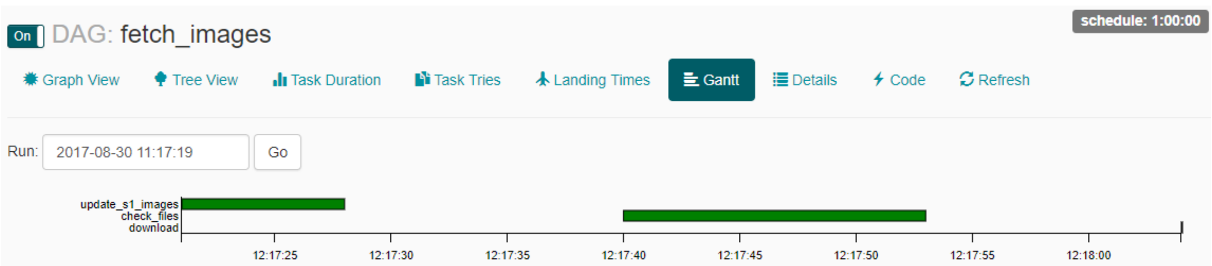


Figure 7. GUI of the Apache Airflow, here shown three subfigures depict the image database updating and Sentinel-1 images downloading processing chain's (named fetch_images) individual processing tasks (top subfigure, a), task's durations (middle subfigure, b) and Gantt chart view (bottom subfigure, c).

Comparison of histograms

For every polygon, *before pixels* were found as a collection of all pixels over its area and some time window.

After pixels were found analogously.

Values in plot titles (see Figure 9):

- "count": (number of images) x (number of pixels of polygon in each image).

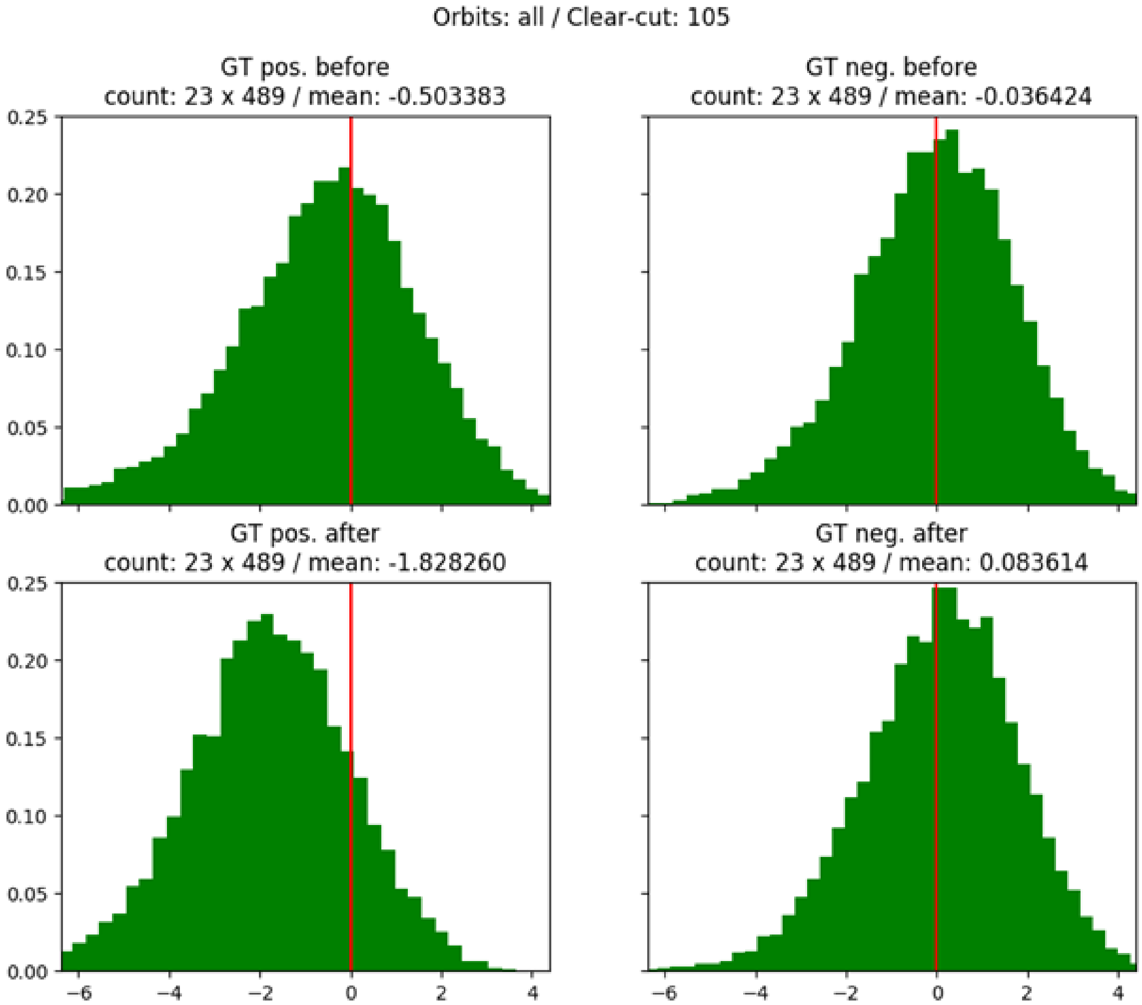


Figure 9. Histograms for values of *before pixels* and *after pixels*, original polygons.

Comparison of orbits

For every polygon, *before value* was found as mean of *before pixels*; *after value* as mean of *after pixels*. *Change signal* of polygon was found as:

before value - after value.

Next, 10- and 90-percentiles were calculated for *change signals* of all *ground truth positive* polygons. The same was done for *ground truth negative* polygons.

We aimed to find a single-valued statistic which best separates collection of *ground truth positive* polygons from collection of *ground truth negative* polygons. For this purpose, we introduced a following quantity, *difference of change signals* (DCS), for every *ground truth positive* polygon and resp. *ground truth negative* polygon:

change signal of ground truth positive - change signal of ground truth negative.

Summary plots

Values in plot titles:

- number of images in *before* time window, number of images in *after* time window;
- number of polygon pairs analyzed;
- 10- and 90-percentile of *change signals of ground truth positive* polygons;
- 10- and 90-percentile of *change signals of ground truth negative* polygons;
- 10- and 90-percentile of *differences of change signals* of polygons.

Legend of plots (see Figure 10):

- horizontal axis: ID of *ground truth positive* polygon;
- vertical axis: signal change in dB;
- red dots: *change signals of ground truth positive* polygons;
- red horizontal lines: 10- and 90-percentile of *change signals of ground truth positive* polygons;
- green dots: *change signals of ground truth negative* polygons;
- green horizontal lines: 10- and 90-percentile of *change signals of ground truth negative* polygons;
- orange vertical line segments: *differences of change signals* of polygons, positive-valued;
- magenta vertical line segments: *differences of change signals* of polygons, negative-valued.

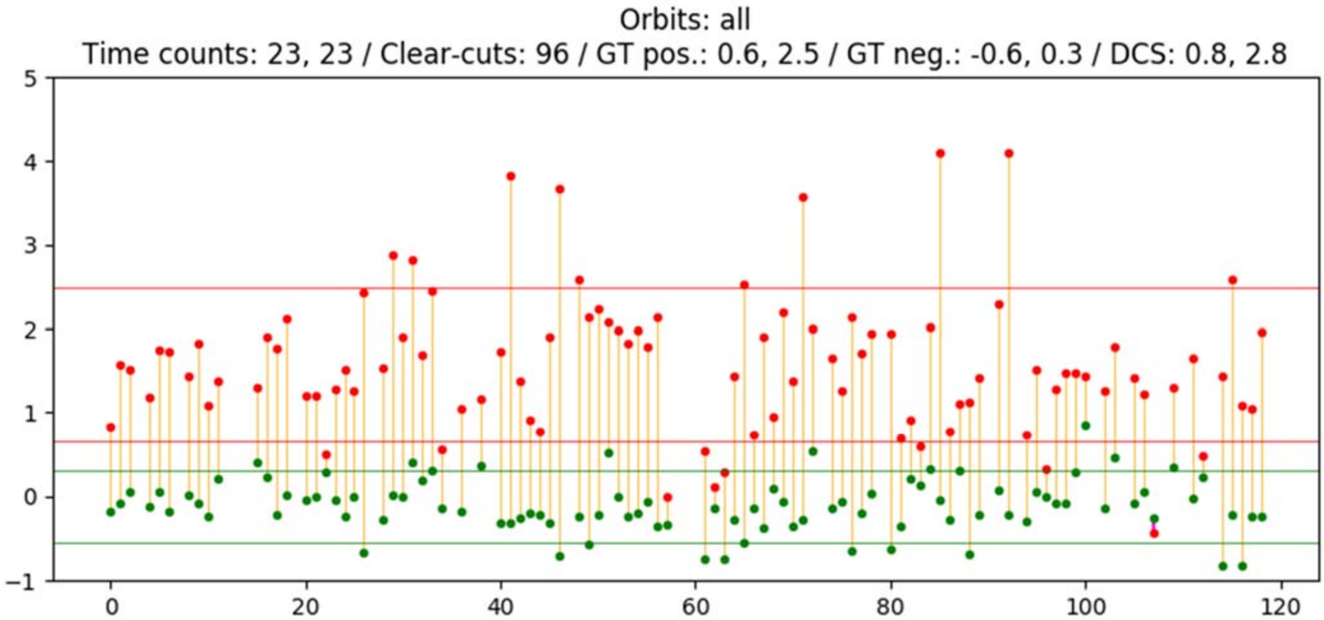


Figure 10. Summary plot for 15 m shrunk polygon pairs.

Summary tables

The next table (Table 5) shows the following quantities:

- 10- and 90-percentile (resp. *lower*, *upper*) of *change signals of ground truth positive* polygons;
- 10- and 90-percentile (resp. *lower*, *upper*) of *change signals of ground truth negative* polygons;
- 10- and 90-percentile (resp. *lower*, *upper*) of *differences of change signals* (DCS) of polygons.

10-percentile of DCS is highlighted with colour for each table separately.

Table 5. Summary table for data from all orbits.

		all orbits					
		GT positive		GT negative		DCS	
		lower	upper	lower	upper	lower	upper
original polygons	ToDecibels	0.625	2.156	-0.238	0.307	0.434	2.222
	HistogramMatching	0.533	2.058	-0.328	0.212	0.429	2.224
	SpatialEqualisation	0.53	2.027	-0.335	0.229	0.443	2.225
5 m shrunk polygons	ToDecibels	0.646	2.24	-0.246	0.331	0.599	2.35
	HistogramMatching	0.555	2.147	-0.323	0.239	0.604	2.35
	SpatialEqualisation	0.563	2.183	-0.348	0.255	0.608	2.354
10 m shrunk polygons	ToDecibels	0.743	2.415	-0.37	0.349	0.674	2.589
	HistogramMatching	0.643	2.327	-0.447	0.264	0.672	2.589
	SpatialEqualisation	0.644	2.343	-0.44	0.239	0.667	2.603
15 m shrunk polygons	ToDecibels	0.757	2.582	-0.491	0.378	0.771	2.776
	HistogramMatching	0.653	2.492	-0.567	0.278	0.765	2.789
	SpatialEqualisation	0.65	2.49	-0.56	0.299	0.753	2.79
20 m shrunk polygons	ToDecibels	0.772	2.59	-0.419	0.467	0.569	2.976
	HistogramMatching	0.686	2.493	-0.505	0.378	0.552	2.986
	SpatialEqualisation	0.702	2.493	-0.543	0.373	0.569	2.985

Conclusions

After analyzing all the outputs as exemplified above, the following conclusions were drawn:

- Tables in previous section show that for purifying signal, optimal shrinking amount of forest polygon is 10 m or 15 m. This optimum remains to be verified with another dataset.
- The same tables show that separation of collections of *ground truth positive* polygons and *ground truth negative* polygons depends significantly on orbit used as a data source. As omitting data from any orbit increases detection time after clear-cut event, a final method for combining data from different orbits remains to be implemented, although some work on it has been done (refer to section 1.5 in TN5).
- Additionally, we examined visual outputs generated by the tool and arrived to conclusion that noisiness of signal does not significantly depend on shape of polygon (for example, square-like vs narrow stripe with the same area). This finding needs also a quantitative verification.
- From the forest stands time series it was found that some forest stands exhibit a significantly different signal than most, even after the application of the processing steps to standardise the time series. These were found to be swamp and bog forests and as already hypothesised in the previous progress report, these areas should be omitted from analysis and processing.
- Some forest polygons seem to have some intraannual seasonal trends in the time series, others didn't exhibit much of a trend and were stable throughout the year. This needs further investigations; the main hypothesis is that these are artefacts caused by the already mentioned swamp and bog forest areas and the inclusion of data from them in the *HistogramMatching* and *SpatialEqualisation* steps.
- There is quite a large variability in the durations of the logging events, as estimated from the time series. Further investigations are needed to identify whether these are caused by simply the differences in the pace at which the forest is felled or whether these are signs of different management practices, e.g. whether the felled trees are immediately transported away or are left at the logging sites for some time first.

3.5 WP5: Forest change rate analysis and change probability assessment

3.5.1 Activities performed

The goal of WP5 was to take generated historical forest change layers and use them to produce forest change history statistics for some region or regions. These could potentially then be used by the insurance companies to assess the trends of forest changes in those regions (e.g. for risk modelling) and to improve their forest insurance processes and offerings to clients. The work here has been somewhat limited by the lack of insurance companies' inputs about their exact requirements for the change layers and analyses from those, so the work done was based on a compromise on the technical limitations and accuracy of the change workflow results and Reach-U's best guess at what would be useful to the end users from the information that was gathered under WP1: User consultancies, mapping customer needs and feedback.

3.5.1.1 WP5.1: Assess forest changes and the probability factor in the region over past 12 months

Data on forest changes in the South-East of Estonia (covering the counties of Põlvamaa and Võrumaa and partly Tartumaa and Valgamaa, roughly 100 km x 100 km) during the year 2016 were generated and analysed. GRD-format Sentinel-1 images from the year 2016 and from a time period of three months before and after were used as input data. A somewhat modified change detection workflow was used, as opposed to the operational live version of the change detection workflow. Most processing steps were identical, the main difference being in the last classification step where the simpler thresholding based method was replaced with a function fitting and thresholding step. This configuration allows for more accurate event modelling and is better for historical analyses where many data points exist from both before and after the clear-cut has taken place. EEA European 10 km x 10 km grid based on the ETRS-LAEA projection

3.5.1.2 WP5.2: Assess change probability by type: legal and illegal logging, natural disasters

An analysis was made on the separability of logging, wind damage and fire damage events in the outputs of the forest change detection workflow as well as using ancillary data (e.g. weather forecasts and alerts). In addition, the classification of logging events to legal and illegal was also assessed. The findings were applied to the 12 month change dataset.

3.5.1.3 Provide probability maps by region and type for the insurance cost calculations

Change intensity maps on the EEA European 10 km x 10 km grid based on the ETRS-LAEA projection using the year 2016 change dataset were created to demonstrate a way to statistically aggregate the changes to a regular grid and build time series of changes in each grid cell for number of forest changes and area of forest changes time series and trend analysis.

3.5.2 Main results achieved

A dataset of forest changes for the year 2016 was generated (see Figure 11) with the changes categorised according to the month it took place as identified by the change detection workflow. In addition, monthly maps of change intensities within a regular grid were produced (see Figure 12 for an example). Three sets of such maps were done: one describing the number of changes per month per grid cell, one describing the changed area per month per grid cell and one describing the changed area with respect to the total forest area per month per grid cell.

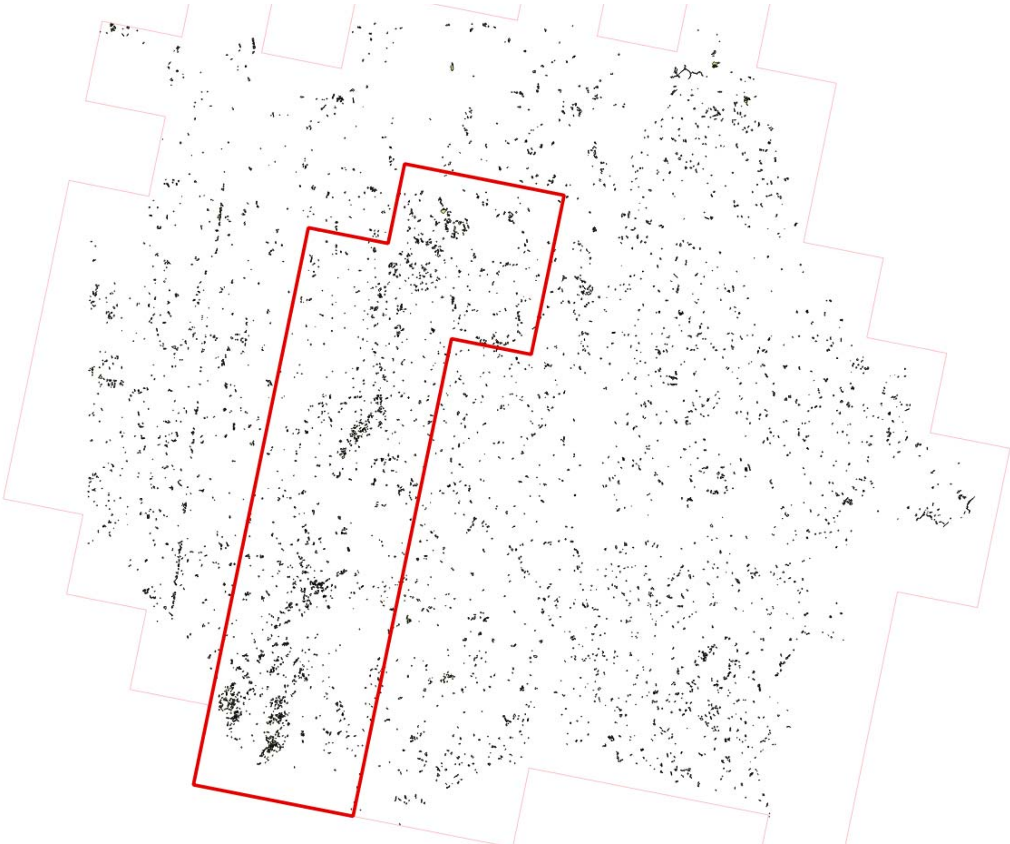


Figure 11. Forest changes of 2016 and the area most affected by the 03.07.2016 storm (in bold red).

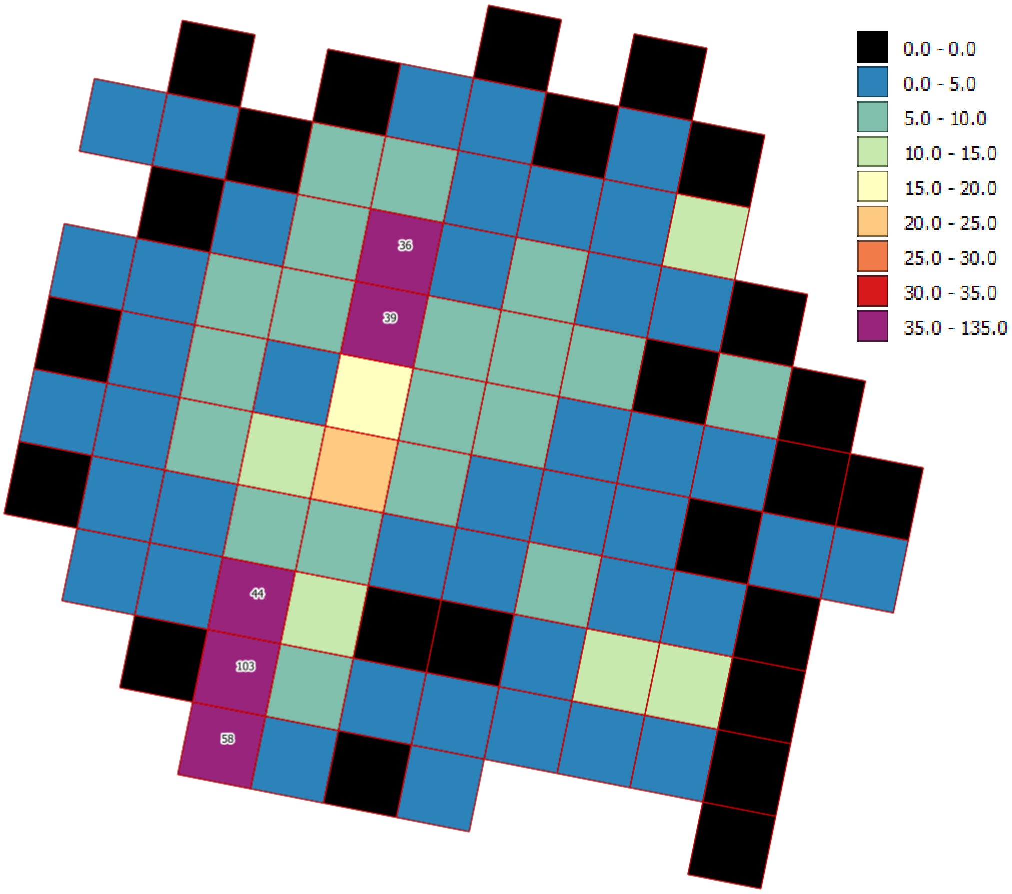


Figure 12. Number of clear-cuts in August of 2016. For grid cells with more than 35 changes per month, the map is labelled with the number of changes.

A clear pattern of intensified clear-cutting emerged in the dataset following the months after a storm passed through the area. The storm track is shown in Figure 11 and the rise in clear-cut intensity can be seen from Figure 13.

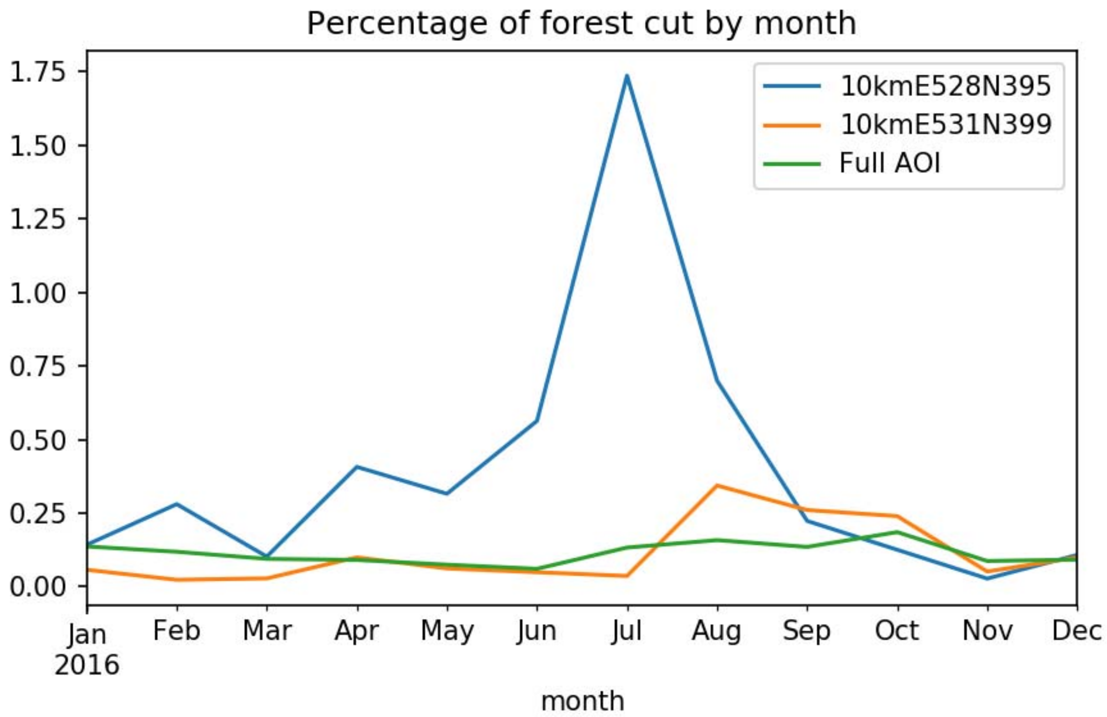


Figure 13. Percentage of changed forest with respect to the whole forest area for a grid cell affected by the 3rd of July storm (10kmE528N395, blue), a reference grid cell unaffected by the storm (10kmE531N399, orange) and the whole AOI (green).

It was concluded that the categorisation of the changes into the different damage types or activities is best done using ancillary information to identify major events (storms, fires) and then linking the changes identified as being caused by these. The categorisation couldn't be done from the time series as the signals of the different change types are not separable and the shape of the disturbance cannot be analysed as the change detection workflow works on a forest stand level.

For more details on the activities and results, please see deliverable TN5.

3.6 WP6: Project management and reporting

Three progress report and all the respective deliverable have been submitted to and approved by ESA.

4. Conclusion

The objectives of the application development project "Customised Forest Assessment Service for Insurance" were to develop forest value assessment and temporal forest change monitoring services for the insurance and reinsurance sectors.

On the technical side, from the first round of meetings with potential end users and stakeholders it was decided to focus on forest change detection (clear-cut and severe windfall) algorithm development. After which a software package for the generation of forest change products using the aforementioned algorithm was developed and a first set of sample products were generated.

On the business side, the first rounds of meeting with potential end users and partners were promising as there was interest from most on forest change detection products. Unfortunately during the second part of the project and during further analysis from the three main insurance or reinsurance partners regarding their exact needs things slowed down. Either because it was identified that such products aren't currently necessary in the insurance's internal processes in providing forest insurance and/or the inclusion of such or similar datasets into the insurance's processes need more analysis than previously anticipated. This partly due to the complicate nature of these processes and partly due to forest insurance not being a well developed insurance sector. In the end no concrete product or service could be identified during the duration of the project.