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LIFE+ PROJECT NAME or Acronym

Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques

Data Project

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List of abbreviations

AVHRR	Advanced Very High Resolution Radiometer
CH4	Methane
CICES	Common International Classification of Ecosystem Services
CLARA-SAL	CMSAF cLouds, Albedo and RAdiation Surface ALbedo
CLIPC	Climate Information Platform for Copernicus
CMIP5	Coupled Model Inter-comparison Project Phase 5
CO2	Carbon dioxide
COPERNICUS	The European Earth observation programme
CRYOLAND	Copernicus Service Snow and Land Ice
DSLR	Digital Single-Lens Reflex camera
EC	European Commission
EC	Eddy Covariance
ECCP	European Climate Change Programme
ECMWF	European Centre for Medium-Range Weather Forecasts
EO	Earth Observation
ESA	European Space Agency
EU	European Union
ET	Evapotranspiration
FLUXNET	Global network of micrometeorological tower sites
FMI	Finnish Meteorological Institute
FMIPROT	Finnish Meteorological Institute image PROcessing Toolbox
FSC	Fractional Snow Cover
FTP	File Transfer Protocol
GA	Grant Agreement
GCC	Green Chromatic Coordinate
GEOSS	Global Earth Observation System of Systems
GIS	Geographical Information System
GPP	Gross Primary Production
GSSD	Growing Season Start Day
GSED	Growing Season End Day
ICOS	Integrated Carbon Observation System
IPCC	Intergovernmental Panel on Climate Change
JSBACH	Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg
LAI	Leaf Area Index
LUKE	The Natural Resources Institute Finland
LTER	Long Term Ecological Research
MC	Monte Carlo
METLA	Finnish abbreviation for Finnish Forest Research Institute
MoD	Melting of Day
MODIS	MODerate-resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
N	Nitrogean
NDWI	Normalized Difference Water Index
NEE	Net Ecosystem Exchange
NFI	National Forest Inventory
OGC	Open Geospatial Consortium
PRI	Photochemical Reflectance Index

PRELES	PREdict with LES or PREdict Light-use efficiency, Evapotranspiration and Soil water
PSP	Permanent Sample Plots
RCP	Representative Concentration Pathway
REMO	Regional Climate Model of MPI
RCP	Representative Concentration Pathway
RSR	Reduced Simple Ration
SCA	Snow Covered Area
SG	Steering Group
SMI	Soil Moisture Index
SMOS	Soil Moisture and Ocean Salinity
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
SYKE	Suomen ympäristökeskus (Finnish Environmental Institute)
SWE	Snow Water Equivalent
UHEL	University of Helsinki
US	United States
VAP	Vegetation Active Period
WMS	Web Map Service
WUE	Water Use Efficiency
YASSO	Soil Carbon Model

1 Executive Summary

EU Life+ MONIMET was an ambitious project spearheaded by scientists in Finland to increase turnover of climate data by implementing a network of webcams in Finland's boreal forest and wetland environments. The main activity of MONIMET was implementing a new innovative approach to in situ monitoring and mapping of climate change indicators that have an influence on the mitigation potential and vulnerability estimates of boreal forests and peatlands. The approach was based on a combination of different information sources describing phenology, CO_2 and CH_4 exchange, land cover, snow evolution and albedo. The information sources include in situ observations and Earth Observation (EO) (satellite) data, as well as ancillary data supporting vulnerability assessments. Dedicated high resolution regional models were applied to describe climate and land surface fluxes of carbon and water by different ecosystems.

While climate change is a problem in need of global action, its effects are localised and affect regions in very different ways. Equally, certain areas exert a greater influence on the global climate and carbon balance than others, and it is this dynamic relationship that makes tackling climate change so complex. One example of such unpredictable feedback is found in the arctic and subarctic regions, where the climate is changing rapidly – and projected changes in years to come suggest a challenging for the future. Over the next century, scientists predict a mean annual temperature increase of 2-6 °C. This change will be particularly important in the boreal forest biome, which is distributed in a band around the northern sub-polar regions of Earth.

Boreal forest represents the world's largest terrestrial biome and exerts a pronounced effect on global climate and weather systems. It is expected that, as well as enhancing annual growth in the boreal forest, climate change will simultaneously increase emissions from soil and wetland sources and alter the occurrence of events including heat waves, droughts, floods and storms. Positive and negative impacts may potentially unfold in unpredictable combinations, and these changes will occur to varying degrees and at different rates in separate areas within the boreal zone. A regional approach to study will therefore be essential in determining the regional and global outcomes of climate change, and suggesting possible routes towards correcting the carbon balance.

In Finland, the boreal zone is blended with wetland environments that account for one-third of the country's territory. Moreover, forest growth is estimated to start earlier in spring and end later in autumn in the warming climate. When considering the carbon balance, therefore, the extended period of activity for vegetation brought about by rising temperatures must be set against the increase in methane emissions from unfrozen wetlands. In addition, the effect of shorter winters on the dormant development of trees – as well as the impact of storm events on trees anchored in thawed ground – are open questions, with a further problem posed by the projected decrease in snow depth and coverage. This decline will reduce surface refection, meaning that less heat will be reflected back into the sky. Overall, Finland presents a complex knot of problems for those concerned with the future of the climate.

The plan of MONIMET project was to observe climate change through the use of indicators such as water and carbon cycles and phenology – the study of plant and animal life cycles. This is also the approach used by the EU; the European Environment Agency, for example, lists more than 40 indicators of climate change based around vegetation, water and gas levels.

Accordingly, the first step in MONIMET's plan was to improve the methods by which scientists gather environmental data.

The first step was implementing an innovative new system for in situ monitoring: a webcam network. The aim of this new network was to provide an unparalleled insight into forest ecosystem services, enabling spatially representative monitoring of vegetative processes and their change over time. Indeed, this work will lead to the design and harmonisation of webcam networks all over Finland.

Furthermore, while the aim of MONIMET was to provide the groundwork for efficient and sustainable future observations – the researchers involved espouse sustainable approaches to all aspects of their own work. Their decision to build on the work of others was carbon efficient in itself, but they also aimed to maximise the use of electronic material in dissemination and avoid unnecessary travel by prioritising teleand videoconferencing as a means of communication between partners. One of the project's most exciting aspects is its methodology. The first innovation in approach is to build wherever possible on existing monitoring mechanisms, forming new links and adding value. This involves interacting with a wide variety of stakeholders at the national and international levels, especially meta-networks. To support this effort, the project partners have made use of their existing relationships to throw the endeavour open to the Global Earth Observation System of Systems (GEOSS), COPERNICUS – the European Earth Observation Programme, the Integrated Carbon Observation System (ICOS) and FLUXNET, a network of regional networks integrating worldwide CO_2, water and energy flux measurements. Using this new data – and the novel observational approaches the webcam network facilitated – the team of MONIMET project then plans made to create and calibrate high-resolution climate models for developing accurate estimates of climate change effects on soil and plants. These models are not only useful in Finland, but worldwide – and the data produced may contribute to climate models for other regions within the boreal forest or peatland biomes. The project therefore had clear scalability, beginning at the level of individual webcams and building up to local, national and global relevance.

The project used its accumulated data in conjunction with more advanced modelling techniques to determine vulnerability maps for wetlands and boreal zones in the context of various climate situations. The purpose of these maps are to provide a reliable and clear path towards efficient future strategies, then this would be an invaluable asset to Finland and the EU. The project's studies provided an indication of the mitigation potential in these habitats, and an estimate of the risk of decrease in the provision of ecosystem resources such as the carbon sequestration of trees, and the nitrogen retention of soil.

The objectives of MONIMET project are listed below

1. To collect information, data and expertise that is currently spread over several institutes, in order to build a comprehensive platform for analysing climate change effects on seasonal dynamics of various phenomena,
2. To create links and add value to existing monitoring mechanisms such as ICOS and EO systems (COPERNICUS) and make use of data acquired in previous EU Life+ funded, and other projects related to ecosystem monitoring,
3. To create new webcam monitoring system in order to facilitate Earth Observation systems by providing time-series of field observation for calibration and validation, as well as to improve the assessment of forest ecosystem services,
4. To synthesize modelling and observation approaches to identify climate change indicators,
5. To establish link between the climate change indicators and their effects in order to create vulnerability maps of boreal zone in connection to climate change scenarios.

The main expected results are

- A harmonized webcam network for monitoring the seasonal cycle in boreal ecosystem carbon exchange,
- Demonstration of the mapping of climate indicators in boreal forest zone,
- Demonstration of the vulnerability assessment for Finnish municipalities to climate change effects,
- Calibrated soil-vegetation-atmosphere model parametrisations for the boreal zone,
- Estimates of the uncertainty of the results.

In chapter 2, a short introduction on background, problems and objectives of MONIMET project is given. **In chapter 3**, management system of the project is described. **In chapter 4**, technical progresses for each Action are given. Achievements of the Actions and future work are also presented. **In chapter 5**, financial issues such as overview of costs incurred and an allocation of the costs per action are reported. **Chapter 6** and **chapter 7** report administrative, technical, dissemination and financial annexes.

2 Introduction

The increased temperature in the boreal region has extended the growing season. Especially the spring recovery of photosynthesis has the potential to start earlier, which increases the net uptake of CO_2. In the autumn, on the other hand, higher temperatures increase soil respiration (CO_2 emission). This has been shown to be significant during the warm late autumns, when low light levels cannot anymore maintain high photosynthesis levels. During the summer, the changing climate may increase the carbon uptake due to enhanced gross primary production (GPP). However, net uptake may also be reduced as a result of increased respiration or if excess heat and droughts reduce GPP. The drier and warmer conditions are also suggested to increase the frequency of forest fires. In addition to meteorological factors, carbon sinks are enhanced by the direct influence of higher CO_2 levels (CO_2 fertilization) and increasing nitrogen availability (atmospheric deposition and mineralization in the soil). In MONIMET project, flux measurements by Eddy Covariance (EC) technique at six Finnish forest sites with the longest time series spanning over 15 years were used. In order to study the influence of climate change, these results were up-scaled in time and space. For this, modelling techniques were implemented at various scales (process models, land surface/biosphere models, global transport models), as well as the inversion technique based on tall-tower measurements of background concentrations. The use of web cameras were also investigated in upscaling and monitoring ecosystem processes. Image colour information provides a useful and cost-efficient way to monitor leaf onset and snow cover from broad areas, and they can be used as proxies and indicators of spring timing, for example. In addition, ecosystem behaviour can be monitored with earth observation satellites, which provide global data on various environmental variables. Moreover, in MONIMET, an extensive network of web-cam phenological observation sites in Finland was implemented. The data was used to assess the indicators produced with the models. Finally, the models were run with climate scenario data, and consequently the impact of the climate change on land surface was observed in terms of climate change indicators. The main results of the project are to estimate vulnerability of boreal forest ecosystems to climate change impacts in the future, and to assess uncertainties due to measurements, climate models and ecosystem models. Results we aimed to achieve listed as below

1. A harmonized webcam network for monitoring the seasonal cycle in boreal ecosystem carbon exchange
2. Demonstration of the mapping of climate indicators in boreal forest zone
3. Demonstration of vulnerability assessment for Finnish municipalities to climate change effects in boreal forest
4. Calibrated soil-vegetation-atmosphere model parametrisations for the boreal zone
5. Estimates of the uncertainty of the results

MONIMET project demonstrated carbon and water cycle related methodologies and monitoring systems and vulnerability assessments for Finland and surrondings areas. Outcomes of the project can be used for other EU countries. The results of project would be useful and can be used in legislation, programmes and policies for reducing the EU's vulnerability to the impact of climate change. The outcomes of the project are directly linked to DG ENV ECCP (European Climate Change Programme) as a policy strategy to adapt to the impacts of climate change at assisting local, regional and national efforts. The project results supports very much EU COPERNICUS programme which is the establishment of a European capacity for Earth Observation. The MONIMET project contributed to the objectives of ICOS (Integrated Carbon Observing System) infrastructure which is a long term (20+ years) European Research Infrastructure for quantifying and understanding the greenhouse balance of the European continent and adjacent regions. Data provided from MONIMET camera monitoring system (established during the project) and remote sensing and flux measurements with different carbon cycle models are important for environmental policy and legislation, including the integration of the environment into other policies, future EU and Global applicability. Demonstrated system in MONIMET project can be reproducible within other EU countries.

3 Administrative Part

LIFE12 ENV/FI/000409 MONIMET-Amendment to Grant Agreement for Project was signed and sent to the European Commission on January 12, 2016.

3.1 Description of the management system

The project manager was in close contact with the partner coordinators, representatives of the project stakeholders and project personnel. The Midterm Report was delivered on September 3, 2015. We organized meetings involving the full project team ever 3 months regulary and then organized extra meeting when needed. We also organized management meetings in line with the project meetings. In addition to these meetings the members of the project team worked very closely together and had smaller, informal meetings to coordinate the project activities in their Actions. We also organized Steering Group (SG) meetings two times a year. In last year we organized one SG meeting, but we invited all SG members to our final workshop where we received their final remarks to our project which were quite positive.

The management and monitoring of the progress in the MONIMET project were carried out by management and steering groups, who met regularly during the project. The Management Board of the project was formed by

- Project Principal Investigator (Prof. Jouni Pulliainen, FMI),
- Project Manager (Dr. Ali Nadir Arslan, FMI),
- Partner Coordinators (Ms. Kristin Bötcher, SYKE, Dr. Mikko Peltoniemi, LUKE and Dr.Annikki Makela, UHEL),
- Project secretaries (Ms. Riitta Aikio from FMI and Ms. Maria Koski from SYKE, Tiina Luoto from LUKE and Mervi Kuri from UHEL),
- Action Managers:
    - Action B.1: Dr.Mikko Peltoniemi, LUKE
    - Action B.2: Ms.Kristin Böttcher, SYKE
    - Action B.3: Dr.Mika Aurela, FMI
    - Action B.4: Dr.Tuula Aalto, FMI
    - Action B.5: Dr.Tiina Markkanen, FMI
    - Action B.6: Dr.Annikki Mäkelä, UHEL
    - Action B.7: Dr.Maria Holmberg, SYKE
    - Action C.1: Dr.Ali Nadir Arslan, FMI
    - Action C.2: Dr.Maria Holmberg, SYKE
    - Action D.1: Dr.Ali Nadir Arslan, FMI
    - Action E.1: Dr.Ali Nadir Arslan, FMI
    - Action E.2: Ms.Riitta Aikio, FMI
    - Action E.3: Dr.Ali Nadir Arslan, FMI
    - Action E.4: Dr.Ali Nadir Arslan, FMI

The project Steering Group includes

- Principal Investigator
- Project Manager, Partner Coordinators
- The representatives of the stakeholders (Statistics Finland, Ministry of Transport and Communications, Ministry of Environment, Ministry of Agriculture and Forestry, Vanajavesi Centre, Centre for Economic Development, Transport and the Environment, MTT Agrifood Research).

The project teams within the project partners were led by the partner coordinators (except at FMI, where the team was led by the principal investigator). The project teams assigned action managers for each action to lead the daily work. Detailed list and their contacts of project personnel and members of Steering Group can be found in http://monimet.fmi.fi. The management board and the steering groups were planned to meet twice a year. The management board meetings were organized as part of the project meetings in terms of getting more benefit from the project meetings which were organized more often. The steering group monitored the project progress based on a progress report issued by the management board. The feedback and recommendations from the steering group were provided to the project teams through the management board. The action personnel of the project met at least quarterly to ensure that all project activities were fully coordinated. Small working meeting relevant to ongoing project activities were organised as necessary. The organigramme of the MONIMET project is presented in Figure 1.

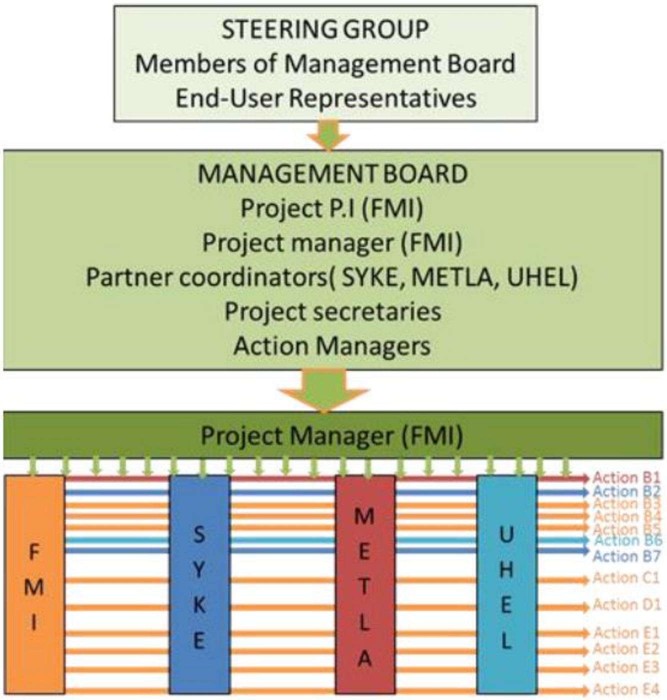

Figure 1: Organigramme of the MONIMET project

3.2 Evaluation of the management system

Management system worked very well. We did not have any major issues among the partners. One reason was that all the project partners have been familiar with EU Life+ projects and they know how to management system works very well. Another big benefit of our consortium was that we knew each other very well and we also worked together and still make close collaboration in other national and international projects. Communications among partners were very easy since we are all located in same city. Communications with the Commission and Monitoring team were very smooth and no problems at all. The project management team did not have any serious problems impacting the project objectives, work plan or schedule in the management system of MONIMET.

4 Technical Part

4.1 B. Implementation actions

4.1.1 Action B.1: Webcam network implementation and harmonization by FMI, SYKE, LUKE, UHEL

Monitoring of the status of ecosystems using low-cost web (IP) or time-lapse cameras has received wide interest globally. Networked cameras can be useful for monitoring snow cover and vegetation status without little maintenance afterwards. Cameras can be deployed to reach a broad spatial coverage and configured to supply images at high temporal resolution. Cameras can thus supplement earth observations, by e.g. gap-filling of cloudy areas in earth observation time series. Networked cameras can also supplement phenological field surveys and citizen-science projects, which also suffer from observer-dependent observation bias.

During the project, we executed several feasibility studies of using cameras in phenological monitoring. While cameras provided easier possibilities for monitoring certain distinctive phenological events of deciduous forest trees, it was not clear at the project start how useful camera colour information is detecting subtler changes or how well they perform in sparser light. Furthermore, it was not clear how well the camera observed colour changes time with eco-physiologically meaningful parameters frequently measured in forest ecosystems.

We established a network of digital cameras for automated monitoring of phenology of vegetation and snow in the boreal ecosystems of Finland (Peltoniemi et al., 2017a). Cameras were mounted at 15 sites, each site having 1-3 cameras. Each of the cameras submits half-hourly images to an FTP server maintained by FMI. Besides the camera installations, we deployed some ancillary measurements to sites critical measurements were lacking, and compared field collected materials to interpret camera observations.

Based on the results of the study (Peltoniemi et al., 2017b), we concluded that standard surveillance cameras can supplement traditional field phenological by providing information about canopy colour changes of winter deciduous trees. We found out that camera-derived seasonal transition dates of birch trees compare well with the visual observations and with conventional field observations of birch phenology. We also propose a useful metrics, which could be automatically extracted from image time series for the image subareas consisting of birch crowns, and which compares well with the traditional field observation. Another type of metrics was found to be useful for predicting season end. We concluded that applying cameras in phenological monitoring sites can reduce workload of the field phenological monitoring. Low image quality surveillance cameras are able to capture the most important phenological signal that is change in colours of the image view, and increased resolution may be of little use for these purposes. In some other purposes, more elaborate cameras, such as DSLR type of cameras, which can produce considerably higher resolution and better colour and light dynamics, may be better choices, although more attention must be paid for to their mounting and operation.

During the project, we found out that web-cameras can be particularly useful for snow cover monitoring (Arslan et al., 2017). Webcam-based snow cover fraction can then be used to evaluate the success of satellite imagery-based snow cover fraction. Further work on the topic requires matching timing of the EO and webcam images, including improving algorithms to identify or to account for the distribution of shadow and sun patches in the images, which introduces uncertainty to the snow cover estimates. We expect that the developments carried out in this project, and potential future improvements benefit operational nationwide snow product quality assessment, which is used e.g. in operative flood forecasting at SYKE. Cameras were useful in tracking vegetation phenology also in other types of ecosystems, and for other types of targets. Tests conducted at Sodankylä wetland showed that the cameras reliably replicate plausible seasonal paths of GCC for wetland vegetation and Scots pine, which are fairly insensitive to seasonal changes of irradiation (Linkosalmi et al., 2016, see also Peltoniemi et al., 2017a). Due to the fact that most forests in Finland are coniferous, we tested the usefulness of web cameras for conifer phenology monitoring and aimed to understand the reasons for detected seasonal chromatic changes in images of conifer crowns. Based on our results, it seems that these changes are real and they seem to be associated with the development of photosynthetic activity in the spring. Further chromatic changes in conifer images occur due to the phenophase transitions, namely emergence of new needles and shoot later in the spring/early summer. In pine crowns, chromatic changes also occur in autumn due to needle yellowing. We concluded that: i) Web cameras are useful for conifer phenology monitoring, but that it is more complicated than analyses of deciduous species. It seems necessary that a priori information about the likely period of new shoot/needle growth is incorporated into analyses, e.g. in the form of temperature dependent shoot phenology model. ii) It seems possible to use chromatic changes in conifer crown images to inform models of development of photosynthetic activity, as GCC seems to increase in tandem with chlorophyll fluorescence as well as the photosynthetic activity of trees in spring.

We also conducted other tests and feasibility studies associated with the cameras. We reported a feasibility study with low-cost phenology monitoring instrument, tests for using cameras in providing correlates for the photosynthetic status of needles of conifers, the use of cameras in agricultural applications, and for using monitoring of the understorey vegetation phenology in the deliverable report of Action B.1 (Report on evaluation of first results from camera network-31/12/2016).

Finally, we provided open access to recorded image material from camera sites in 2014-2016, and tools developed to extract phenological information from the image time series during the project. The image material is accompanied by an online report (Peltoniemi et al., 2017a). The report describes the network and our image repository (www.zenodo.org/communities/phenology_camera/), which locates in Zenodo research data storage established by EU OpenAire. We additonally share openly the image analysis methodology developed during the MONIMET project.

4.1.1.1 FMIPROT and general methodology

We developed Finnish Meteorological Institute image PROcessing Toolbox (FMIPROT) for easy analyses of and extraction of colour information from the image time series. The program allows the extraction of basic vegetation colour information and snow cover information from sub-regions of images, and is able to link to existing image repositories. FMIPROT is free to use and available online with a proprietary distribution (http://monimet.fmi.fi/?page=FMIPROT). The software manual is also available online at Zenodo (https://doi.org/10.5281/zenodo.891068).

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4.1.2 Action B.2: Earth Observation and data processing by FMI, SYKE

In this action satellite time series of vegetation indices and snow cover covering a period of 16 years were prepared from MODIS observations. Climate change indicators of the start of the vegetation active period and the snow melt-off day were derived from these time series. In addition, coarse resolution satellite data sets on snow water equivalent (SWE), snow melt-off day and soil freeze were made available to the project. Satellite products were evaluated against in situ observations (provided by Action B.3) and overall good correspondence was found. Indicators of the start of vegetation period and snow melt-off day were also correlated with seasonal changes in satellite-derived surface albedo.

Using the long time series of the snow melt-off day from microwave observations, an advancement of the snow melt-off day in boreal forests in Finland was observed. To find satellite-proxies for the end of the vegetation active season, indicators on snow accumulation from SWE and the start of soil freeze in autumn were compared to the end of the vegetation active period in coniferous forest as obtained from CO_2 flux measurements (Action B.3). The start of soil freeze in autumn seems to be a suitable indicator for the end of the vegetation active period in northern Finland. Data sets on the start of the vegetation period and the Leaf Area Index were utilized in model calibration (Action B.4).

4.1.2.1 Satellite data processing

SYKE extended the time-series of snow cover and vegetation status in Finland that was available from the SnowCarbo project (LIFE07 ENV/FIN/000133) (http://snowcarbo.fmi.fi) for the period 2001 to 2011. The full time series consists now of 16 years of daily Normalized Vegetation Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI) and Fractional Snow Cover (FSC). The three products are based on Moderate Resolution Imaging Spectrometer (MODIS) observations.

Terra/MODIS Level 1B satellite data sets were obtained from the National Data Satellite Centre (NDSC) at FMI. Pre-processing was done using automated processing lines developed by SYKE. In 2016, processing lines were implemented to the Finnish portal for on-demand processing of satellite data sets (Calvalus) at the NDSC. The Calvalus system is developed by Brockmann Consult GmbH, Germany. It is designed for the processing of large amount of data and it is based on the massive parallelisation of tasks combined with a distributed file system. For this, software codes for the product generation were transferred from MATLAB to Python programming language. By using the Calvalus system, processing performance was significantly improved from three machines and respective simultaneous processes to about 100 simultaneous processes. Furthermore, the data management effort is reduced as all data sets are stored online and only final products are downloaded to local machines.

In addition to the project plan, specifications for the Fractional Snow Cover (FSC) product as well as the cloud masking algorithm were revised (Deliverable reports: First Data document (15/05/2014) and EO products and comparison with in situ data (28/04/2017)/ Appendix 1). FSC was calculated using the improved specifications and the FSC time series from the SnowCarbo project (2001-2011) were re-processed (not foreseen in the project plan). The improved cloud masking algorithm was designed to work throughout the winter-spring-summer-season so that only one algorithm is used, in contrast to two algorithms for winter and summer previously. The use of two algorithms led to inconsistencies in the time series for the transitional period from spring to summer, which is important for the correct determination of spring phenological events from time series, such as the start of the vegetation period. Furthermore in the previous dataset, too low FSC estimates were found in areas with unrecognized cloud shadows; therefore the recognition of cloud shadows was added to the algorithm. Classified cloud shadows are provided as a separate layer in the cloud mask. The improved cloud detection method reduced errors in FSC. The new cloud masks were calculated and applied to the three daily products: FSC, NDVI and NDWI for the period 2001 to 2016. That necessitated a re-processing of the time series for the period 2001 to 2011 (additional effort not foreseen in the project plan).

In addition to vegetation indices NDVI and NDWI, **SYKE** calculated advanced vegetation indices, the Reduced Simple Ratio (RSR) and the Photochemical Reflectance Index (PRI), for selected in situ sites in

Finland for the period 2012 to 2016. Specifications for the technical implementation were developed in discussions with the project team and outside experts. Software code was prepared in Python. Prior to the calculation of RSR and PRI, subsets of MODIS covering in situ sites were atmospherically corrected using observations of aerosol optical depths provided by FMI. Leaf Area Index (LAI) was derived from RSR based on the method by Heiskanen et al. (2011). The LAI product specifications are provided in the Action B.2 deliverable reports: First Data document (15/05/2014), and EO products and comparison with in situ data (28/04/2017)/ Appendix 2).

FMI worked on the algorithm specifications for the Reduced Simple Ratio (RSR) that is used to determine the LAI. For this, the dependence of reflectance of closed canopy and open areas in the shortwave-infrared on the sun zenith angle was investigated based on simulations with reflectance spectra from the US Geological Survey data base (Clark et al. 2007). Furthermore, an LAI map for the JSBACH model calculations was constructed using the Landsat based LAI map by Heiskanen et al. (2011). The data set was provided to Action B.4.

FMI provided the soil freeze/thaw product from the Soil Moisture and Ocean Salinity (SMOS) sensor for years 2010 and 2016. The grid resolution of the data set is 25 km. For comparison with the date of the end of the vegetation active period from CO_2 flux measurements (Action B.3), time series of the soil freeze state were extracted for the sites Sodankylä, Kenttärova and Hyytiälä. The Snow Water Equivalent (SWE) and snow extent (SE) dataset (GlobSnow SWE v2.0) have been processed and released by FMI for the period of 1979 - 2016. The grid resolution of the product is 25 km. SWE time series were extracted at CO_2 measurement sites Sodankylä, Kenttärova and Hyytiälä for the period 1999-2014. They were used to determine the start of the snow accumulation period in autumn that was utilized in comparisons with the end of the vegetation active period. Furthermore, FMI provided observations of the snow melt date from microwave radiometer data that were compared to snow melt-off dates from MODIS FSC (Metsämäki et al. 2017).

Detailed description of the satellite data sets and processing steps are provided in the Action B.2 deliverable report: First Data document, 15/05/2014).

4.1.2.2 Climate change indicators

Satellite data sets provided by the Monimet project can be utilized to monitor changes in snow cover and the vegetation cycle in Finland. **SYKE** worked specifically on indicators for the vegetation active period and the snow melt-off day from MODIS observations that cover a period of 16 years.

Vegetation active period:

Yearly maps of the start of the vegetation active period in coniferous and deciduous forest were calculated at a grid resolution of 0.05° x 0.05° from MODIS FSC and NDWI time series, respectively. Averages for the 16-year period and examples for a phenologically early and late year are shown in Figure 2. The processing algorithms are described in Action B.2 deliverable: Report on EO products and comparison with in situ data (28/04/2017). The data sets were spatially aggregated to allow comparisons with simulated start of vegetation period by the JSBACH model and provided to Action B.4 (Böttcher et al. 2016). Furthermore, the data set on the start of the vegetation active period in deciduous forest was applied to predict the timing of the peak flying date of moth species (Pöyry et al. 2017).

To derive proxy indicators for the end of the vegetation active period in coniferous forest, we made comparisons between satellite observations and the end of the vegetation active period that was determined from CO_2 flux measurements at sites Sodankylä, Hyytiälä and Kenttärova (Action B.3). The comparison included time of snow accumulation determined from GlobSnow SWE time series and the soil freeze in autumn from the soil freeze/ thaw product. Initial comparisons were presented in the Action B.2 deliverable: Report on data comparison (08/03/2016) and additional analysis were included in the Action C.1 deliverable: 3rd report on the monitoring (31/03/2017) and presented as poster (Böttcher et al. 2017). While we found good correlation between the end of vegetation active period and the start of snow accumulation obtained from in situ observations of snow depth, the correlation with a similar start of snow accumulation indicator from weekly GlobSnow SWE time series was low. Moreover, there was a delay of about one month between the GlobSnow SWE snow accumulation indicator and the date from weather station observations. Significant correlations were found between the end of the vegetation active period and the day of partial soil freeze at northern boreal sites.

FMI compared the indicators of the start of the vegetation active period with the time of decrease in surface albedo using the CLARA-A2-SAL product (www.cmsaf.eu; Anttila et al. 2017; Karlsson et al. 2017). The onset day for the coniferous species follows roughly 20 days the first signs of snow melt detected in the albedo (reaching 99% level of its dynamic range during snow covered period) (Figure 3). The deciduous species follow the start of snow melt as defined from albedo with about 50 days delay (Figure 4).

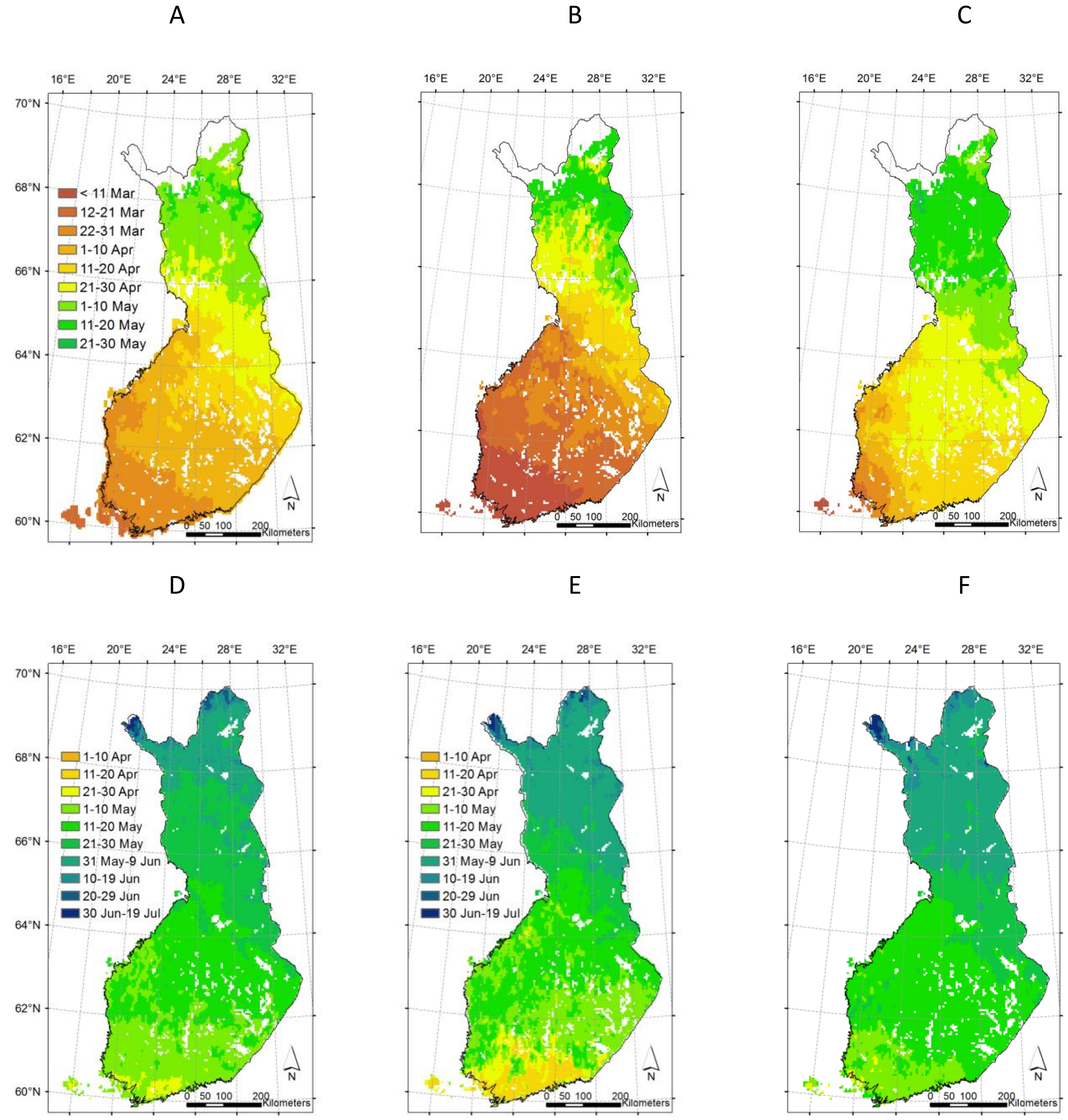

Figure 2: Start of the vegetation active period in evergreen forest (upper panel) and deciduous vegetation (lower panel) for (A, D) the average period of 2001-2016, (B, E) a phenologically early year (2007) and (C, F) a phenologically late year (2012).

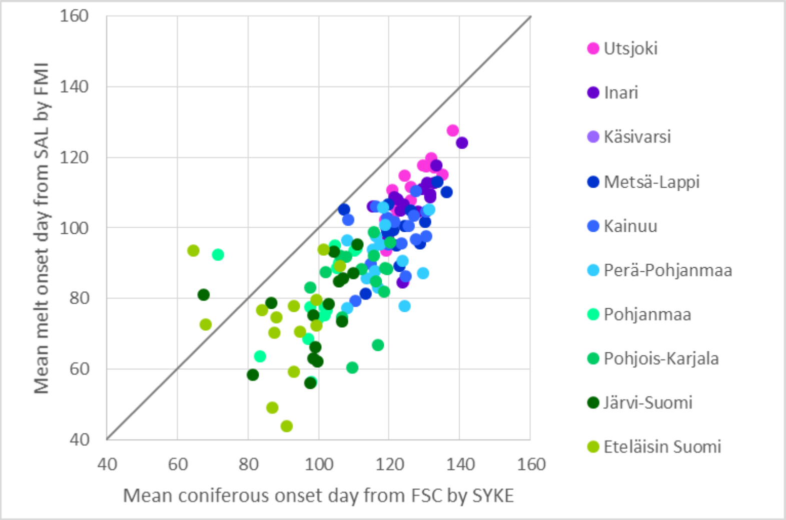

Figure 3: Comparison of coniferous growth onset day with the melt onset day based on albedo change for 10 vegetation zones of Finland in years 2001-2015. Åland islands, Southwestern coast and Bothnian coast are excluded, because they consist of mixed pixels in the coarse resolution albedo data.

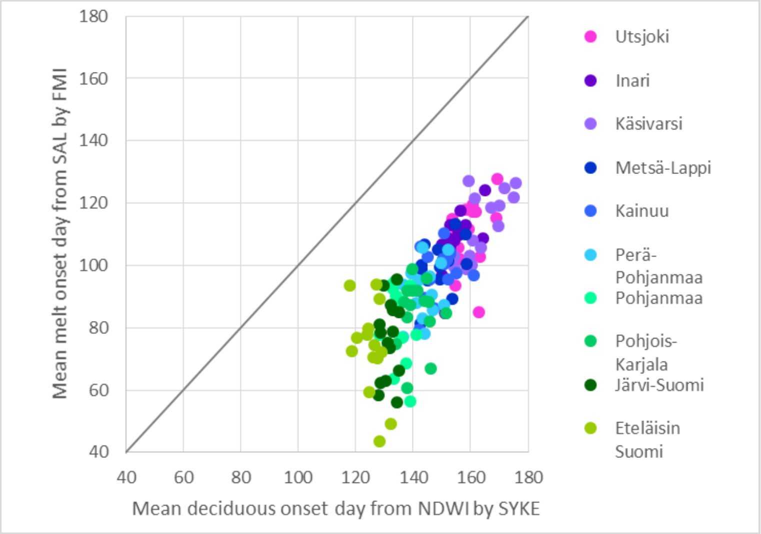

Figure 4: Comparison of deciduous growth onset day with the snow melt onset day based on albedo change for 10 vegetation zones of Finland in years 2001-2015. Åland islands, Southwestern coast and Bothnian coast are excluded, because they consist of mixed pixels in the coarse resolution albedo data.

Snow melt-off day:

The pan-European Snow Extent product from the Copernicus Service Snow and Land Ice (CryoLand, http://www.cryoland.eu/) was used for the detection of the snow melt-off day (MoD) (Metsämäki et al., 2017). The product is provided daily with a spatial resolution of 500 m. The method for the detection of MoD was developed in the framework of the FP7 project CLIPC (Climate Information Platform for Copernicus, http://www.clipc.eu/). A subset for the Finnish area was extracted from the pan-European MoD product for the Monimet project and yearly maps were produced for the period 2001 to 2016. Examples for two years with differences in timing of the MoD are shown in Figure 5. The data set was further used to determine the inter-annual changes in the timing of the MoD in the different vegetation zones in Finland (Figure 6). In addition to the 16 years' time series of Cryoland FSC-based Melt-off day shown in Figure 7, the 35 years Microwave radiometer (MWR)-derived MoD dataset provided by FMI (Takala et al. 2009) was exploited to analyse the trend in MoD for boreal forests in Finland. Although there is no clear trend visible during the last 15 years, the analyses made for 35 years' microwave radiometer-based melt-off day information revealed an advancement of the MoD in boreal forests in Finland (Figure 7).

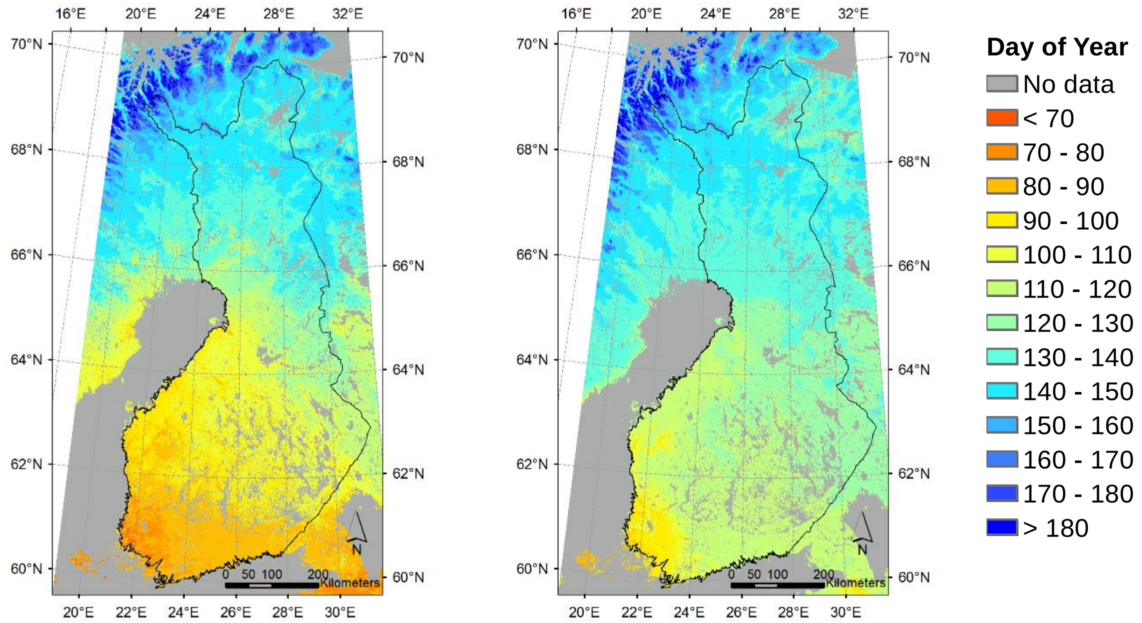

Figure 5: Snow melt-off day in 2007 (left) and 2012 (right) in Finland. In 2007 snow melted earlier in southern Finland than in 2012.

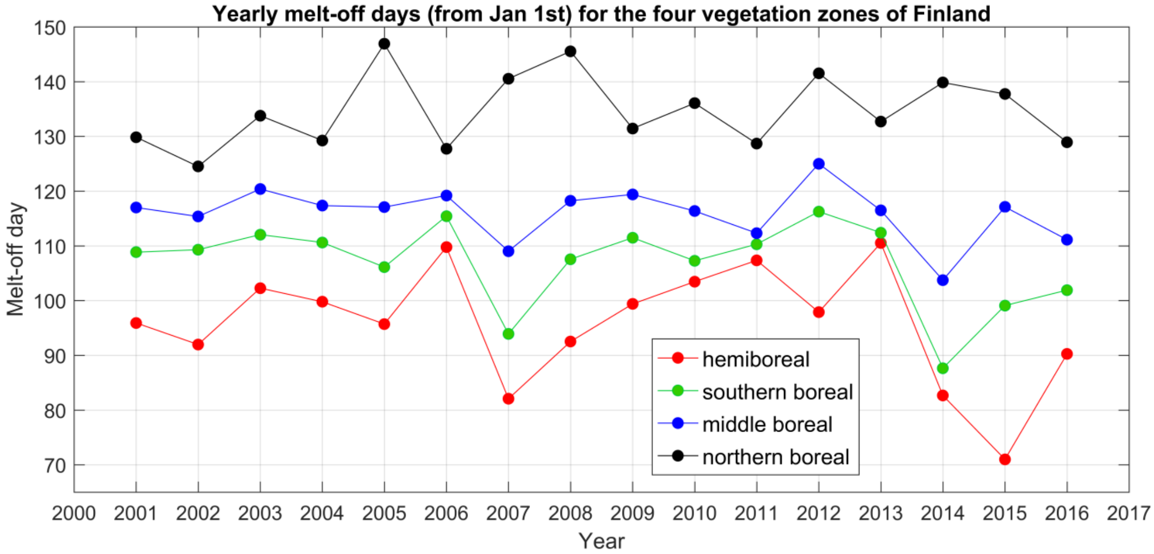

Figure 6: Yearly snow melt-off days for vegetation zones in Finland.

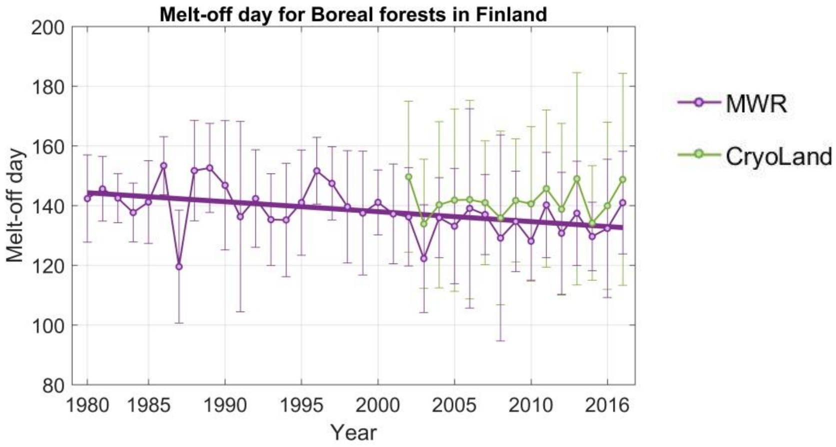

Figure 7: The evolution of melt-off day in the last 35 (16) years. Vertical lines indicate standard deviation of yearly data.

The end of the snow melt season was also estimated using the surface albedo product CLARA-A2-SAL (www.cmsaf.eu; Anttila et al. 2017; Karlsson et al. 2017). In comparisons by **FMI**, it turned out that at the time of end of the permanent complete snow cover the albedo reaches the 10% level of its dynamic range during the snow covered season. The snow has disappeared completely, when the albedo reaches the 1% level. In practice this takes about two weeks (Figure 8). The MoD based on the FSC product of SYKE correlates well with the end of the permanent snow cover based on snow depth measurements.

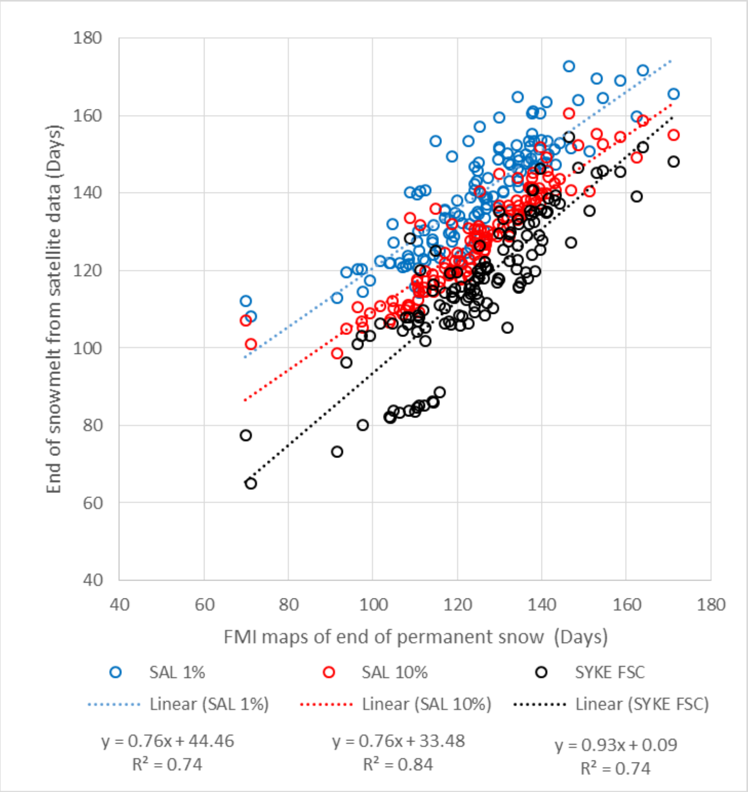

Figure 8: Comparison of end of snow melt days based on snow depth measurements (Kersalo and Pirinen, 2009) and satellite observations. The data covers 10 vegetation zones of Finland in years 2001-2015. Åland islands, Southwestern coast and Bothnian coast are excluded, because they consist of mixed pixels in the coarse resolution albedo data.

Start of soil freeze in autumn:

FMI provided data on soil freezing using the SMOS based freeze/thaw algorithm (Rautiainen et al. 2016). Using this data, **FMI** prepared maps on the date of soil freeze in autumn for the period 2010 to 2016 (2010 and 2013 shown in Figure 9). The time series is still too short to analyse changes in the timing of soil freeze in Finland. Our results suggest that the time of partial soil freeze gives indications of the end of the vegetation active period in northern Finland.

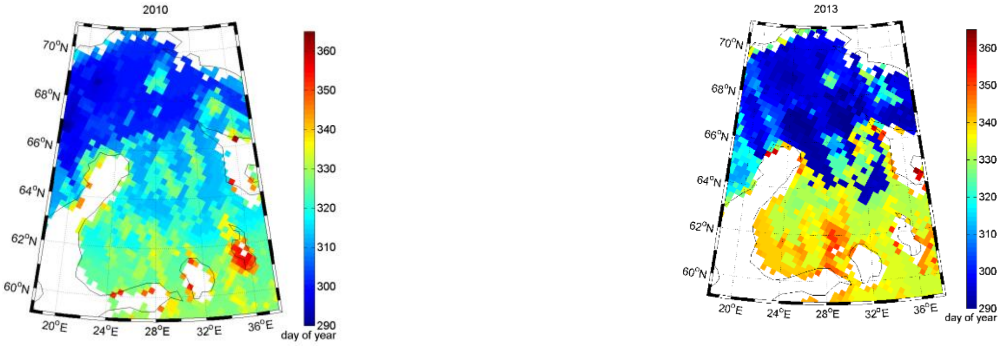

Figure 9: Start of soil freeze in autumn for 2010 (left) and 2013 (right) from SMOS observation.

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4.1.3 Action B.3: Ground-based and airborne observation and data processing by FMI, SYKE, LUKE, UHEL

The general objective of Action B.3 was to collect and process the in-situ data for calibration and validation of earth observation (EO) data obtained in Action B.2 and the two ecosystem models (JSBACH and PRELES) used in Action B.4 and Action B.6. The data provided by Action B.3 include the ecosystem-atmosphere fluxes of carbon dioxide, water and energy at six measurement sites, snow cover data from networks covering the whole Finland, and campaign-based albedo and LAI data from Sodankylä.

4.1.3.1 Flux data

The flux data describes the measurements of CO_2, CH_4 and H_2O exchange between atmosphere and different ecosystems.

Micrometeorological ecosystem-scale carbon dioxide, water and energy flux measurements were used within MONIMET for assessing the functionality of the models, for calibrating the models by means of data assimilation (Actions B.4 to B.6) and for evaluating the phenological parameters of the EO data (Action B.2). Such flux data have been measured for several years at various stations maintained by FMI and UHEL, and the measurements have continued during the MONIMET project without any major problems.

The meteorological data have been collected at all the flux measurement sites during the period of flux measurements and the collection was continued during the MONIMET project. The weather data relevant for ecosystem fluxes were processed into complete time-series with the time resolution adjusted for the models.

The gap-filled time series had been processed to meet the needs of the models, and the data sets from the Sodankylä and Hyytiälä Scots pine forests and the Kenttärova spruce forest had been delivered for use in Actions B.4 and B.6. An extended soil moisture data set for Sodankylä and Kenttärova was collected as required for the validation of the soil moisture parameters of JSBACH. Soil moisture and water table depth data from a wetland in Sodankylä were also delivered for the validation of EO products. The flux measurements made it possible to derive detailed phenological and plant physiological data (e.g. growing season stages, their dynamics and interannual variation) for validating the EO data and the results of webcam exercise in Action B.1.

The details of the flux data can be found in in the deliverable reports of Action B.3 (1st summary report of flux data-31/3/2014, 2nd summary report of flux data-31/3/2015, 3rd summary report of flux data-31/3/2016, and 4th summary report of flux data-31/3/2017).

4.1.3.2 Snow data

The in situ observations that were used for validating the EO snow cover data and the melt-off date (Action B.2) were obtained from two separate measurement networks. The snow course network consists of ~160 courses, which are visited on a monthly basis. For each snow course and for each visit, observations on the fraction of snow-free ground and the snow depth are made at 40–80 locations along the course. Information on local land cover type (6 classes) is associated with each observation. The weather station network of FMI consists of 250 stations, where observations on snow depth and snow coverage (visually estimated fractional snow cover described as E-code) are made on a daily basis.

Snow course observation are extracted from hydrological data bases in SYKE (2001-2016) and further processed to allow comparisons with satellite observations related to snow properties. The following data fields are retained in the final Excel-file: 1. Snow course ID, 2. coordinates (lat,long) in WGS-84 system, 3. Date of observation, 4. Snow depth, 5. Patchiness, 6. Landcover type. The landcover-specific average values are also calculated and provided as separate Matlab-tables, so that one table is created for each individual snow course visit.

As a new feature concerning the processing of Snow course data: Patchiness was converted to Fraction of snow-covered area; FSC=100-Patchiness (%), to be consistent with the EO-retrievals. In addition, the matlab-files including the visit-specific average for each land cover type now include also standard deviations for Snow Depth and for FSC. These would be useful when interpreting the results of in-situ validations and also when developing new approaches for validation.

While collecting snow course data, updates also for the course location were made. For instance, in 2015-2016, the track (route) of three snow courses was changed due to the changes in local land/vegetation cover. These changes were updated also in the GIS-database on the routes. In addition to the updates presented above, the 2015-2016 courses were rasterized in order to enable their use in validation of the snow products. The resulting rasters are in two different resolutions, 250 m 500 m, enabling the validations of different resolution snow maps.

For five selected snow courses around Sodankylä-Pallas area a historical time series has been processed and is available for the last 30 years period.

E-code observations have been extracted from FMI data bases (2001-2016) and processed for the comparison with satellite observations on snow cover. The data fields retained in the final Excel-file are the following: 1. coordinates (lat,long) in WGS-84 system, 2. Date of observation, 3. Snow depth, 4. e-code.

In addition to the Finnish in-situ data, the data near the area of Finland would benefit the evaluation of MONIMET snow products. The standard suite of measurements from weather stations in the Russian Research Institute for Hydro-meteorological Information (RIHMI) network include observations of snow cover (Bulygina et al. 2015a). Snow depth, the fraction of snow cover around the station and information on snow characteristics around the station are daily measured and observed.

The details of the snow data can be found in in the deliverable reports of Action B.3 (1st summary report of snow data-30/9/2014, 2nd summary report of snow data-30/9/2015, 3rd summary report of snow data-30/9/2016, and 4th summary report of snow data-31/03/2017).

4.1.3.3 Albedo and LAI data

The MONIMET project was provided with the access to the campaign data of NorSEN 2007 and SNORTEX 2008–2010, in which an extensive set of ground-based measurements of diverse snow properties, albedo and leaf area index were collected. In addition to the ground-based data, SNORTEX also provides a large amount of airborne LAI and albedo data for the Sodankylä area. The ground-based and airborne LAI data from the SNORTEX campaign are reported in detail in the deliverable report of Action B.3 (Summary report of LAI data-31/5/2014). The ground-based canopy floor albedo data and the newly calibrated airborne forest albedo data are reported in the deliverable report of Action B.3 (Summary report of albedo data-31/5/2015).

Dedicated LAI maps for the climate model input were also generated, starting from the high resolution (25 m) LAI maps provided by Dr. Janne Heiskanen, University of Helsinki (Heiskanen et al., 2011a; Heiskanen et al., 2011b). Statistical parameters of the original LAI maps for 2000 and 2006 were first produced in a resolution of 20 km x 20 km within the grid used in climate models. The mean, standard deviation and minimum and maximum value of each window was determined so that the missing values and pixels having a LAI value of 0 (mostly water and fells) were excluded from the statistics. The number of LAI values used for the statistics of each window was stored as well. Finally, all this information was transformed to the coordinate system used in the climate models (i.e. latitudes and longitudes instead of the original metric coordinates).

4.1.3.4 References

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4.1.4 Action B.4: Model System Calibration by FMI, SYKE, LUKE, UHEL

JSBACH land ecosystem model and PREBAS forest growth and carbon balance model have been involved in model calibration. The photosynthesis module of PREBAS (PRELES) has been calibrated for 10 boreal sites; its growth module (CROBAS) has been calibrated with long term growth experiment data collected across Finland. Common management routines (i.e., harvest and thinning) have been also implemented in the model. We analysed the impact that management practices have on the carbon balance of the forests. PREBAS has been coupled with YASSO to model the soil carbon dynamics. The JSBACH model has been developed by adding new soil carbon, methane and water related modules and parametrisations and optimizing hydrological, evapotranspiration and photosynthesis – related parameters. Data collected by project partners in Actions B.1 to B.3 has been used in this Action, including evaluation and validation of the new developments. The impact of these developments is expressed through their effect on country-level and site GHG balances. FMI, UHEL and SYKE have participated in JSBACH calibration work, and LUKE and UHEL in PREBAS calibration work. FMI, UHEL, LUKE and SYKE data and data analyses have been used in calibrations of both models.

The soil component is important in modeling energy, water and carbon balances as it regulates the water reservoir essential for optimal plant functioning, as well as a large carbon storage responsible for the majority of respiration flux to the atmosphere. Furthermore, properties of soil properties influence the surface conditions like length of snow period and droughts. Traditionally models have used a 1-layer 'bucket' model for soil water whereas novel descriptions include several layers. There, for example, the soil moisture content is expressed as a profile instead of single value, enabling sophisticated descriptions of e.g. water levels in soil and freezing of soil layers. We have taken into use and tested a new 5-layer soil module in JSBACH model replacing the old 1-layer module. The model results have been compared to latent heat flux observations at Sodankylä (Figure 10). The new module is able to produce more realistically the annual cycle of evapotranspiration.

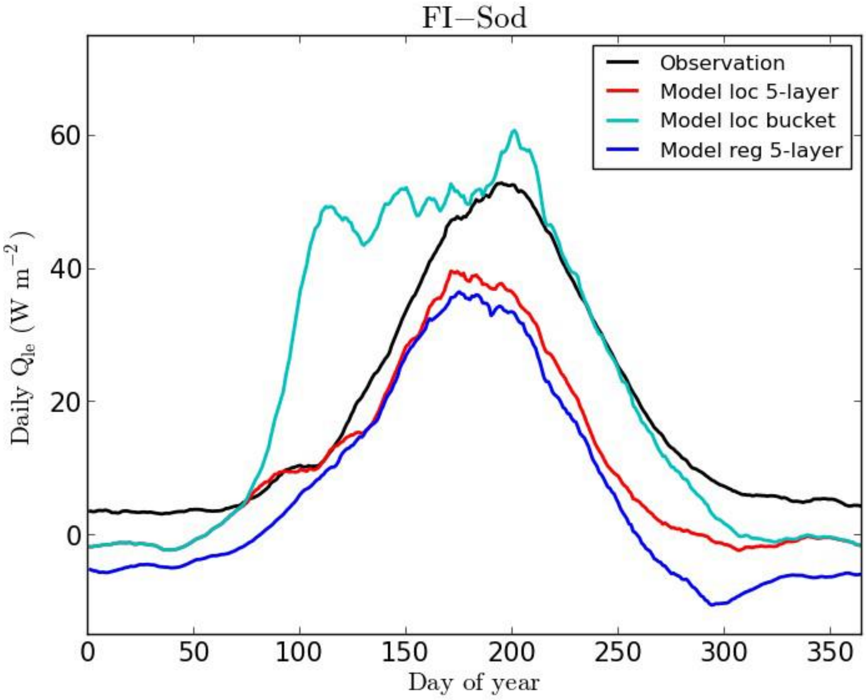

Figure 10: Latent heat flux at Sodankylä, averaged over years 2001-2008, with the so-called bucket model and 5-layer model.

Further, regional evaporation and transpiration rates have been studied and they have been connected to CO_2 uptake, enabling investigation of regional Water Use Efficiency (WUE) values. Regulation of CO_2 uptake by loss of water through stomata and available soil water and their practical implementation in models is still an open issue. The present 5-layer version of the model is able to reproduce the dynamics of observed soil moisture at individual Finnish flux sites during wet and dry periods (Gao et al., 2015), such as the drought in July-August 2006, which affected forest health in southern Finland (Muukkonen et al., 2015). Also, regional WUE values show that the model is able to capture the change in WUE during drought year 2006. The WUE results for individual sites are generally in accordance with regional results, however the non-stomatal effects that may rarely cause distress on carbon uptake during extremely severe drought are not described in the model and are thus missed (Gao et al., 2016). The calibrated model results connected to soil water status will be used when deriving climate change indicators in Action B.5.

JSBACH includes two options for soil carbon modules, new YASSO (Liski et al., 2005, Tuomi et al., 2009) with six carbon pools: four fast decomposing pools separated according to solubility of decomposing material, one pool for slowly decomposing coarse woody litter and one very slow pool for humus, and old CBALANCE with two pools for fast and slow decomposition rates. CBALANCE was used in previous SNOWCARBO Life+ project. New YASSO version has now been taken into use and the results have been compared to old CBALANCE module at local and regional level and against empirical evidence on soil carbon content. Also Finland-validated distribution of soil property values for peatlands and mineral soils (field capacities, porosities etc., see Törmä et al., 2015) have been implemented in the model. Regional results are shown in Figure 11. According to earlier global scale studies with ECHAM/JSBACH climate-biosphere model system, YASSO releases more carbon into atmosphere and has smaller carbon storages in soil, which globally is better in line with observations (Thum et al., 2011). Also for Finland JSBACH/YASSO predicts carbon storages which agree better with the nation-wide distributed soil carbon observations by LUKE (Figure 12, Markkanen et al., in prep.). YASSO will be adopted for the future projections of carbon balances.

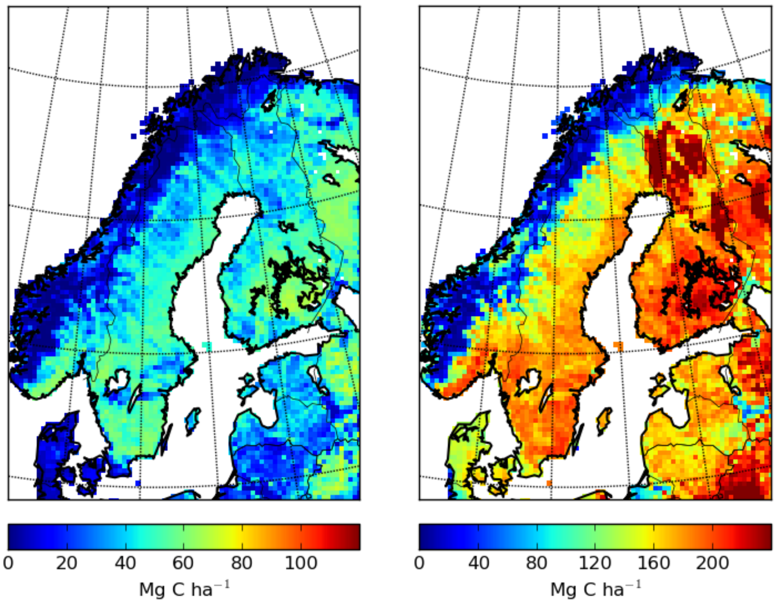

Figure 11: Soil carbon pools for July 2011 according to JSBACH/YASSO model (left) and JSBACH/CBALANCE (right) after spin-up and 30-yr climate run ending at 2011.

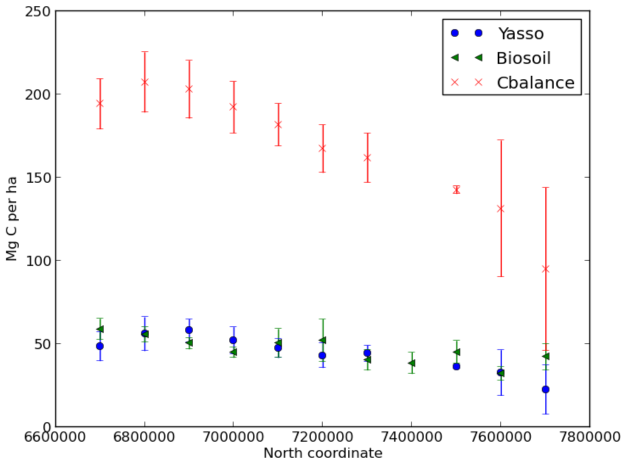

Figure 12: South - north gradient of soil carbon pools across Finland according to YASSO, CBALANCE and LUKE soil carbon observations (Biosoil data from Aleksi Lehtonen).

It is important to obtain information of which model parameters can be constrained by observations, what are their most probable values in local and regional scales, and which parameters are in key position regarding the carbon and water balance uncertainty estimations. We have optimized a set of JSBACH hydrological, evapotranspiration and photosynthesis parameters using statistical Monte Carlo (MC) Adaptive Metropolis algorithm (Mäkelä et al., NPG 2016). A computing scheme for MC simulation runs was implemented, and then a parameter set was optimized against Hyytiälä evapotranspiration (ET) and GPP observations using data from years 2000-2004 and validated using data from years 2005-2008. As an initial step, LAI, maximum carboxylation rate and fraction of vegetative soil were adjusted for the site. Different levels of parameter tuning were applied, applying seasonal summary statistics, and point-wise daily and half-hourly optimization.

The parameters were further optimized for six boreal sites in Finland, Russia and Canada in order to study the variability between sites and to obtain a representative model parameter set for boreal zone coniferous forests. The optimizations were performed for all sites together and each site separately, and further tested at four independent validation sites.

LAI is one of the most important variables determining the level of CO_2 assimilation by the forest. JSBACH can produce estimates of the annual cycle of LAI. Alternatively, the maximum LAI value or full LAI annual cycle can be assimilated from an independent data source. The option to assimilate remotely sensed (LANDSAT) LAI for model use was examined. The distribution and level of GPP in Finland are shown in Figure 13. These results were used in model carbon balance uncertainty estimation in country level.

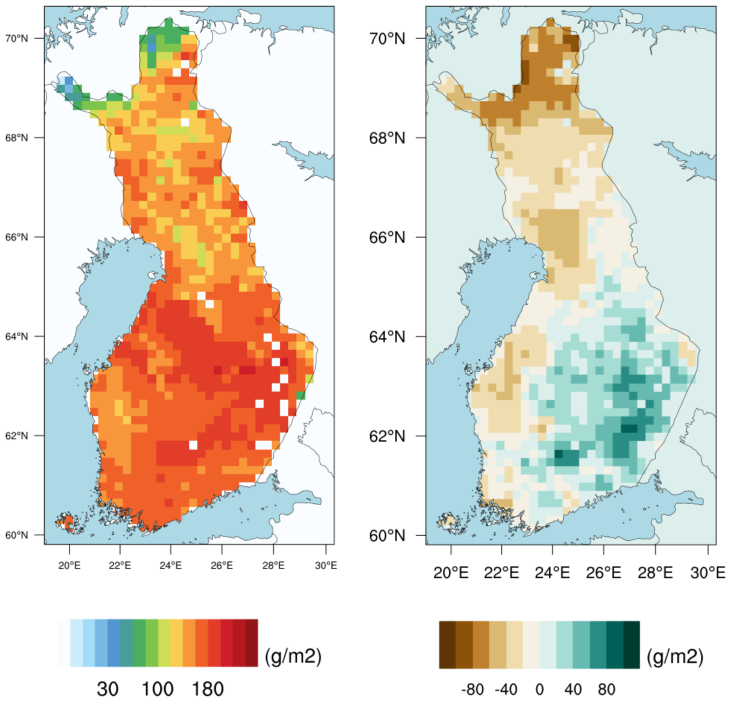

Figure 13: July 2000 mean GPP according to JSBACH model version with standard LAI (left) and difference to satellite-calibrated LAI (right).

The **PREBAS** model developed by UHEL includes modules for monitoring daily GPP and ET on the basis of weather data and minimal stand structure information (PRELES, Mäkelä et al. 2008, Peltoniemi et al. 2015a, 2015b, Minunno et al. 2016), a stand growth module based on carbon balance (CROBAS, Mäkelä 1997, Valentine and Mäkelä 2005) which helps translate the GPP into NPP and stemwood growth when combined with observations on stand structure (Härkönen et al. 2010), and a soil carbon model (Yasso, Liski et al. 2005, Tuomi et al. 2009) which, in combination with the other modules, complete the estimation of net ecosystem exchange (NEE).

In MONIMET we have calibrated **PRELES** for boreal forests in Finland (Minunno et al. 2016) and CROBAS for the three main commercial forest species of Finland (i.e., Scots pine, Norway spruce and Silver birch. The Yasso model has already been calibrated for boreal forests by Lisky et al. 2006 and was just coupled with the PRELES and CROBAS. We have calibrated PRELES model parameters related to photosynthesis and transpiration against eddy-site flux measurements from 10 sites in Finland and Sweden, as had already been done previously using Hyytiälä and Sodankylä GPP and evapotranspiration results. Bayesian calibration was carried out for site specific parameters (S-S) as well as for all sites combined (M-S for Multi-Site). M-S has the advantage that the data involved in the calibration cover a wider variability in terms of climate and forest structure since they come from different sites, including measurement and other errors which may or may not partially cancel out when all data are used in parameter inference. In contrast, S-S could provide good correspondence to local data, but may not be spatially generalizable, firstly because the processes may not be generic, and secondly because the risk of bias increases with less measurements.

CROBAS (Mäkelä 1997, Valentine and Mäkelä 2005) is a generic tree growth model that can be applied to different stand structures but is here used as a mean-tree model by species. Growth in CROBAS is based on carbon acquisition and allocation and is calculated using an annual time resolution. The model describes individual trees in terms of 13 variables, including biomass variables and crown, stem, and root system dimensions. Growth is assumed to follow from net annual photosynthesis, allocated to the different biomass components. The allocation is performed to maintain a number of empirically and theoretically based structural rules the parameters of which are sensitive to climate and site conditions.

We used PRELES for calculating the photosynthetic production that drives the growth in CROBAS. A feedback from CROBAS to PRELES is through which is calculated dynamically from CROBAS state variables as the stand develops. After coupling the two models, PRELES and CROBAS, the calibration and validation of the new model was essential in order to test its applicability at different scales. To do so, different data sources, covering a wide range of variability in space and time, were utilised.

The most intesive data set comes from Hyytiälä and consists of a range of forest variables, i.e. diameter at breast height (DBH), height (H), volume (V), basal area (BA), foliage biomass (WF), crown length (Lc). Furthermore an eddy-covariance tower is measuring the carbon and water exchanges between the Biosphere and the Atmosphere since 1996, providing information about the photosynthesis activity (gross primary production, GPP) and evapotranspiration (ET).

Secondly, we used data from 785 Permanent Sample Plots (PSP) from Finland, 657 were dominated by Pine forests and 128 where spruce dominated stands. The PSP dataset consists of stand variables (i.e., DBH, H, Hc, V and BA). The data were collected along forest rotation development, covering a time interval of 50-80 years. The plots were divided in two parts, half of the plots were used for the calibration and half for the validation.

Thirdly, permanent plots of the National Forest Inventory (NFI) provide data on consists of H, DBH and BA measurements collected at 151 plots spread across Finland in 1995 and 2005. The NFI data were Pine, Spruce and Birch mixed forests; by means of this calibration we were able to obtain parameter estimates for the three main comercial species of Finland. A comprihensive validation of the model was carried out. The results of the uncertainty analyses were reported in in the deliverable report of Action B.6 (Report on the range of variability due to different climate change scenarios-01/09/2017).

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4.1.5 Action B.5: Retrieving climate change indicators by models FMI, LUKE, UHEL

In Action B.5 we processed driving data for JSBACH and PRELES models. For current climate we possess both daily and hourly forcing fields where temperature and precipitation are bias corrected. More details were given in the deliverable report of Action B.5 (1st report on climate data processing-30/06/2014). For future scenarios we had meteorological forcing from 1980 to 2099 from six CMIP5 models that are all bias corrected with FMI gridded homogenized data. The emission scenarios follow trajectories rcp8.5 and rcp4.5 that represent a very high global warming of land areas of 5 degrees and a warming approximately half of that, respectively. For needs of Action B.6 we selected three models each with one rcp that represent mean and upper and lower extremes among the six models. For sub region runs required for analysis in Action B.6, more models were adopted. Additionally, time slices with the whole set of the six bias corrected CMIP5 models were run for whole Finland.

Action B.5 produced trancient ecosystem model runs through years from 1981 to 2100 with regionally bias-corrected climate scenario driving data from five global climate models and three representative concentration pathways (RCPs) of the CMIP5 project. The time-series and trends of the climate change indicators were consequently retrieved from the model results. The impact models used in our project were land ecosystem models JSBACH (FMI) and PREBAS (LUKE and UHEL). The land ecosystem models were run in relatively high spatial resolutions of approximately 10km and the models were operated with daily driving data. The target climate change indicators retrieved from the model results are the duration of a yearly Vegetation Active Period (VAP), vegetation carbon uptake rate (i.e. Gross Primary Production, GPP), vegetation and ecosystem respiration rates (i.e. autotrophic and heterotrophic respiration), methane emission rate, evapotranspiration (sum of surface evaporation and plant transpiration), soil moisture drought, length of soil frost period, snow cover and surface albedo.

The climate change indicators were described in the deliverable report of Action B.5 (First progress report-30/06/2015). A limited set of indicators (GPP, TER, NEE, the beginning, the end and the duration of VAP) was also processed for **Climateguide.fi**. For Climateguide.fi purposes the yearly values were averaged over four 30 year periods: 1981-2010, 2011-2040,2041-2070 and 2071-2099. Additionally, changes of the indicators from the first period that is considered as a baseline were calculated. For Climateguide.fi also JSBACH results that are originally in geographical coordinates were transformed into plane coordinates.
For visualization purposes in addition to the grid cell wise data we synthesized the results for 13 forest eco-sub-regions in Finland. While with a regional map it is possible to visually inspect one dimensional variables such as trends or time averages, regional averaging enables showing time series with associated statistics. In Figure 14 there are shown GPP time series averaged for one southern and one northern Finnish forest growth region together with the start and the end days of VAP.

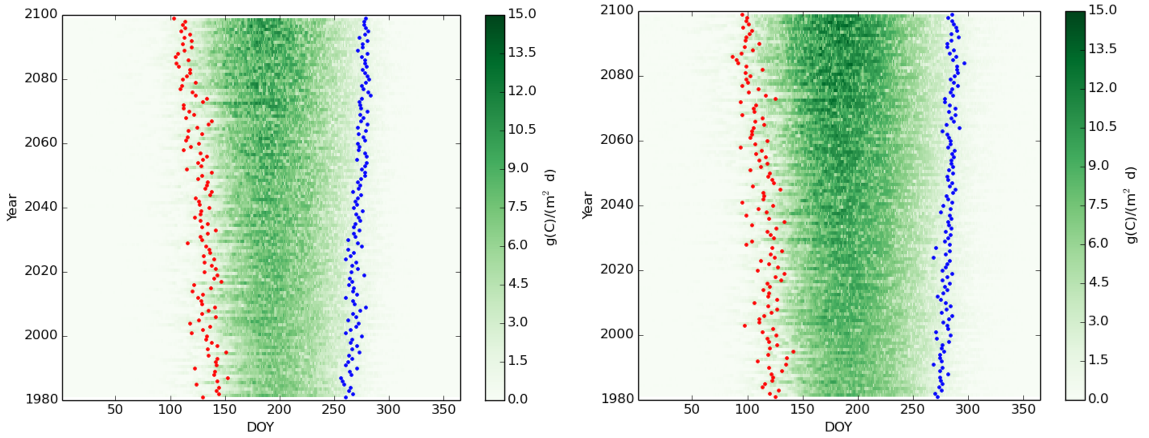

Figure 14: GPP (in green) produced with climatic drivers from GFDL-CM3 under RCP4.5. The dots framing the start (in red) and the end (in blue) of VAP is indicated with dots. At left a northern and atright a southern forest growth region.

Changes of VAP length in days from the baseline period 1981-2010 to period 2071-2100 according to JSBACH model are given in Figure 15 .

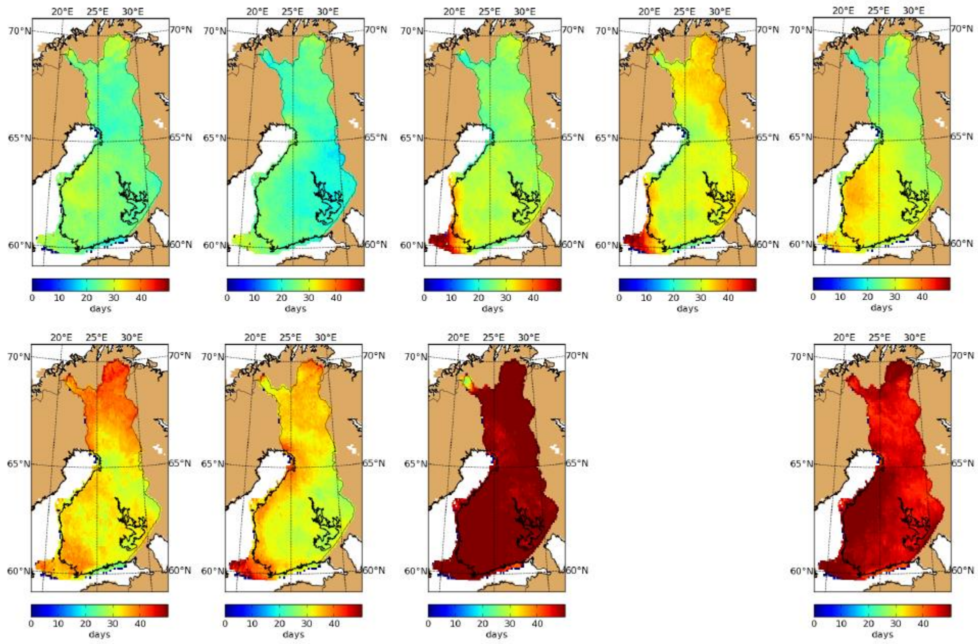

Figure 15: Changes of VAP length in days from the baseline period 1981-2010 to the period 2071-2100 according to JSBACH model. Driving climate models from left to right: CanESM2, CNRM-CM5, GFDL-CM3, HadGEM2-ES and MIROC5. RCP 4.5 in the upper row and RCP 8.5 in the lower row.

A methane production and transport model HIMMELI was developed and calibrated in collaboration between University of Helsinki and Finnish Meteorological Institute during the project. In its current state HIMMELI is a point-wise model that uses soil temperature, leaf area index of gas transporting vegetation, water table depth (WTD) and anaerobic carbon decomposition that can be derived from NEE as driving data. The model simulates microbial and transport processes that take place in the peat column, keeping track on the concentration profiles of CH_4, O_2 and CO_2. The output is fluxes of CH_4, O_2 and CO_2 between the soil and the atmosphere. Driving data can be derived either from observations or from a model. In MONIMET we adopted the drivers from JSBACH climate scenario runs averaged for 13 ecological regions (forest growth zones) in Finland. Methane fluxes were estimated for mires in sub-regions further aggregated to south, middle and north boreal zones (Figure 16). Regional estimates show clear trend towards the end of the century. However, also the uncertainty deriving from driving models also increases towards the end of the century being 5.5 gCH4/m2/a during the baseline and 9.0 gCH4/m2/a during the last scenario period (average over all the boreal zones).

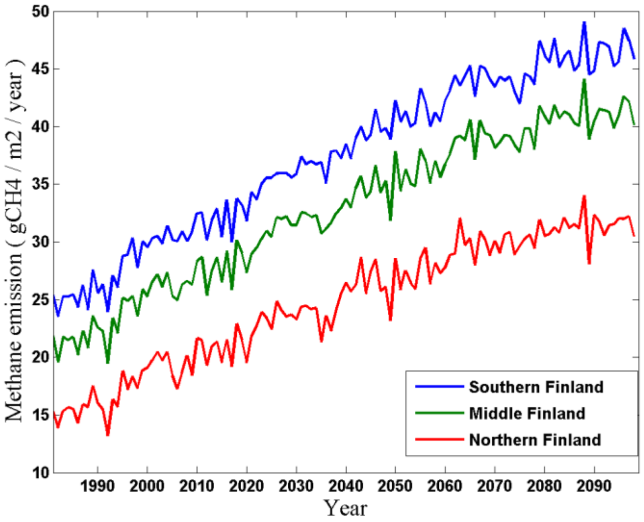

Figure 16: Mean yearly wetland methane emissions predicted with all RCP4.5 climatic drivers for three boreal zones.

More details and examples of climate change indicators were reported in the deliverable report of Action B.5 (Final report (2nd progress report)-31/03/2017 (planned-31/03/2016).

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4.1.6 Action B.6: Assessment of uncertainty of climate change indicators by FMI, LUKE, UHEL

The objective of Action B.6 was to quantify the uncertainties originating in the different sources and to compare their significance temporally and spatially. In particular, we aimed at identifiying the variables where different model structures (JSBACH and PREBAS) produced different results, i.e., where uncertainty about model structure was significant. The uncertainty analyses were carried out at two locations, Hyytiälä and Sodankylä, where the area of one grid point was considered. We found that the uncertainty about photosynthetic production and variables related to phenology were very similar between models. The uncertainty of evapotranspiration was larger than that of photosynthesis. The uncertainty of net ecosystem exchange (NEE) had different trends in different models, although both models used the same soil carbon submodel. This suggests that the different descriptions of above-ground biomass and its changes are significant in understanding NEE and need to be further analysed. When comapring the different sources of uncertainty, we found that climate sensitivity of the results increased with time in both models and was greater in the north (Sodankylä) than in the south (Hyytiälä). In **JSBACH**, this comparison was primarily made with parameter uncertainty. In **PREBAS**, climate uncertainty was compared with uncertainty of forest management, which was significant in the south but only medium significant in the north, where climate uncertainty was larger and had an increasing trend.

We produced projections of water and carbon balances of Finnish forests under climate changing conditions. The output where presented in form of maps and summary graphs and tables, however model predictions are always characterized by uncertainty that needs to be provided to give a complete picture of the forecasts. From the modelling side, the main categories of uncertainty are “input uncertainty” and “structural uncertainty”. Input uncertainty includes parameters, initial states and drivers (Figure 17).

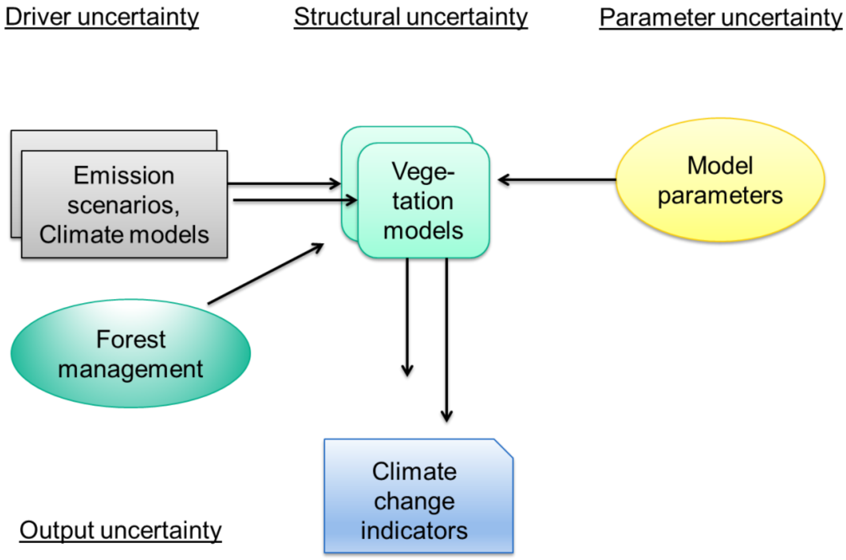

Figure 17: Description of uncertainties and their propagation in vegetation models.

Initial state uncertainty (ISU):

In ecological models *ISU* tends to be important at the beginning of the simulations, while through time ISU will decay exponentially because internal dynamics of the systems have stabilizing feedbacks on model output.

Driver uncertainty (DU):

The most important drivers in vegetaton models are environmental factors, such as radiation, temperature or site characteristics. This category also includes forest management. Generally *DU* tends to increase through time causing an increase of model output uncertainty. The impact of such uncertainty depends of course on the magnitude of *DU* and on the sensitivity of the model to its inputs.

Parameter uncertainty (*PU*):
Parameter uncertainty is strongly related to the availability of data. The variance of the parameters tends to 0 when the amount of data used in the calibration process increases. The impact of parameter variation on model output uncertainty depends on two factors: the uncertainty of the parameter itself and the sensitivity of the output to the parameters.

Structural uncertanty (*SU*):
Structural uncertainty covers the remaining uncertainty that is not captured by the model. This uncertainty is very difficult to quantify, as it is largely due to our insufficient understanding of the processes described by the model. Some insight into structural uncertainty can be otained by comparing the results from models of different structural assumptions.

All the input uncertainties propagate to the model outputs, the extent depending on the degree of the input uncertainties and on how sensitive the model is to them. If the statistics of the input uncertainties are known, we can take random samples of the range of input uncertainties and make simulations to see how the uncertainty is reflected in the results. However, in the case of climate change projections, the environmental drivers themselves are uncertain results from other models that use a set of emission scenarios as their inputs. The climate models also include structural uncertainty, which is demonstrated in the fact that different models produce very different results.

The objective of Action B.6 was to assess the overall uncertainty of our predictions of the climate change indicators, and to estimate how this could be attributed to the different component sources of uncertainty. The uncertainty analysis was carried out for two locations only, namely Hyytiälä and Sodankylä, which were assumed to represent southern and northern Finland, respectively.

In our simulations driver uncertainty was taken into account considering five general circulation models and two different Representative Concentration Pathways (see Action B.5). In PREBAS runs we also considered the uncertainty given by different management scenarios. Model parametric uncertainty was quantified in the calibration of JSBACH and PREBAS by means of Bayesian statistics. Results of PREBAS and JSBACH were compared to gain some insights into the structural uncertainties.

The uncertainty of the vegetation models varied across time and across sites (Hyytiälä and Sodankylä). In both models, the uncertainty originating in the climate models remained constant through time and the uncertainty due to RCP scenarios was greater than that due to climate models. The uncertainty due to model parameters uncertainty gave the lowest contribution to the predictions. In fact, PREBAS was calibrated with a high amount of data and the uncertainty of the parameters was strongly reduced. In JSBACH parameter uncertainty was of similar significance as climate model uncertainty, probably at least partly because JSBACH did not use any information about existing vegetation. In PREBAS vegetation inputs could reduce the parameter uncertainty.

The uncertainty due to RCP scenarios increased with time in both models and was also greater in the north (Sodankylä) than in the south (Hyytiälä). In JSBACH, this comparison was primarily made with parameter uncertainty. In PREBAS, climate uncertainty was compared with uncertainty of forest management. In PREBAS a significant part of the uncertainty was associated to the management routines. This component of uncertainty remained almost constant over time. At Hyytiälä the largest source of uncertainty was given by the management because in the South of Finland the forests have higher growth rates and therefore are more sensitive to the management practices. In Sodankylä management was not as significant as climate (model + scenario) uncertainty which was larger and had an increasing trend.

The detailed results of the uncertainty analyses were reported in in the deliverable report of Action B.6 (Report on the range of variability due to different climate change scenarios-01/09/2017).

4.1.7 Action B.7: Demonstration on ecosystem services and vulnerability by FMI, SYKE, LUKE, UHEL

Boreal forests provide an array of ecosystem services. They regulate climate, and carbon, water and nutrient fluxes, and provide renewable raw material, food, and recreational possibilities. Rapid climate warming is projected for the boreal zone (IPCC 2013), and observed in Finland (Mikkonen et al. 2015), which sets these services at risk. In the MONIMET project, scenarios on future climate conditions are used to drive dynamic process-oriented models which yield information on climate change indicators and ecosystem services of boreal forests in Finland (Figure 18).

In Action B.7, Demonstration on ecosystem services and vulnerability, projected future values of climate change indicators were interpreted in terms of provision of ecosystem services and vulnerability was studied as the risk of decreasing provision of ecosystem services in future climate conditions.

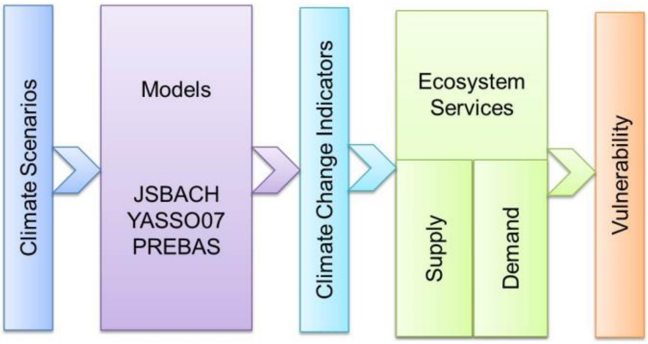

Figure 18: From Climate Scenarios to Vulnerability in MONIMET.

4.1.7.1 Ecosystem services of the boreal forests

Ecosystem services are the contributions that ecosystems make to human well-being (e.g. Costanza et al. 1997, Daily and Matson 2008). The pathway from ecosystems, their biophysical structure, processes and functions to their benefit to and value to society, is illustrated by the ecosystem service cascade model (Figure 19, Potschin and Haines-Young 2011). The cascade model portrays ecosystem services as emerging from the functional and structural properties of the ecosystem once some beneficiary can be identified.

In the Common International Classification of Ecosystem Services (CICES), services are classified into provisioning services, regulating and maintenance services, and cultural services (Haines-Young and Potschin 2013, Potschin and Haines-Young 2013). The sections are further divided into divisions and groups (Table 1). The sections represent the three main categories of ecosystem services, which are further divided into main types of output or process. The group level splits division categories by biological, physical or cultural type or process. The groups are further subdivided into biological or material outputs and bio-physical and cultural processes that can be linked back to concrete identifiable service sources (CICES-V4-3 2013). In this classification, regulating and maintenance services cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance, such as carbon sequestration, water purification, nitrogen retention, pollination and biodiversity (Haines-Young and Potschin 2013).

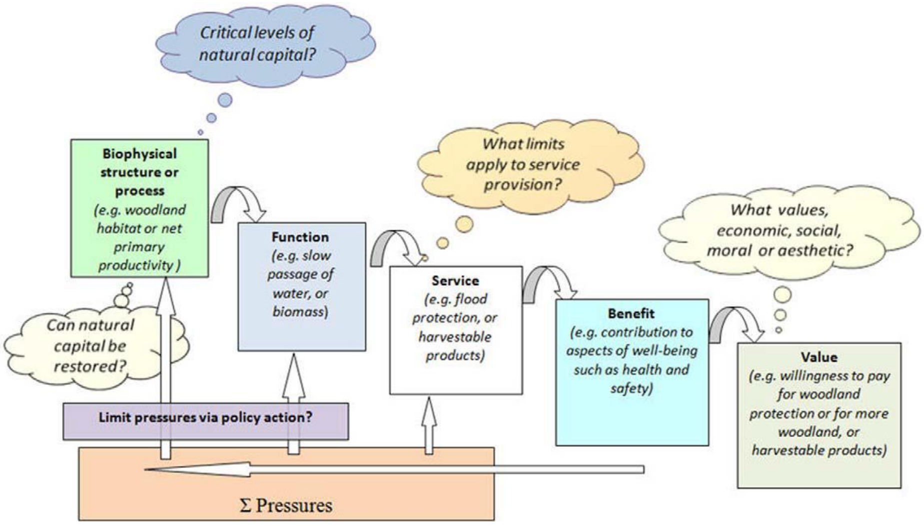

Figure 19: The ecosystem service cascade model, from Potschin and Haines-Young (2011).

Table 1: Common International Classification of Ecosystem Services CICES V4.3 (From Haines-Young and Potschin 2013)

Section	Division	Group
Provisioning	Nutrition	Biomass
		Water
	Materials	Biomass, Fibre
		Water
	Energy	Biomass-based energy sources
		Mechanical energy
Regulation and Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota
		Mediation by ecosystems
	Mediation of flows	Mass flows
		Liquid flows
		Gaseous/ air flows
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
		Pest and disease control
		Soil formation and composition
		Water conditions
		Atmospheric composition and climate regulation
Cultural	Physical and intellectual interactions with environmental settings	Physical and experiential interactions
		Intellectual and representational interactions
	Spiritual, symbolic and other interactions with environmental settings	Spiritual and/or emblematic
		Other cultural outputs

Saastamoinen et al. (2014) applied the CICES hierarchy on the boreal forest ecosystem services in Finland, reporting their results in a conceptual and historical context. They collated a detailed list of services found in Finnish forests, subdividing the service groups into 44 classes with additional subclasses. Saastamoinen et al. (2014) listed ecosystem services such as fibres and other materials from trees and other forest plants as well as forest biomass as energy source. The ecosystem services found include water purification, carbon sequestration, reduction of other greenhouse gases, forests and cloud formation, climate regulation and timberline forests. They also identified that forests maintain the hydrological cycle, regulate water flow, balance spring floods and reduce run-off (Saastamoinen et al. 2014).

Mononen et al. (2016) developed a framework of ecosystem service indicators for Finland that complies both with national circumstances and with international typologies such as the CICES and the cascade model. They developed indicators for 28 ecosystem services (10 provisioning, 12 regulating and maintenance and 6 cultural services), a set of four indicators for every stage of the cascade model (structure, function, benefit, value); altogether 112 indicators. These indicators represent all main ecosystem types found in Finland: forests, mires, the Baltic Sea, inland waters and farmlands (Mononen et al. 2016).

4.1.7.2 Climate change indicators and ecosystem services

Climate change indicators related to carbon cycling, vegetation activity, soil drought and soil frost were derived in Action B.5. The land ecosystem models JSBACH and PREBAS were used (as described in Action B5 and Action B.6) to produce annual values for key climate change indicators for the period 1981 to 2100. In Action B.7, climate change indicators related to nitrogen cycling were derived with the INCA-N model, as described in Rankinen et al. in prep. The simulated physical values of the climate change indicators were considered to represent ecosystem services of provisioning, regulating and cultural values.
Ecosystem services were estimated as the physical values of the following climate change indicators:

1) Vegetation carbon uptake ratio (gross primary production GPP, gC m^{-2} yr^{-2})
2) Stem wood growth (Growth m^3 ha^{-1} yr^{-1})
3) Length of vegetation active period (VAP length, days)
4) Start of vegetation active period (VAP start, days from beginning of year)
5) End of vegetation active period (VAP end, days from beginning of year)
6) Flux of carbon from the ecosystem to the atmosphere (net ecosystem exchange of CO_2 NEE gC m^{-2} yr^{-2})
7) Number of drought days (Drought, number of days)
8) Number of soil frost days (Frost, number of days)
9) Nitrogen retention (N retention kg N ha^{-1})

The climate change indicators 1 to 8 were derived for all of mainland Finland. Regional statistics for the countrywide indicators were calculated for four time periods (1981–2010, 2011–2040, 2041–2070, 2071–2011) and three regions. The regions follow the division of forest vegetation prepared by the environmental administration. The southern region covers the hemi- and southern boreal regions, the central region corresponds to the central boreal region, and the northern region is the northern boreal region (Figure 20).
The climate change indicators 1 to 6 were published in the national portal on climate change issues, **Climateguide.fi**. The new variables were presented under the header Terrestrial ecosystems, and they appear in the section on Maps, Graphs and Data of the Climateguide.fi. Seven variables were presented: Gross Primary Production; Net Ecosystem Exchange; Total Ecosystem Respiration; Length, Start and End of Vegetation Active Period; Stem growth. The indicators were presented under the header Terrestrial ecosystems, and they appear in the section on Maps, Graphs and Data of the Climateguide.fi. For each variable, results obtained as model simulated projections are presented as gridded maps for the reference period 1981 – 2010, and three future periods: 2011– 2040; 2041– 2070 and 2071– 2100. For stem growth, only CROBAS results were presented, for the other variables both JSBACH and CROBAS were used to simulate the results. Regional statistics are given for each variable on the NUTS3-level (maakunta). The models used to simulate the climate change indicators are presented under 'Ecosystem models' under the heading 'Impact models' in the section 'Impacts' in 'Climate Change Explained' of the Climateguide.fi. The details were described in **Technical Annex B7.1 Contribution to Climateguide**.
For the climate change indicators 1 to 8, parameters mean, median and percentiles 5, 25, 75 and 95 were given in **Technical Annex B7.2 Climate change indicator statistics**.

The corresponding ecosystem services are:

a) Provisioning: Biomass, rate of increase (indicators 1 and 2)
b) Regulating: Reproductive success and survival of species (indicators 3, 4, and 5)
c) Regulating: Avoided increase in radiative forcing (negative indicator 6)
d) Regulating: Avoided drought (negative indicator 7)
e) Regulating: Opportunities for winter harvest (indicator 8)
f) Cultural: Opportunities for nature tourism (indicators 3, 4, and 5)
g) Regulating: Avoided eutrophication (indicator 9)

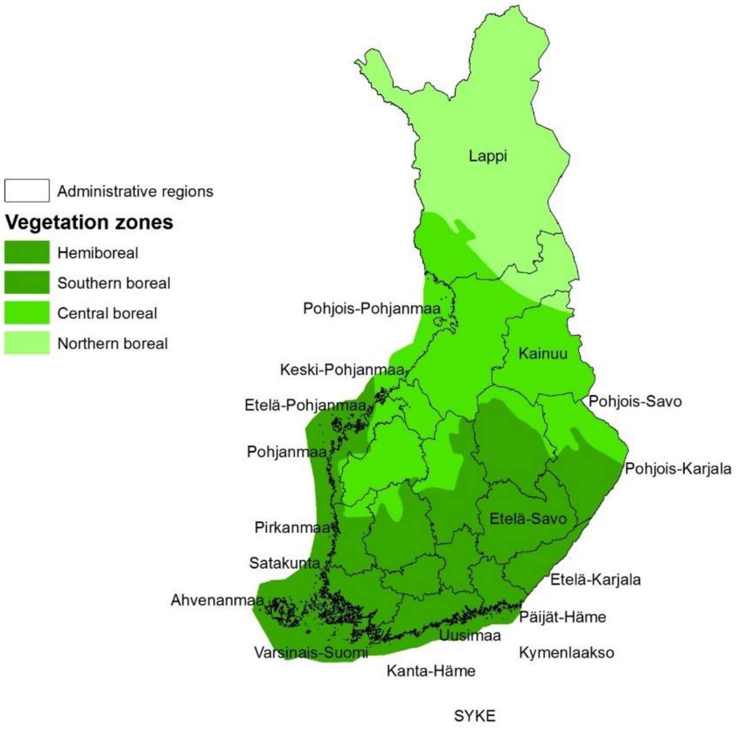

Figure 20: Forest vegetational zones and administrative regions in Finland.

Table 2: Administrative regions and vegetational regions

Administrative region	Vegetational regions
Uusimaa	South
Varsinais-Suomi	South
Satakunta	South, Central
Kanta-Häme	South
Pirkanmaa	South, Central
Päijät-Häme	South
Kymenlaakso	South
Etelä-Karjala	South
Etelä-Savo	South
Pohjois-Savo	South, Central
Pohjois-Karjala	South, Central
Keski-Suomi	South, Central
Etelä-Pohjanmaa	Central
Pohjanmaa	South, Central
Keski-Pohjanmaa	Central
Pohjois-Pohjanmaa	Central, Northern
Kainuu	Central, Northern
Lappi	Northern, Central
Ahvenanmaa	South

N retention was derived for twelve municipalities in the Vanajavesi river basin, located in Kanta-Häme in the southern boreal region (Figure 21).

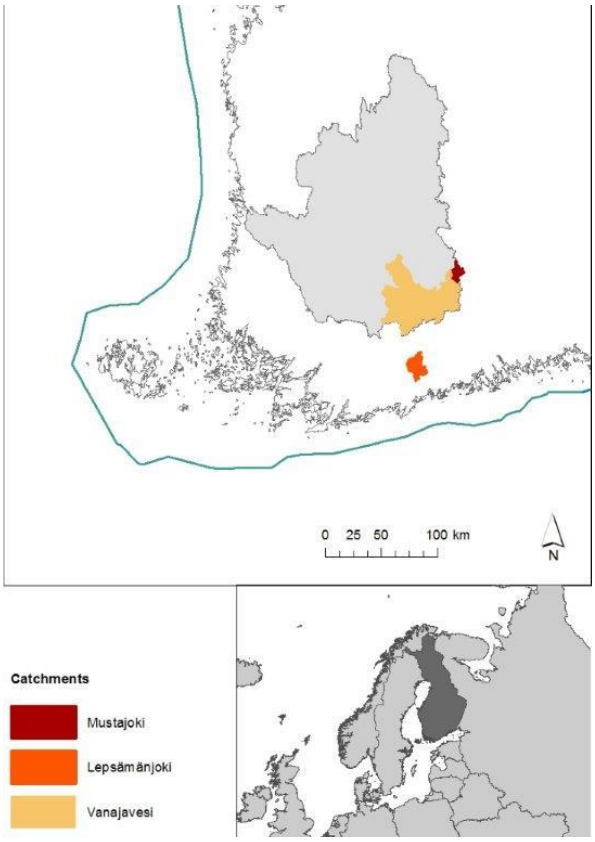

Figure 21: Location of the Vanajavesi catchment in Southern Finland.

4.1.7.3 Ecosystem services under changing climate

The impact of climate warming on the studied ecosystem services was estimated in terms of the positive or negative change, compared to median reference values, in climate change indicator median values in response to warming.

Increasing biomass growth:
The rate of biomass growth is increasing for all regions and all scenarios, with the largest improvement for the RCP8.5 scenario. JSBACH predicts smaller impact in the north than in the south, while PREBAS results indicate larger impacts in the north than in the south.

Both increasing and decreasing carbon sink:
The median of the flux of carbon from the ecosystem to the atmosphere (NEE) is predicted to decrease in the south with the RCP8.5 scenario simulated with JSBACH. In the other runs, JSBACH predicts and increase, which is lower in the north and with the RCP8.5 scenario. In the PREBAS simulations, NEE decreases with all scenarios in all regions. Interpreted as an ecosystem service, this means that the increase in radiative forcing is better avoided, or the carbon sink increases more or decreases less, in the north, and with the higher warming scenario RCP8.5.

Increasing risk for drought:
The risk for drought is slightly increasing for all scenarios, with only small differences between regions.

Decreasing opportunities for winter harvest:
The median of the number of soil frost days decreases with around -30% in the south and the central region, and with around -20% in the north, in simulations with the lower warming scenario RCP4.5. With RCP8.5, however, the decrease is around -50% in the south and -30% in the north. The opportunities for winter harvest are decreasing in all regions with all scenarios, more in the south than in the north.

Longer vegetation active period:
The length of the vegetation active period (VAP length) increases about 20 and 30 days for all regions with the RCP4.5 and RCP8.5 scenarios, respectively. In terms of regulating ecosystem services, this means that there is a positive impact on the reproduction and survival of birds, insects and other species that are dependent on forest vegetation activity. In terms of cultural ecosystem services, this means a positive impact on such forms of nature tourism that depend on forest vegetation activity.

Earlier spring:
Compared to reference conditions, the vegetation active period starts (VAP start) two to three weeks earlier with the RCP4.5 scenario, and almost one month earlier with the RCP8.5 scenario. For the south, this means that the vegetation active periods begins end of March or mid-March, instead of mid-April, and mid-April or early April, instead of early May, in the north. For regulating ecosystem services, earlier start of vegetation active period means earlier opportunities for birds, insects and other species, but is also linked to the risk for coincident occurrences of cold spells that may be detrimental. For cultural ecosystem services, climate warming is expected to lead to earlier opportunities for nature tourism linked to the coming of spring, such as bird watching and observing shoot growth, bud bursting and flowering.

Later end of vegetation active period:
Compared to reference conditions, the vegetation active period ends (VAP end) two to three weeks earlier with the RCP4.5 and the RCP8.5 scenario, respectively. For the South, this means that the vegetation active periods ends mid-October instead of end of September, and end of September instead of early September in the North. For regulating ecosystem services, later end of vegetation activity may mean

decreased leaching of N in autumn. For provisioning and cultural ecosystem services, later end of vegetation may be associated with improved opportunities for the growth and picking of mushrooms and berries, although the success of these species is mostly regulated by local weather conditions.

<u>Increasing rate of N retention but more leaching in winter</u>:
Vegetation uptake of N does not increase considerably, even though growing period becomes longer. Even though spring cereals may be sown earlier, their yield season does not change considerably. Growing season of forest becomes longer, but only two scenarios shows a shift of maximum N uptake from April to March. Nitrogen leaching from forests follows the general pattern of discharge, so that in current climate the peak occurs in April. In future the peak will occur earlier in spring, and there will be more leaching in winter. In spring cereal fields the peak leaching occurs in May, though there will be more dispersion between scenarios in future. Leaching from fields decreases less than 10% in far future, though there is no change in near future. Leaching from forests decreases by 9% in near future and by 15% in far future. Small groundwater aquifers and private wells close to agricultural fields risk increased N concentrations, and increased concentrations may occur also in forested areas on permeable soil types (Figure 22).

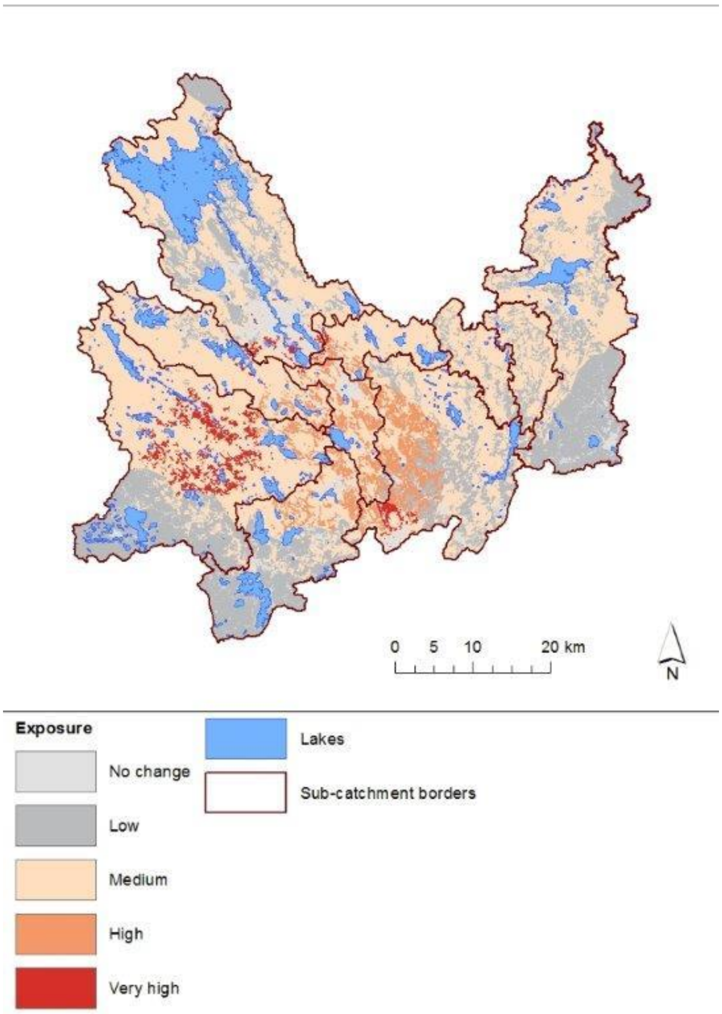

Figure 22: Exposure for increased nitrogen leaching due to climate change in the Vanajavesi river basin.

While some of the studied ecosystem services are expected to improve with climate change (biomass growth, nature tourism, N retention), the projected decrease in number of soil frost days is expected to decrease the opportunities for winter harvest in forestry. Future levels of net ecosystem exchange of CO_2 are uncertain, some simulations indicate decreasing radiative forcing levels, while other simulations lead to increasing levels. The risk for drought is slightly increasing in the whole country. Especially in the south, decreasing number of soil frost days is expected to deteriorate the opportunities for winter harvesting in forestry. Climate warming is expected to lead to earlier opportunities for spring-time nature tourism, and may improve opportunities for autumn mushroom and berry picking. The annual retention of N is expected to improve, while the timing of N leaching is shifting towards winter.

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4.1.8 Action C.1: Monitoring of the impact by FMI

The impact of MONIMET project was monitored with Action C.1. The idea was to monitor the impact in the beginning of the project, during the project and at the end of project to see whether there is true communication between the different modeling and experimental approaches and thus convergence of the results at project end. There we defined indicators of the project impact that are common to the different approaches, and thus easily comparable. One such indicator is Vegetation Active Period (VAP), which can be derived from webcam, flux tower, model and remote sensing results. Another indicator is albedo, which can be derived from flux tower, model and remote sensing results. Both VAP and albedo potentially obtain different values depending on the method of estimation, but for example experimental results can be used to tune model parameters, drawing the estimates closer together.

The beginning of the season, end of season, and their difference (VAP) were calculated using the different tools and methods described above. Webcam results were added to the portfolio. VAP from model results is shown below (Figure 23), using a threshold of 15% GPP for both start of season and end of season. The result was averaged over the period from year 1980 to year 2011, and it clearly shows the south-north gradient in VAP. Difference to VAP results using calibrated JSBACH model was also shown (average between years 2001 - 2011). There the relationship between photosynthetic efficiency and temperature history was taken into use in the model, delaying the springtime start of vegetation active period due to cold spells. VAP from calibrated PRELES model is shown in Figure 24. The south-north gradient is clearly visible there, and the results are generally in agreement with JSBACH.

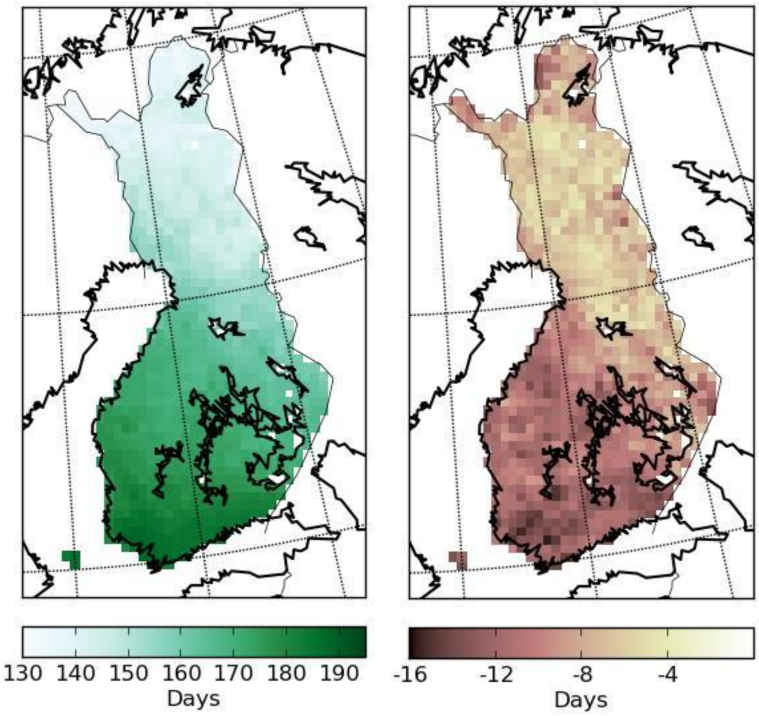


Figure 23: Vegetation active period according to JSBACH model results (left) and Difference to calibrated JSBACH model results (right).

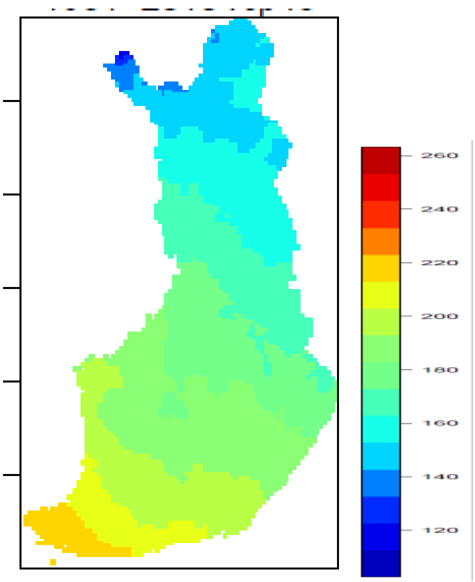


Figure 24: Vegetation active period according to PRELES model results, average between 1981 – 2010.

Webcam results for GSSD and GSED are shown in Figure 25 together with JSBACH model results. JSBACH results cover the period 1981-2017, and GSSD and GSED averages over these years are shown for several webcam and phenology monitoring sites. JSBACH results show the latitudinal gradient, against which the webcam results from year 2014-2016 are compared. The gradients are quite similar, however the definition of the end of growing season in the model needs further consideration, which can better assessed when there are more webcam years available.

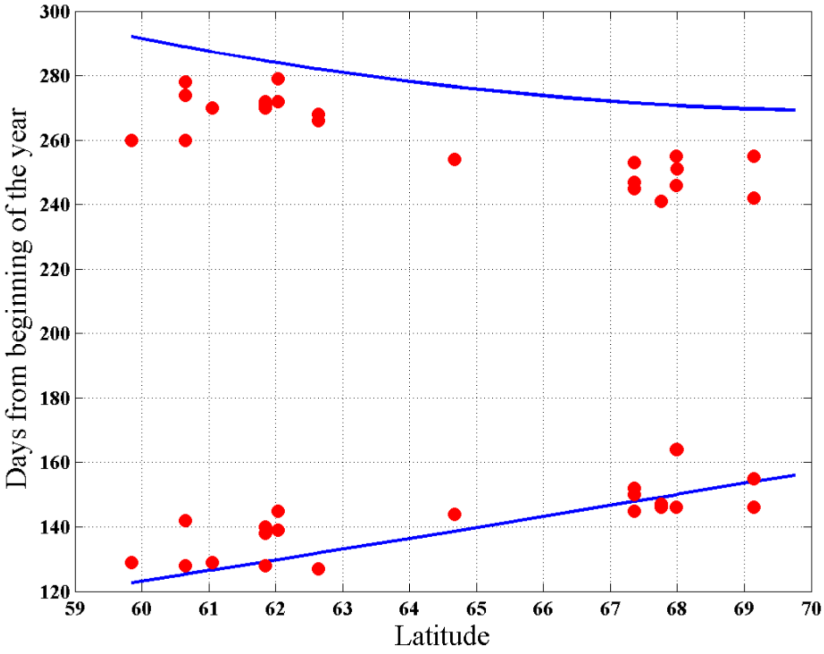


Figure 25: Webcam results for GSSD and GSED and JSBACH average GSSD and GSED results for a set of observation sites in Finland. JSBACH is shown in blue and Webcam in red.

The total surface albedo can be retrieved from remote sensing as well as models and in situ measurements. The alteration of snow covered and snow free periods create a distinct annual cycle in albedo in boreal region. During the growing season some albedo variation is created through changes in vegetation cover and leaf status. Autumn is again more difficult for albedo retrievals, hence the satellite based analysis was restricted to sprint and summer. Here a long albedo time series (AVHRR CLARA-SAL) were applied, and compared to model albedo development.
Data from the new release of the CLARA-SAL product is shown in Figure 26 together with JSBACH total surface albedo results. The data is averaged over the period from 1982 to 2015, and is shown for the different, mainly boreal, vegetation zones in Finland. In addition to climate drivers, albedo is affected by e.g. the leaf area index and plant species, and contribution from bare ground. CLARA-SAL albedo shows larger variation and decreases to lower summer level than JSBACH albedo. The CLARA-SAL values contain contributions from surface water in mixed pixels, which decreases the summertime albedo values. The spring decrease also occurs later than in JSBACH, indicating later snow melt. The seasonal cycle of model albedo is largely driven by the climate drivers and existence of snow cover, and thus a significant impact on model results could be achieved through applying alternate snow descriptions. This was left for future work.

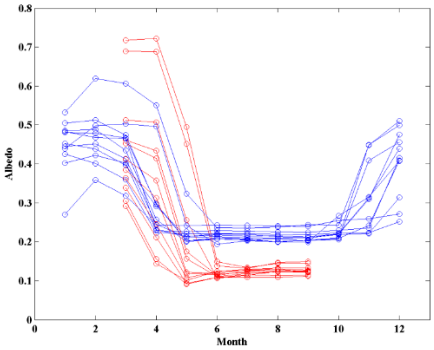
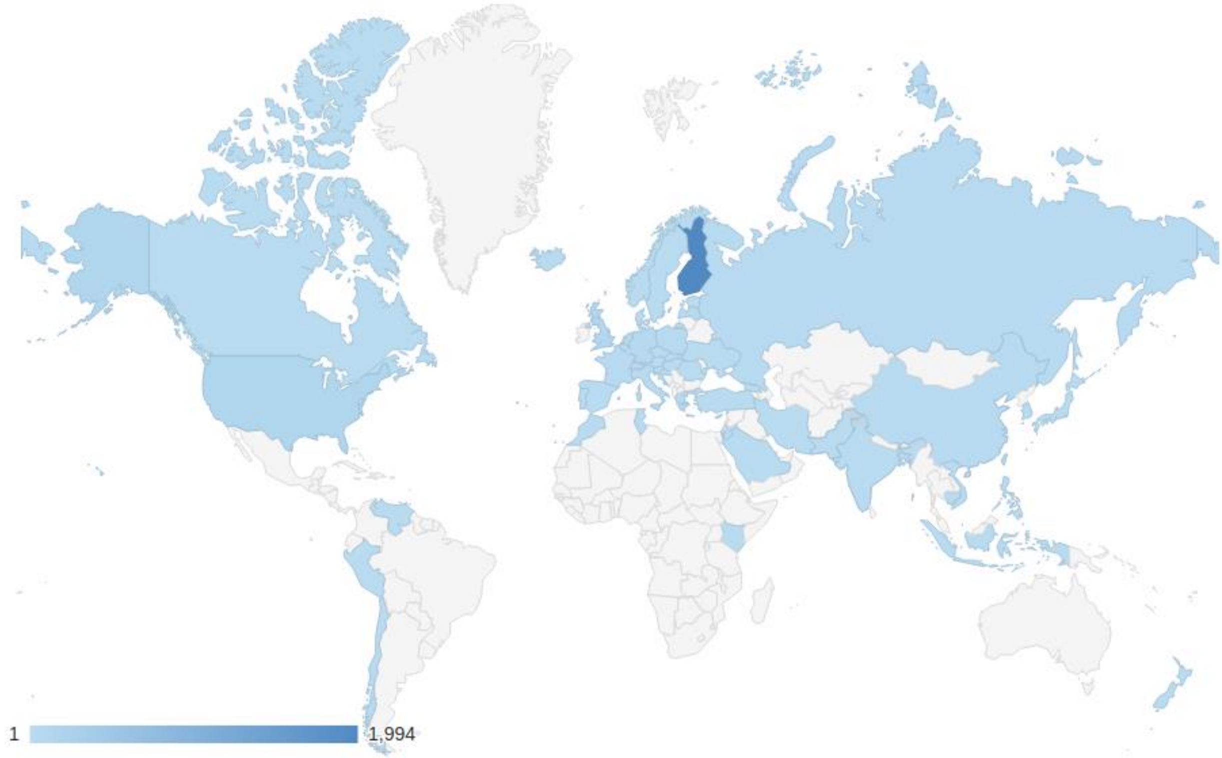


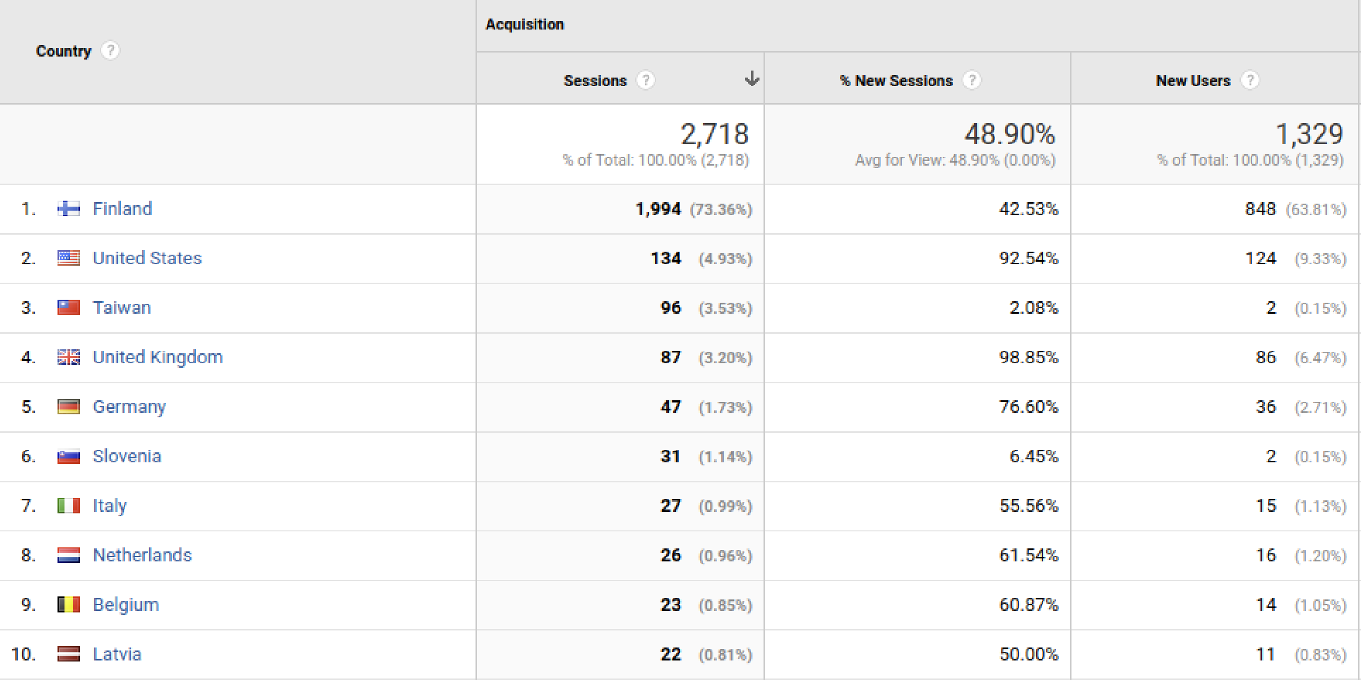
Figure 26: Annual cycle of albedo in the different vegetation zones in Finland. CLARA-SAL is given in red and JSBACH results in blue. Full year is not shown for CLARA-SAL because lack of sunlight prohibits albedo estimates during winter.

The start, end and length of the vegetation active period (VAP) were estimated from flux measurements, satellite observations, and by two models, JSBACH and PRELES. Albedo estimations were obtained from satellite (AVHRR CLARA-SAL) time series and JSBACH model. The albedo results showed a distinct annual cycle with largest changes occurring in the time of snow melt and onset of snow cover, The results for vegetation active period showed that the definition of VAP can be challenging, but results that are comparable within the different approaches can be obtained, and that models can be trained with experimental data regarding VAP.

We also monitored website statistics of the MONIMET project from the beginning of the project. As the website is still running these statistics are continuously available. We implemented Google statistics to the MONIMET website and monitoring started on 16/6/2016. We had also earlier statistics and these are reported in the deliverable of Action E.1 (Midterm report-03/09/2015). Below we gave some statistics between 16/06/2016-30/10/2017 to show the impact of the monitoring (Figure 27).



(a)



Country	Acquisition		
	Sessions	% New Sessions	New Users
	2,718 % of Total: 100.00% (2,718)	48.90% Avg for View: 48.90% (0.00%)	1,329 % of Total: 100.00% (1,329)
1. Finland	1,994 (73.36%)	42.53%	848 (63.81%)
2. United States	134 (4.93%)	92.54%	124 (9.33%)
3. Taiwan	96 (3.53%)	2.08%	2 (0.15%)
4. United Kingdom	87 (3.20%)	98.85%	86 (6.47%)
5. Germany	47 (1.73%)	76.60%	36 (2.71%)
6. Slovenia	31 (1.14%)	6.45%	2 (0.15%)
7. Italy	27 (0.99%)	55.56%	15 (1.13%)
8. Netherlands	26 (0.96%)	61.54%	16 (1.20%)
9. Belgium	23 (0.85%)	60.87%	14 (1.05%)
10. Latvia	22 (0.81%)	50.00%	11 (0.83%)

(b)

Figure 27: (a)-sessions per country (b)-sessions from top 10 countries

The detailed results were reported in in the deliverables report of Action C.1 (1st report on the monitoring -31/03/2015, 2nd report on the monitoring -31/03/2016 and 3rd report on the monitoring -31/03/2017).

4.1.9 Action C.2: Monitoring of socio-economic impact by SYKE

To assess the awareness of local population regarding the role of forests in carbon balance and the vulnerability of municipality to climate change, two web surveys of public awareness were conducted. The views of Finnish citizens were monitored with a web-based survey, first conducted in the period June to August 2014 (76 respondents), repeated in the period February to April 2017 (652 respondents). The surveys were published in the HARAVA web tool, and promoted by SYKE, LUKE and FMI. The respondents were asked to choose alternative answers to six questions and to indicate locations where they anticipate impacts of climate change to occur in Finland. The respondents were also given the opportunity to respond in their own words. Because of the set-up of the survey, the results are not representative, but can give qualitative understanding on how people think about climate change and, e.g. increasing the use of bioenergy. The responses to the multi-choice questions are summarized in graphs.

Majority found impacts already occurring in their municipality :
There are many similarities in the distribution of replies in 2014 and 2017, e.g. majority of respondents were from Uusimaa region, 62% were employed, with a university degree (60-70%). There are some differences in the distribution of replies in 2014 and 2017, e.g. in the second survey, there were more male respondents (45% compared to 26% in 2014). In responding to statements in the section “In your opinion, how is climate change manifested?”, the majority of the respondents agreed with the statement “Global warming occurs” (95 % in 2014, 91% in 2017), and with the statement “Human actions affect global warming” (93% in 2014, 87% in 2017). More than half of the respondents chose the option “Very alarmed” in response to the question “Is climate change alarming?” (67% in 2014, 60% in 2017).
The majority were of the opinion that impacts of climate change already appear globally, and in Finland. To the question “When do you expect climate change to have global impacts”, 87% in 2014 and 82% in 2017 chose the option “Impacts already appear”. Similarly, 68% and 74% of the respondents in 2014 and

2017, respectively, chose the option “Impacts already appear” when asked “When do you expect climate change to have impacts in your municipality”.

No obvious differences from 2014 to 2017 were seen in the distributions of observations concerning rain events, floods, etc., or in the views on anticipated beneficial or damaging impacts.

The free text responses to the question concerning observations during the last decade were grouped according to their key messages. Observations of warmer winters and less snow were key messages that were identified in roughly 20% of the free text responses of the 2014 and 2017 surveys. Also observations of shifting seasons and weather conditions were identified in more than 10% of the responses. Other key messages includedobservations of shorter winters, later winters, more wind, rain and frequent storms. Some respondents reported observations of normal climate (5%), and some were critical to the survey (5%). Many respondents thought forest policies should promote recreation, landscape enjoyment, berry and mushroom picking, noise control and carbon sequestration. Many respondents found the adaptation to be very urgent in the education sector.

Second survey found fewer positive consequences of increasing use of forest bioenergy :

In the responses to a question concerning increasing use of forest bioenergy, there were some differences in 2017 compared to 2014. In 2017, fewer thought increasing use of bionenergy would have large impacts on providing business opportunities, improving the municipality’s image, and decreasing greenhouse gas emissions. In 2017, more found that it would have large impacts on damaging the landscape and decreasing the recreational value of the area.

Anticipated impacts of climate change in Finland :

Respondents were asked to locate anticipated impacts on the map, and the responses were aggregated by land use class. In 2014, 76 respondents anticipated impacts of climate change at 356 map locations (53% in forests and seminatural areas); in 2017, 652 respondents identified 19 840 map locations (55% in artificial surfaces) for anticipated impacts of climate change.

The detailed results were reported in in the deliverable report of Action C.2 (Contribution to final report -07/08/2017).

4.1.10 Action D.1: Dissemination by FMI, SYKE, LUKE, UHEL

The Dissemination was very successful. There has been lots of dissemination from MONIMET project. Detailed information of the dissemination is presented in chapter 4.2 Dissemination action.

4.1.11 Action E.1: Project management and monitoring by FMI, SYKE, LUKE, UHEL

The activities in Action E.1 have included arrangements of the official project meetings, coordination and monitoring of the project progress, preparation of the project deliverables according to the project plan, and monitoring of the project expenses. The meetings were very successful with good discussions and exchange of opinions between the project manager and project partners and personnel. Project team meetings and working meetings between project team members ensured the coordination of the project work and clarify any issues related for example to the deliverables between project Actions.

The monitoring of the project expenses is based on the financial management systems of the participating institutes (see Chapter 5 for more details).

4.1.12 Action E.2: Auditing

This action was performed and detailed information given under chapter 5 Financial report.

4.1.13 Action E.3: Networking with other projects

The project participants have been actively collaborated with other projects, research groups and new collaborators which were established during the project time and disseminating information on project results. They travelled on scientific and networking meetings in Finland, Europe and overseas. The progress made and results obtained during the MONIMET project were presented to a wide community of experts and general public.

The networked projects are given below

- Finnish and Nordic Centres of Excellence, FCoE 'Centre of Excellence in Atmospheric Science, https://www.atm.helsinki.fi/FCoE/
- CRESCENDO (EU H2020 project 2015-2019), https://www.crescendoproject.eu
- EMBRACE (EU FP7 project 2013-2016), http://www.embrace-project.eu/
- Nordic ESM (Nordic Earth System Modeling, 2014-2017), https://nordicesm.bitbucket.io/
- ICOS-Research Infrastructure, https://www.icos-ri.eu/
- COST Action FP1304 PROFOUND, http://cost-profound.eu/site/
- COST Action ES1404 HARMOSNOW, http://www.harmosnow.eu
- North State (EU FP7 project 2013-2016), http://northstatefp7.eu/
- SEN3APP (EU FP7 project 2013-2016), http://sen3app.fmi.fi
- COST Action FP1106 STReESS, http://streess-cost.eu/
- FinLTSER (FinLTER), http://www.syke.fi/projects/lter
- EnviBASE, http://www.ymparisto.fi/envibase
- CLIPC (EU FP7 project 2013-2016), http://www.clipc.eu/
- N-SINK (EU Life+ project, LIFE12 ENV/FI/597), http://www.helsinki.fi/lammi/NSINK/
- OpenNESS, http://www.openness-project.eu/
- PEAT RESTORE (EU Life+ project, LIFE15 CCM/DE/000138), https://life-peat-restore.eu/en/
- RESTORE (EU Life+ project, LIFE09 INF/UK/000032), https://restorerivers.eu
- WETLANDS (EU Life+ project, LIFE13 NAT/LV/000578), http://www.mitraji.lv/about-the-project/?lang=en

The details of networking activities are described in the Action E.3 deliverable report: Report on networking (30/06/2017).

4.1.14 Action E.4: After Life+ Communication plan

Following issues are listed in the After-LIFE communication plan of MONIMET project:

- MONIMET camera network (**LUKE**, **FMI**, **SYKE**, **UHEL**) will be maintained and free open access to recorded image material from camera sites will be updated continuously.
- MONIMET camera network will be extended by adding new cameras by all project partners or also other partners who are interested.
- Finnish Meteorological Institute image PROcessing Toolbox (FMIPROT) will be developed further and make available freely.
- Accumulated data of MONIMET project in conjunction with more advanced modelling techniques to determine vulnerability maps for wetlands and boreal zones in the context of various climate situations will be used further with all project partners(**LUKE**, **FMI**, **SYKE**, **UHEL**).
- **SYKE** plans to continue the provision of vegetation phenological data sets. **FMI** is currently working on a soil freeze product using Sentinel-1 data that could improve the spatial resolution of the product. The analysis of albedo trends will continue in connection with changes in forest.

- MONIMET project website and notice boards will be kept as long as needed and possible. Each partner will advertise and give a link to MONIMET website at their MONIMET related new projects websites.
- As continuation of the MONIMET project, several potential actions arising from cooperation between existing project partners and project stakeholders has emerged. There will be a new proposal submitted in coming calls for EU Life+ programme or other suitable programmes nationally and European level.

4.2 Dissemination action

4.2.1 Objectives

Main objective was the dissemination of end-results produced in Action B.7 to stakeholders and general public. Following activities produced and delivered during 02.09.2013-30.06.2015 from MONIMET project:

a) Project brochures and leaflets
b) MONIMET project website (and ftp)
c) Notice boards at strategic places of the partners
d) Via participation to meetings/conferences/seminars
e) Scientific publications
f) Also as part of dissemination MONIMET plans to utilize a portal Climateguide.fi which was created in an EU Life+ project (LIFE07 INF/ FIN/000152 CCCRP). This portal offers practical climate change information.

Distribution of the material was carried out through web-services (and ftp) and in meetings /conferences and seminars with stakeholders. Results were published in project reports and scientific refereed journals.

4.2.2 Dissemination: overview per activity

Project brochures and leaflets:

Following project brochures and leaflets were produced by all partners of the project:

1) 1st project brochure - http://monimet.fmi.fi/publications/Monimet_Brochure_Low_Res.pdf
2) Promotional article of MONIMET project – http://www.research-europe.com/magazine/ISSUE/125/index.htm , pages 104-107
3) Contributions from MONIMET project to LIFE Focus Brochure, on LIFE & Climate mitigation
4) 2nd project brochure – http://monimet.fmi.fi/project/deliverables/Action_D1/monimet_brochure_web.pdf

All these brochures and leaflets were disseminated via MONIMET project website (http://monimet.fmi.fi), sent by emails to stakeholders and interested partners. Hardcopies of these material were distributed at scientific meetings/conferences and two dissemination stakeholder workshops. 200 hard copies were produced.

MONIMET project website:

MONIMET project website was updated regularly. An ftp server was set up to support the data exchange with guidelines on how to upload files to the ftp server. Files on the ftp server are then uploaded to the project website. All project results, reports, deliverables can be found at the website. The MONIMET project website was maintained by FMI. All other partners contributed contents of the website. MONIMET website will be kept as long as needed. Each partner is advertising and give a link to MONIMET website at their MONIMET related websites of projects.

Notice boards:
Each partner placed Notice boards related to MONIMET project at strategic places accessible and visible to the public at their institutes.

Online resources:
Web-application: Kasvukauden alku -karttapalvelu / Vegetation phenology maps - web map application
http://syke.maps.arcgis.com/apps/webappviewer/index.html?id=a446e987496b4d8794b307e882da718a
Web-application: ESLAB Municipal Greenhouse Gas Budgets. Information on the contribution of natural ecosystems to greenhouse gas sources and sinks in Finnish municipalities.
http://wwwd3.ymparisto.fi/d3/test_services/ESLab/ESLab_test_and_demo_service.html
http://wwwd3.ymparisto.fi/d3/test_services/ESLab/ESLAB_GHG_budgets.html
Web-application: MONIMET Climate Change Indicators, projected values for reference and future climate presented under the header "Terrestrial ecosystems", in the section on Maps, graphs and data in the Climatguide.fi national portal on climate change https://ilmasto-opas.fi/en/datat . Model descriptions in the Impact models- section of the Climateguide.fi
http://ilmasto-opas.fi/en/ilmastonmuutos/vaikutukset/-/artikkeli/16ba8680-eac2-4d15-be31-8bd390904f8f/ekosysteemimallinnus.html
Data download: SYKE avoin tieto web pages
http://www.syke.fi/fi-FI/Avoin_tieto/Paikkatietoaineistot#F
in english: http://www.syke.fi/en-US/Open_information/Spatial_datasets#P
Metadata: Kasvukauden alku havumetsissä 2001-2016 / Start of vegetation period in coniferous forest, 2001-2016
http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid={31F4499F-5F0F-4500-967B-6C275082A3AD}
Kasvukauden alku lehtimetsissä 2001-2016 /Start of vegetation period in deciduous species, 2001-2016
http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid=%7B45D3F820-DA63-47FE-8ABA-53047CDCEF37%7D
Kasvukauden alku -karttapalvelu / Vegetation phenology maps - web map application
http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid=%7B858F5579-7817-4992-8DD4-7F9046E58206%7D
ESLAB: Information on the contribution of natural ecosystems to greenhouse gas sources and sinks in Finnish municipalities.
http://metatieto.ymparisto.fi:8080/geoportal/catalog/search/resource/details.page?uuid=%7BC2E9C9BB-0B3A-407C-B54C-5FECB2010F95%7D

Poster and oral presentations:

- Poster of MONIMET project presented, by Tuula Aalto, at Global Vegetation Monitoring and Modeling International Conference, February 3-7, 2014, Avignon-France, http://monimet.fmi.fi/publications/MONIMET_Poster_final.jpg .
- Poster of MONIMET project presented, by Ali Nadir Arslan, at the Arctic Science Summit Week (ASSW) and Arctic Observing Summit (AOS), April 5-11, 2014, Helsinki-Finland, http://monimet.fmi.fi/publications/MONIMET_Poster_final.jpg .
- Poster of MONIMET project presented, by Tiina Markkanen, at REKLIM Conference 2014: 'Our Climate - Our Future, Regional perspectives for Global future', Oct 6-8, 2014, Berlin, Germany, http://monimet.fmi.fi/publications/MONIMET_Poster_final.jpg
http://www.reklim.de/fileadmin/user_upload/redakteur/home/Aktuelles_und_Aktivitaeten/REKLIM_Veranstaltungen/Berlin-2014/sessions/Webversion-ges.pdf.
- Markkanen et. al., Evaluation of one-way coupling between a regional climate model and a land surface model. Poster session presented at: Global Vegetation Monitoring and Modeling International Conference, 2014 Feb 3-7; Avignon, France.

- Oral presentation of MONIMET project, EU Life+ MONIMET project by Ali Nadir Arslan, at LIFE Platform Meeting May 14 – 15, 2014, Norwich, UK. http://monimet.fmi.fi/publications/Life_platform_Norwich_Arslan.pdf.

- Oral presentation of MONIMET project, Carbon Cycle Studies in Northern Region with a land surface model by Tiina Markkanen, at 2nd CRAICC - PEEX workshop, February 9-10, 2015, Helsinki, Finland, https://www.atm.helsinki.fi/peex/index.php/2nd-craicc-peex-workshop .
- The survey on public awareness, conducted by Action C.2, was presented to the OpenNESS (http://www.openness-project.eu/) stakeholder meeting in Hämeenlinna on 9.6.2014. OpenNESS stakeholders were invited to participate in the survey since they represent the Vanajavesi region which is also key area for MONIMET project.
- Presentation, Satellite-observed start of vegetation active season in Finland and comparison with estimated from biosphere model. Presentation by Kristin Böttcher, at Geoinformatics research days, May 20-21, 2015, Helsinki, Finland, http://fiuginet.fi/wp-content/uploads/2015/05/Böttcher_Gitutkimuspaivat_2015.pdf.
- Presentation, Mapping carbon budgets in forested landscapes by Anu Akujärvi, at IUFRO Landscape Ecology, August 23-30, 2015, Tartu, Estonia http://iufrole2015.to.ee/ .
- Holmberg, M., Aalto, T., Akujärvi, A., Arslan A.N., Liski, J., Markkanen, T., Mäkelä, A., Peltoniemi, M., Rankinen, K. 2015. Vulnerability to climate-induced changes in ecosystem services of boreal forests. Presented by A.N. Arslan in poster session at GEO-XII Plenary & Mexico City Ministerial Summit, 2015 November 11 - 13, Mexico City, Mexico. Presented by K. Rankinen in poster session at European Geosciences Union General Assembly 2016, 2016 April 18 - 22; Vienna, Austria.
- Peltoniemi et. al., Phenology cameras observing boreal ecosystems of Finland. Poster session presented at European Geosciences Union General Assembly 2016, 2016 April 18 - 22; Vienna, Austria.
- Rankinen, K., Holmberg, M., Markkanen, T. 2016. Vulnerability of boreal zone for increased nitrogen loading due to climate change. Presented by K. Rankinen in poster session at European Geosciences Union General Assembly 2016, 2016 April 18 - 22; Vienna, Austria.
- Böttcher, K., Peltoniemi, M., Tanis, M.C., Härmä, P., Arslan, A. N. 2016. Comparison of webcamera and satellite observations on vegetation phenology in Finland. Presented by Kristin Böttcher in the poster session at 19th AGILE International Conference on Geographic Information Science, 2016 June 14 - 17; Helsinki Finland. http://monimet.fmi.fi/publications/Poster_Bottcher_A0_MONIMET_14062016_FINAL_lowres.pdf
- Rankinen, K., Akujärvi, A., Holmberg, M., Markkanen, T., and Peltoniemi, M. 2017. Assessing vulnerability to climate-induced changes in ecosystem services of boreal croplands and forests. Presented by K. Rankinen in poster session at European Geosciences Union General Assembly 2017, 2017 April 23 - 28; Vienna, Austria.
- Böttcher, K., Aurela, M., Rautiainen, K., Walther, S., Arslan, A.N. 2017. Satellite-observed phenology of boreal coniferous forests. Presented by Kristin Böttcher at the poster session of the 7th ESA Advanced training course on land remote sensing, 2017 September 4 – 9, Gödöllö, Hungary, http://eoscience.esa.int/landtraining2017/page_posters.php,
  Poster session presented at EU Life+ MONIMET(LIFE12 ENV/FI/000409) Final Stakeholder Workshop on "Climate Change Indicators and Vulnerability of Boreal Zone Ecosystems", 2017 November 2; Helsinki Finland.
- Presentation, Automatic digital image processing system for multiple camera networks. Presention by A. N. Arslan at Remote Sensing of the Cryosphere: Past – Present – Future, 2017 February 7 – 9, Bern, Switzerland.
- Presentation, Introduction of a new toolbox for processing digital images from multiple camera networks: FMIPROT. Presented by C. M. Tanis at European Geosciences Union General Assembly 2017, 2017 April 23 - 28; Vienna, Austria.

- Presentation, MONIMET Webcam Network, Database and Toolbox for Monitoring Phenology and Snow Cover. Presention by A. N. Arslan at International Conference: Snow - An Ecological Phenomena, 2017 September 19 – 20, Smolenice, Slovakia.
- Tanis, C. M., Arslan, A. N., 2018. An automated image processing system for multiple camera networks. Presented by C. M. Tanis at the poster session of Remote Sensing Days 2018, 2018 May 16 – 17, Helsinki. Finland.

Scientific publications:

1. Menard et al. (2015) Effects of meteorological and ancillary data, temporal averaging and evaluation methods on model performance and uncertainty in a land surface model, Journal of Hydrometeorology, e-View, doi: http://dx.doi.org/10.1175/JHM-D-15-0013.1, (http://journals.ametsoc.org/doi/abs/10.1175/JHM-D-15-0013.1) .
2. Holmberg, M., Akujärvi, A., Anttila, S., Arvola, L., Bergström, I., Böttcher, K., Feng, X., Forsius, M., Huttunen, I., Huttunen, M., Laine, Y., Lehtonen, H., Liski, J., Mononen, L., Rankinen, K., Repo, A., Piirainen, V., Vanhala, P., Vihervaara, P. 2015. ESLab application to a boreal watershed in southern Finland - preparing for a virtual research environment of ecosystem services. Landscape Ecology 30: 561-577 doi:10.1007/s10980-014-0122-z.
3. Akujärvi, Anu, Aleksi Lehtonen, and Jari Liski. 2016. Ecosystem services of boreal forests-Carbon budget mapping at high resolution. Journal of Environmental Management 181: 498-514.
4. Forsius, M., Akujärvi, A., Mattsson, T., Holmberg, M., Punttila, P., Posch, M., Liski, J., Repo, A., Virkkala, R. Vihervaara, P. 2016. Modelling impacts of forest bioenergy use on ecosystem sustainability: Lammi LTER region, southern Finland. Ecological Indicators 65: 66-75. http://dx.doi.org/10.1016/j.ecolind.2015.11.032
5. Vanhala, P., Bergström, I., Haaspuro, T., Kortelainen, P., Holmberg, M., Forsius, M. 2016. Boreal forests can have a remarkable role in reducing greenhouse gas emissions locally: Land use-related and anthropogenic greenhouse gas emissions and sinks at the municipal level. Science of the Total Environment 557-558:51-57. http://dx.doi.org/10.1016/j.scitotenv.2016.03.040.
6. Böttcher, K., Markkanen, T.,Thum, T., Aalto, T., Aurela, M., Reick, C.H., Kolari, P., Arslan, A.N., Pulliainen, J. 2016. Evaluating Biosphere Model Estimates of the Start of the Vegetation Active Season in Boreal Forests by Satellite Observations. Remote Sensing, 8, 580, DOI:10.3390/rs8070580.
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9. Y. Gao, T. Markkanen, M. Aurela, I. Mammarella, T. Thum, A. Tsuruta, H. Yang, and T. Aalto. Response of water use efficiency to summer drought in boreal Scots pine forests in Finland. Biogeosciences, 14, 4409-4422, 2017.
10. Raivonen, M., Smolander, S., Backman, L., Susiluoto, J., Aalto, T., Markkanen, T., Mäkelä, J., Rinne, J., Peltola, O., Aurela, M., Tomasic, M., Li, X., Larmola, T., Juutinen, S., Tuittila, E.-S., Heimann, M., Sevanto, S., Kleinen, T., Brovkin, V., and Vesala, T.: HIMMELI v1.0: HelsinkI Model of MEthane buiLd-up and emIssion for peatlands, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2017-52, 2017.
11. Susiluoto, J., Raivonen, M., Backman, L., Laine, M., Mäkelä, J., Peltola, O., Vesala, T., and Aalto, T.: Calibrating the sqHIMMELI v1.0 a wetland methane emission model with hierarchical modeling

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19. Mikko Peltoniemi, et all, Networked web-cameras monitor congruent seasonal development of birches with phenological field observations, Agricultural and Forest Meteorology, Volume 249, 15 February 2018, Pages 335-347, https://doi.org/10.1016/j.agrformet.2017.10.008
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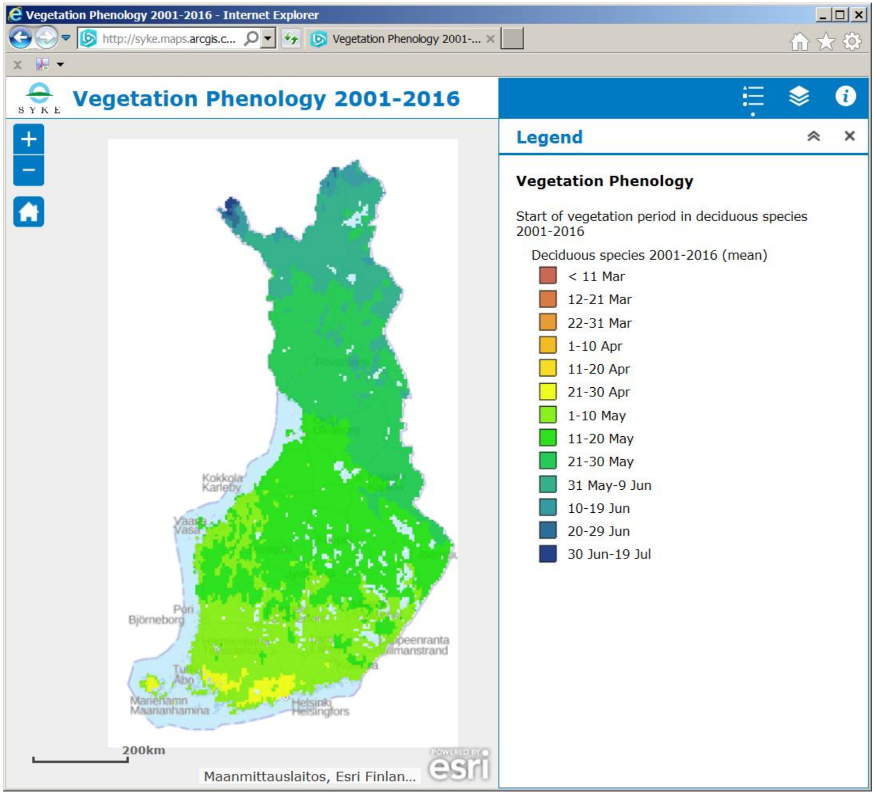
In addition to scientific publications and poster presentation at conferences, SYKE disseminated project results through web map applications and made Monimet data sets freely available. One related achievement was the opening of satellite data sets (action B2) to the general public. Opening the datasets was done in accordance to SYKE's new research data policy, which aims to enhance the openness and effectiveness of research data by enabling the further use of research results by other researchers and anybody interested. The datasets can be used under Creative Commons By 4.0 International license (https://creativecommons.org/licenses/by/4.0/deed.en).

The satellite datasets on the start of the vegetation active period for the period 2001-2016 were published with an open standard (OGC) Web Map Service (WMS) interface. The web map services enable users to view the data directly from the source and they can be utilized in any web map application or GIS software that can make use of standard interfaces. For browsing and viewing of the yearly maps, a simple web map application was created with ArcGIS online. Links to relevant publications, metadata and the site for downloading the data are also provided in the web map application. The datasets can be downloaded at SYKE's open data web service as geotiff files. In addition, the metadata descriptions are available for both the datasets as well as for the web map application, providing more information about datasets and the application thus supporting the further open usage of datasets.



Vegetation Phenology

Start of vegetation period in deciduous species 2001-2016

Deciduous species 2001-2016 (mean)

- < 11 Mar
- 12-21 Mar
- 22-31 Mar
- 1-10 Apr
- 11-20 Apr
- 21-30 Apr
- 1-10 May
- 11-20 May
- 21-30 May
- 31 May-9 Jun
- 10-19 Jun
- 20-29 Jun
- 30 Jun-19 Jul

Figure 28: Screenshot from the web map application showing the maps of the start of the vegetation active period.

SYKE developed in the Envibase project (http://www.ymparisto.fi/envibase) a web-application to present information on the contribution of forests and other natural ecosystems to greenhouse gas sources and sinks in Finnish municipalities under current conditions (ESLab Municipal GHG). The development was supported by the MONIMET project, contributing results from Action B.7. The web-application allows e.g. a comparison between the role of forests and agricultural land, wetlands and lakes. It is based on official statistics corresponding to the national reporting of greenhouse gases. For forest GHG balances, also the dynamic soil model Yasso is applied.

SYKE contributed to the presentation of the MONIMET climate change indicators in the national portal on climate change issues, Climateguide.fi. The new variables are presented under the header Terrestrial ecosystems, and they appear in the section on Maps, Graphs and Data of the Climateguide.fi. Seven variables are presented: Gross Primary Production; Net Ecosystem Exchange; Total Ecosystem Respiration; Length, Start and End of Vegetation Active Period; Stem growth. For each variable, results obtained as model simulated projections are presented as gridded maps for the reference period 1981 – 2010, and three future periods: 2011– 2040; 2041– 2070 and 2071– 2100. For stem growth, only CROBAS results are presented, for the other variables both JSBACH and CROBAS were used to simulate the results.

Regional statistics are given for each variable on the NUTS3-level (maakunta). The models used to simulate the climate change indicators are presented under ‘Ecosystem models’ under the heading ‘Impact models’ in the section ‘Impacts’ in ‘Climate Change Explained’ of the Climateguide.fi. The details are described in Technical Annex B7.1 Contribution to Climateguide.

4.3 Evaluation of Project Implementation

We concluded that cameras could be used even more versatile manner to support various studies associated with ecosystem phenology than previously considered, and they could provide more explanations to the observed seasonal carbon dynamics of ecosystems. Cameras are also useful and informative for conifer phenology monitoring, which was not clear at the beginning of the project. In the following years, we see that more information is needed about the mutual timing of phenology of aboveground and belowground processes of vegetation, and that combined imaging of these processes could reveal new information about within seasonal controls of soil carbon fluxes. Based on our experiences in MONIMET, we also expect that the ecosystem camera monitoring benefits from the recent quick development of multi-use microcontrollers, minicomputers, cameras and other sensors that allow the collection of images and data with moderate effort and low cost. We expect that the technological improvements available already today and more so in the near future, will open new avenues for image-based ecosystem monitoring, e.g. in the form of hyperspectral and low cost multispectral sensors.

We provided open access to recorded image material from camera sites in 2014-2016, and a free tool, Finnish Meteorological Institute image PROcessing Toolbox (FMIPROT), for easy analyses of and extraction of colour information and snow cover from the image time series.

The accuracy of the satellite products was assessed against in situ observations. This evaluation included the following products:

- Daily FSC with a spatial resolution of 0.005° x 0.005° derived from MODIS data (**SYKE**),
- Yearly maps of the MoD with spatial resolution of 0.005° x 0.005° (**SYKE**),
- Yearly maps of the start of the vegetation active period in deciduous forest with spatial resolution of 0.05° x 0.05° (**SYKE**),
- Soil freeze and thaw product determined from SMOS with a spatial resolution of 25 km x 25 km (**FMI**),
- Sample products of the LAI at a resolution of 0.005° x 0.005° derived from the RSR (**FMI**).

Overall the satellite products compared well to in situ observations. The detailed results of this evaluation were presented in Action B.2 deliverable: Report on data comparison (08/03/2016) and updated in the deliverable: Report on EO products and comparison with in situ data (28/04/2017). There was a small delay in the first data comparison report due to needed re-processing of the MODIS time series as described above.

We integrated new components in the models (JSBACH and PREBAS) and the models were parameterised and optimised with new data provided by the consortium. As a result, we were able to better estimate the northern land ecosystem responses to environmental drivers. In PREBAS we implemented also the management practices commonly applied to Finnish forests. By means of the analyses, we were also able to identify the weaknesses of the models. The works needs to be continued regarding e.g. vegetation phenology, non-forest PFTs (e.g. crops, wetland vegetation), peatland hydrology, peat accumulation and methane emissions, respiration components. The autotrophic respiration of PREBAS needs to be improved in the light of new data and a more comprehensive test of NEE flux needs to be carried out in other to draw more conclusive results for the country scale. In the calibration process we used modern computational techniques (i.e., Bayesian statistics) that allow to quantify the uncertainty of model predictions.

We produced projections of specified climate change indicators in the form of maps and graphs. A lot of uncertainty is included in all these indicator projections, originating in the driving variables, parameters and structural assumptions of the models used. The driver uncertainties, furthermore, originate in similar uncertainties of other models, i.e., those that were used to create the climate change scenarios that are inputs to vegetation models.

We found that the uncertainty about photosynthetic production and variables related to phenology were very similar between models. The uncertainty of evapotranspiration was larger than that of photosynthesis in all models. However, the uncertainty of net ecosystem exchange (NEE) had different trends in different models, although both models used the same soil carbon submodel. This suggests that the different descriptions of above-ground biomass and its changes are significant in understanding NEE and need to be focused on future research.

Projected future values of climate change indicators were interpreted in terms of provision of ecosystem services and vulnerability was studied as the risk of decreasing provision of ecosystem services in future climate conditions.

The climate change indicators were derived for all of mainland Finland. Regional statistics for the countrywide indicators were calculated for four time periods (1981–2010, 2011–2040, 2041–2070, 2071–2011) and three regions. The regions follow the division of forest vegetation prepared by the environmental administration. The southern region covers the hemi- and southern boreal regions, the central region corresponds to the central boreal region, and the northern region is the northern boreal region.

The climate change indicators were published in the national portal on climate change issues, **Climateguide.fi**. The new variables are presented under the header Terrestrial ecosystems, and they appear in the section on Maps, Graphs and Data of the Climateguide.fi. Seven variables were presented: Gross Primary Production; Net Ecosystem Exchange; Total Ecosystem Respiration; Length, Start and End of Vegetation Active Period; Stem growth. The indicators are presented under the header Terrestrial ecosystems, and they appear in the section on Maps, Graphs and Data of the Climateguide.fi. For each variable, results obtained as model simulated projections were presented as gridded maps for the reference period 1981 – 2010, and three future periods: 2011– 2040; 2041– 2070 and 2071– 2100. For stem growth, only CROBAS results were presented, for the other variables both JSBACH and CROBAS were used to simulate the results. Climate change indicators related to nitrogen cycling were derived with the INCA-N model. Regional statistics were given for each variable on the NUTS3-level (maakunta). The models used to simulate the climate change indicators were presented under 'Ecosystem models' under the heading 'Impact models' in the section 'Impacts' in 'Climate Change Explained' of the Climateguide.fi.

Two web surveys of public awareness were conducted. The views of Finnish citizens were monitored with a web-based survey, first conducted in the period June to August 2014 (76 respondents), repeated in the period February to April 2017 (652 respondents).

Table 3: Summary on evaluation of tasks of MONIMET project

Task	Foreseen in the revised proposal	Achieved	Evaluation
Website of the project	YES	YES	MONIMET website successfully implemented and continuously being updated
Purchased test cameras	YES	YES	Purchasing cameras successfully completed
1st survey on public awareness	YES	YES	Survey successfully conducted and the results of the survey were analysed
New vegetation indices implemented in processing system	YES	YES	Successfully implemented

EO products processed covering 16 years	YES	YES	Daily time series of Snow Water Equivalent (SWE) (1979-2016), Fractional Snow Cover (FSC, often referred to as SCA) (2001-2016), soil freeze (2010-2016) and vegetation indices (2001-2016) are processes.
Inception report	YES	YES	SUMBITTED
Installation of test cameras	YES	YES	Successfully installed at test sites and working successfully
First test results from stage 1 cameras	YES	YES	Analyses of first test images were completed successfully
Progress report	YES	YES	SUMBITTED
Data compilation completed	YES	YES	Ready for use
Implemented cameras (at 3-8 stage 2 sites)	YES	YES	Successfully installed at test sites and working successfully
Methodology used in evaluating the model calibration impacts	YES	YES	JSBACH land ecosystem model, PRELES photosynthesis and evapotranspiration model and CROBAS tree growth model were involved in model calibration
First results of stage 2 cameras	YES	YES	Analyses of test images from stage 2 cameras were completed successfully
Method for automated processing and extraction of phonological events	YES	YES	The development of our own methodological software to analyse images automatically was completed and will be developed continuously
Midterm report	YES	YES	SUMBITTED
	YES	YES	
Midterm/end-user consultation workshop	YES	YES	The workshop was organized successfully
Full implementation of camera network	YES	YES	All cameras planned implemented and works successfully

Model calibration accomplished and reported	YES	YES	SUBMITTED
Climate change indicators retrieved and reported	YES	YES	SUBMITTED
Assessment of uncertainty of climate change indicators	YES	YES	Uncertainties originating in the different sources were quantified and their significance was compared temporally and spatially
Vulnerability assessment completed	YES	YES	Published in the national portal on climate change issues, Climateguide.fi
2nd Survey on public awarness	YES	YES	Survey successfully conducted and the results of the survey were analysed
Final report	YES	YES	SUBMITTED

4.4 Analysis of long-term benefits

While climate change is a problem in need of global action, its effects are localised and affect regions in very different ways. Equally, certain areas exert a greater influence on the global climate and carbon balance than others, and it is this dynamic relationship that makes tackling climate change so complex. One example of such unpredictable feedback is found in the arctic and subarctic regions, where the climate is changing rapidly – and projected changes in years to come suggest a challenging for the future. Over the next century, scientists predict a mean annual temperature increase of 2-6 °C. This change will be particularly important in the boreal forest biome, which is distributed in a band around the northern sub-polar regions of Earth.

Boreal forest represents the world’s largest terrestrial biome and exerts a pronounced effect on global climate and weather systems. It is expected that, as well as enhancing annual growth in the boreal forest, climate change will simultaneously increase emissions from soil and wetland sources and alter the occurrence of events including heat waves, droughts, floods and storms. Positive and negative impacts may potentially unfold in unpredictable combinations, and these changes will occur to varying degrees and at different rates in separate areas within the boreal zone. ***A regional approach to study will therefore be essential in determining the regional and global outcomes of climate change, and suggesting possible routes towards correcting the carbon balance in long-term.***

The plan of MONIMET project was to observe climate change through the use of indicators such as water and carbon cycles and phenology – the study of plant and animal life cycles. This is also the approach used by the EU; the European Environment Agency, for example, lists more than 40 indicators of climate change based around vegetation, water and gas levels.

The first step is implementing an innovative new system for in situ monitoring: a webcam network. This new network will provide an unparalleled insight into forest ecosystem services, enabling spatially representative monitoring of vegetative processes and their change over time. ***Indeed, this work will lead to the design and harmonisation of webcam networks all over Finland and it will create continues long-term webcam monitoring system which is very important to understand climate change. This idea can be replicable in other EU countries. This work will be prior and assist future monitoring forest ecosystem***

where webcams are utilised. Provided open access to recorded image material from camera sites in 2014-2017(be updated continuously), and a free tool, Finnish Meteorological Institute image PROcessing Toolbox (FMIPROT), for easy analyses of and extraction of colour information and snow cover from the image time series will enable further studies and findings for reductions of emissions, energy or resource savings.

One of the project's most exciting aspects was its methodology. The first innovation in approach was to build wherever possible on existing monitoring mechanisms, forming new links and adding value. This involved interacting with a wide variety of stakeholders at the national and international levels, especially meta-networks. To support this effort, the project partners used of their existing relationships to throw the endeavour open to the Global Earth Observation System of Systems (GEOSS), COPERNICUS – the European Earth Observation Programme, the Integrated Carbon Observation System (ICOS) and FLUXNET, a network of regional networks integrating worldwide CO_2, water and energy flux measurements.

Accumulated data of MONIMET project in conjunction with more advanced modelling techniques to determine vulnerability maps for wetlands and boreal zones in the context of various climate situations will be used further with the project partners and other interested groups in Europe or globally . If such

maps can ultimately be created, providing a reliable and clear path towards efficient future strategies, then this would be an invaluable asset to Finland and the EU. The project's studies will also give an indication of the mitigation potential in these habitats, and an estimate of the risk of decrease in the provision of ecosystem resources such as the carbon sequestration of trees, and the nitrogen retention of soil.

5 Financial part

5.1 Costs incurred (summary by cost category and relevant comments)

Table 4: MONIMET incurred project costs

PROJECT COSTS INCURRED				
	Cost category	Budget according to the grant agreement*	Costs incurred within the project duration	%
1.	Personnel	2 318 762	2 458 311,27	106 %
2.	Travel	78 531	42 046,90	54 %
3.	External assistance	88 000	38 232,36	43 %
4.	Durables: total non-depreciated cost			
	- Infrastructure sub-tot.			
	- Equipment sub-tot.			
	- Prototypes sub-tot.			
5.	Consumables	80 000	62 004,40	78%
6.	Other costs	10 000	23 297,18	233 %
7.	Overheads	179 995	176 056,74	98 %
	TOTAL	**2 755 288**	**2 799 948,85**	102 %

As it can be seen from Table 4 there are some minor differences in some cost categories between what was planned in the grant agreement and what was spent within the project duration. Most of differences are in positive direction as spent less money in travel and consumables and external assistance cost categories without comprising of the project objectives, tasks and deliverables. As we spent less money in these categories we were able to allocate more money in personnel cost. This enabled us to allocate more personnel to work at the project. As a result of this we were able to do our task in more detailed and improve the quality of result delivered during project. Other reason for these differences is that it is very difficult to estimate these cost categories correctly for a project which lasts 4 years. Difficult to estimate amount of work needed for such a big project and a big number of tasks and actions.

5.2 Accounting system

See annexes 6.2.1, 6.2.2, 6.2.3 and 6.2.4

5.3 Partnership arrangements (if relevant)

Financial matters are led and controlled by the coordinating beneficiary, FMI. Every beneficiary including the coordinator has a responsible person for financial issues for the project. All financial related communication has been done among these persons. The coordinating beneficiary is monitoring the project budget continuously. The coordinating beneficiary is collecting financial reports from each beneficiary every 3 months. In reporting period such us midterm report, these communications are getting intensive. The financial responsible person of the coordinating beneficiary is collecting all necessary financial information from the beneficiaries for the reports. And then she is preparing final financial reports and sends to the project manager for reporting.

5.4 Auditor's report/declaration

The full Audit report is given in chapter 7.1. Below text taken from chapter 7 of the Audit report,

"On the basis of financial control, in accordance with the programme described above, we consider that we have obtained reasonable assurance that the financial report of the project no LIFE12ENV/FI/00049 title: "Climate change indicators and vulnerability of boreal zone applying innovative observation and modelling techniques, start date 2.9.2013, end date 1.9.2017, gives a true and fair view of the expenses", income and investments incurred/made by Ilmatieteen laitos (the coordinating beneficiary) and Luonnonvarakeskus, Finnish Environment Institute and Helsingin yliopisto (associated beneficiaries) in connection with the abovementioned project within the time laid down by the Commission and in accordance with the LIFE+ Programme Common Provisions, the national legislation and accounting rules.

5.5 Summary of costs per action

Costs per Action are given in Table 5. We explained the differences between cost categories in chapter 5.1 above. Table 4 shows how these differences are reflected to the different Actions. The most positive changes are done in Action B.4 and Action D.1. Action B.4 is very important Action as it deals with calibration of models used in the project. This Action required more personnel resources than planned. Action D.1 was dealt with the dissemination. As we had an opportunity to shift some money we wanted to strength the dissemination Action.

Table 5: Costs per Action

Action no.	Short name of action	1. Personnel	2. Travel and subsistence	3. External assistance	4.a Infra-structure	4.b Equipment	4.c Prototype	5. Purchase or lease of land	6. Consumables	7. Other costs	TOTAL
B1	Webcam network implementation	461 138,62	16587,65	17446,36					61445,24	19,3	556 637,17
B2	Earth observations and modelling	220 547,46							53,51	11562,33	232 163,3
B3	Observations and Data processing	229 178,48	3611,4						48,86	77,93	232 916,67
B4	Model system calibration	435 938,12								37,04	435 975,16
B5	Retrieving climate change indicators	226 571,92	833,66								227 405,58
B6	Assessment of uncertainty of climate change indicators	191 316,20									191 316,20
B7	Demonstration on ecosystem	166 806,24							91,32		166 897,56
C1	Monitoring of the impact	26 240,22									26 240,22

C2	**Monitoring socioeconic impact**	14 944,18		1116							**16 060,18**
D1	**Dissemination**	214 929,14	9866,58						365,47	11232,58	**236 393,77**
E1	**Project management**	254 878,25	2158,73							368	**257 404,98**
E2	**Auditing**			19670							**19 670**
E3	**Networking with other projects**	15 821,98	8988,88								**24 810,86**
Over-heads											**176056,74**
	TOTAL	**2 458 311,27**	**42046,900**	**38232,360**	**0**	**0**	**0**	**0**	**62004,40**	**23297,18**	**2 799 948,85**

6 Annexes

All annexes were categorized in 3 parts as follows

1. Administrative annexes
2. Technical annexes: Deliverables
3. Dissemination annexes

6.1 Administrative annexes

The partnership arrangements were organized as described in the partnership agreements, which were delivered to the Commission with the Inception report.

6.2 Technical annexes: Deliverables

All deliverables can be retrieved electronically from the project website: http://monimet.fmi.fi. The deliverables of the MONIMET project from 02/09/2013 till 01/09/2017 are given in Table 6. Many of them were sent with the Inception report , the Midterm report and the Progress report as hardcopies. **The bolded ones** will be submitted as hardcopies together with the Final report. But all deliverables will be sending in digital format with USB stick.

Table 6: Deliverables

Deliverable name	**Action**
Website of project	D.1
1st Project brochure	D.1
1st summary of flux data	B.3
Inception report	E.1
Preliminary methodology report	B.4
First data document	B.2
Summary report of LAI data	B.3
Report on climatic data processing	B.5
1st summary report of snow data	B.3

Report on methodological choices and tests with stage 1 cameras	B.1
Progress report	E.1
1st report on monitoring	C.1
2nd summary report of flux data	B.3
Summary report of albedo data	B.3
First progress report	B.4
First progress report	B.5
Carbon footprint report(first contributions)	E.1
Midterm report	E.1
2nd summary report of snow data	B.3
Midterm end-user/stakeholder consultation workshop	D.1
Report on implementation of the cameras and test results from stage 2 sites	B.1
Report on end-user/stakeholder consultation workshop	E.1
Report on data comparison	B.2
2nd report on the monitoring	C.1
3rd summary report of flux data	B.3
Second progress report	B.4
Second progress report	B.5
Report on the climate indicator variation between models	B.6
Progress report	E.1
3rd summary report of snow data	**B.3**
Third progress report	**B.5**
Report on evaluation of first results from camera network	**B.1**
3rd report on monitoring	**C.1**
4th summary report of flux data	**B.3**
4th summary report of snow data	**B.3**
Report on EO products and comparison with in situ data	**B.2**
Ecosystem provision potential and the vulnerability to climate change in Climateguide.fi	**B.7**
2nd project brochure	**D.1**
Report on networking	**E.3**
Carbon footprint report	**E.1**
Contribution to final report	**C.2**
Layman's report	**D.1**
National stakeholder seminar for presentation of overall project results and synthesis	**D.1**
Synthesis report of project results for stakeholders and policy makers (in Finnish and English)	**D.1**
Report on the range of variability due to different climate change scenarios	**B.6**
Final report	**E.1**

6.2.1 Account systems used by FMI

6.2.2 Account systems used by SYKE

6.2.3 Account systems used by LUKE

6.2.4 Account systems used by UHEL

6.3 Dissemination annexes

6.3.1 Layman's report

This report was given separately as a deliverable report of Action D.1.

6.3.2 After-LIFE communication plan

We established MONIMET network of digital cameras for automated monitoring of phenology of vegetation and snow in the boreal ecosystems of Finland. Cameras were mounted at 15 sites, each site having 1-3 cameras. Each of the cameras submits half-hourly images to an FTP server maintained by FMI. MONIMET network will be maintained by the project partners in future as well.

We provided open access to recorded image material from camera sites in 2014-2016, and tools developed to extract phenological information from the image time series during the project. The image material is accompanied by an online report. The report describes the network and our image repository (www.zenodo.org/communities/phenology_camera/), which locates in Zenodo research data storage established by EU OpenAire. We additonally share openly the image analysis methodology developed during the MONIMET project. We have already updated the open access with recorded images from camera site in 2017. These updates will be continued.

We presented a new system of multiple camera networks and a toolbox, FMIPROT, with the ease of use and applicability for analyzing digital images, and demonstrated its use for extracting vegetation indices time series. We will continue to develop this toolbox. Current development of FMIPROT includes processing image time series from camera networks for extracting fractional snow cover.
Future developments of FMIPROT that are planned include (1) to develop support for other image types, such as earth observation data (e.g. Sentinel-2, Sentinel-3, Landsat) with multiple channels (2) to design more user-friendly GUI (3) to implement some comparison tools for automatic validation by comparing the data extracted from webcams to other data sources (4) to implement more algorithms for analyzing and post processing digital images (5) scheduled tasks for operational monitoring. Those features will grant the extension of automated processing of images from multiple camera networks for operational data extraction and validation of various environmental parameters, which are very important for different applications:

- Monitoring land cover change for environmental monitoring
- Agricultural applications, such as crop monitoring and management to help food security
- Detailed vegetation and forest monitoring
- Observation of coastal zones (marine environmental monitoring, coastal zone mapping)
- Inland water monitoring
- Snow cover monitoring

- Flood mapping and management (risk analysis, loss assessment, and disaster management during floods)
- Logistic services for municipalities and public authorities
- Traffic security (road conditions, visibility of traffic signs)

We would like to use MONIMET camera network with FMIPROT for operational monitoring in future. The primary results are framed into the camera pages on MONIMET website, e.g. http://monimet.fmi.fi/?page=Cameras&camid=Hyytiala_Pine_Crown. This work will be continued.

We integrated new components in the models (JSBACH and PREBAS) and the models were parameterised and optimised with new data provided by the consortium. As a result, we were able to better estimate the northern land ecosystem responses to environmental drivers. In PREBAS we implemented also the management practices commonly applied to Finnish forests. By means of the analyses, we were also able to identify the weaknesses of the models. The works will continue on vegetation phenology, non-forest PFTs (e.g. crops, wetland vegetation), peatland hydrology, peat accumulation and methane emissions, respiration components. The autotrophic respiration of PREBAS will be improved in the light of new data and a more comprehensive test of NEE flux needs to be carried out in other to draw more conclusive results for the country scale.

The climate change indicators were published in the national portal on climate change issues, Climateguide.fi. These indicators will be updated in future.

All work conducted and developed models will be continued by partners at other current and possible future projects. There will be a EU Life+ project proposal based on the established MONIMET camera network and developed toolbox FMIPROT.

Partners will continue on writing scientific papers based on the data, model and methods of the MONIMET project.

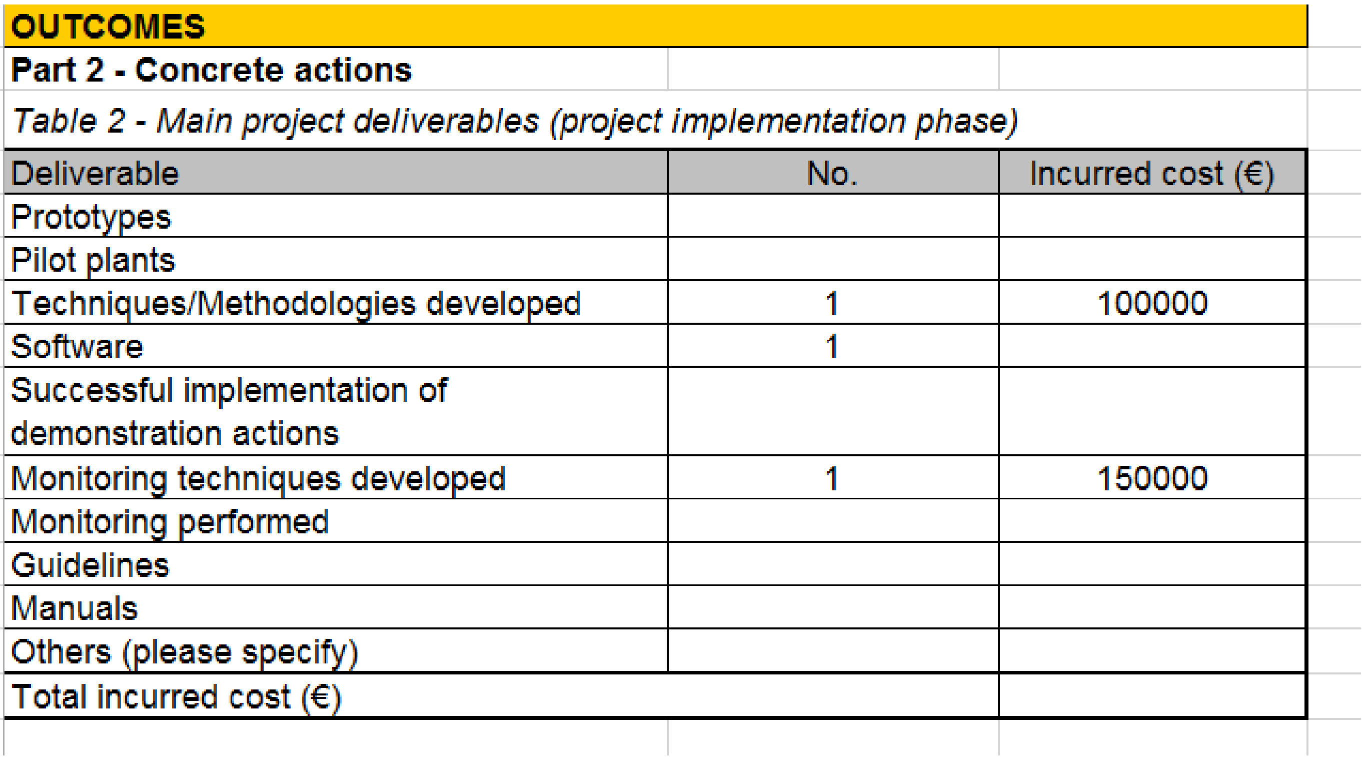
MONIMET webpage-monimet.fmi.fi will be continued by continuously updating.

6.3.3 Other dissemination annexes

List of all dissemination of the MONIMET project is given in chapter 4.2.2 and they are accessible through MONIMET webpage: monimet.fmi.fi

6.3.4 Final table of indicators

Monimet project is based on the results of many years of scientific research in the participating institutes. In the inception report the plan of project outcome indicators were given. Here below we give final project outcome indicators in the below tables.



OUTCOMES

Part 2 - Concrete actions

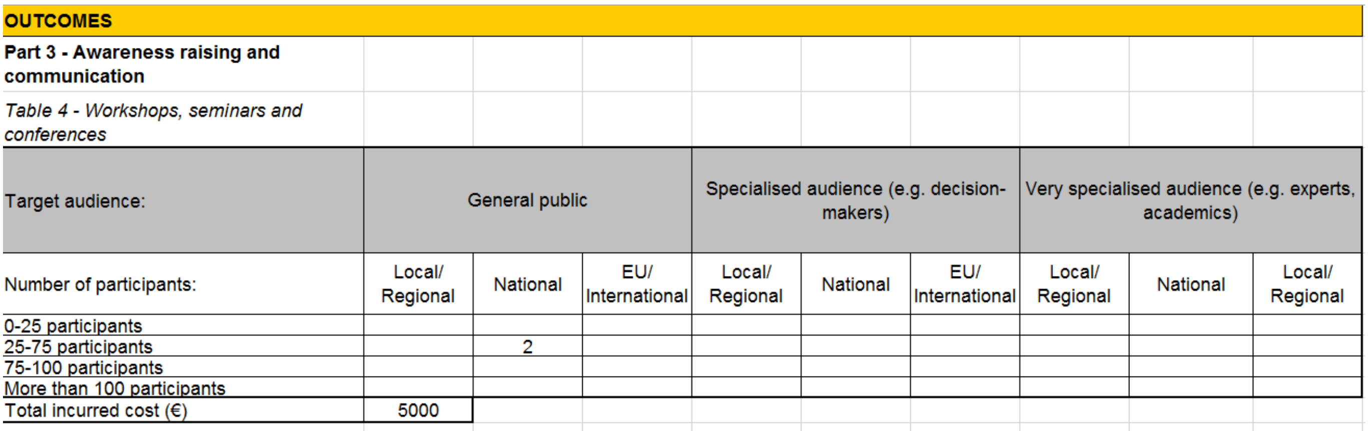
Table 2 - Main project deliverables (project implementation phase)

Deliverable	No.	Incurred cost (€)
Prototypes		
Pilot plants		
Techniques/Methodologies developed	1	100000
Software	1	
Successful implementation of demonstration actions		
Monitoring techniques developed	1	150000
Monitoring performed		
Guidelines		
Manuals		
Others (please specify)		
Total incurred cost (€)		

A real-time monitoring system for the phenology of trees and snow by means of an automated camera system with the aim of integrating these observations to satellite images and a climate impact modelling system was developed. In the project we also developed a methodology for automated processing and extraction of phonological events.

We have also developed FMIPROT toolbox (http://fmiprot.fmi.fi).

There were not dedicated planned training activities in the Monimet project. The end-users and stakeholders of Monimet products had received information through the two workshops that were organised during the project (midterm and dissemination workshops).



OUTCOMES

Part 3 - Awareness raising and communication

Table 4 - Workshops, seminars and conferences

Target audience:	General public			Specialised audience (e.g. decision-makers)			Very specialised audience (e.g. experts, academics)		
Number of participants:	Local/ Regional	National	EU/ International	Local/ Regional	National	EU/ International	Local/ Regional	National	Local/ Regional
0-25 participants									
25-75 participants		2							
75-100 participants									
More than 100 participants									
Total incurred cost (€)	5000								

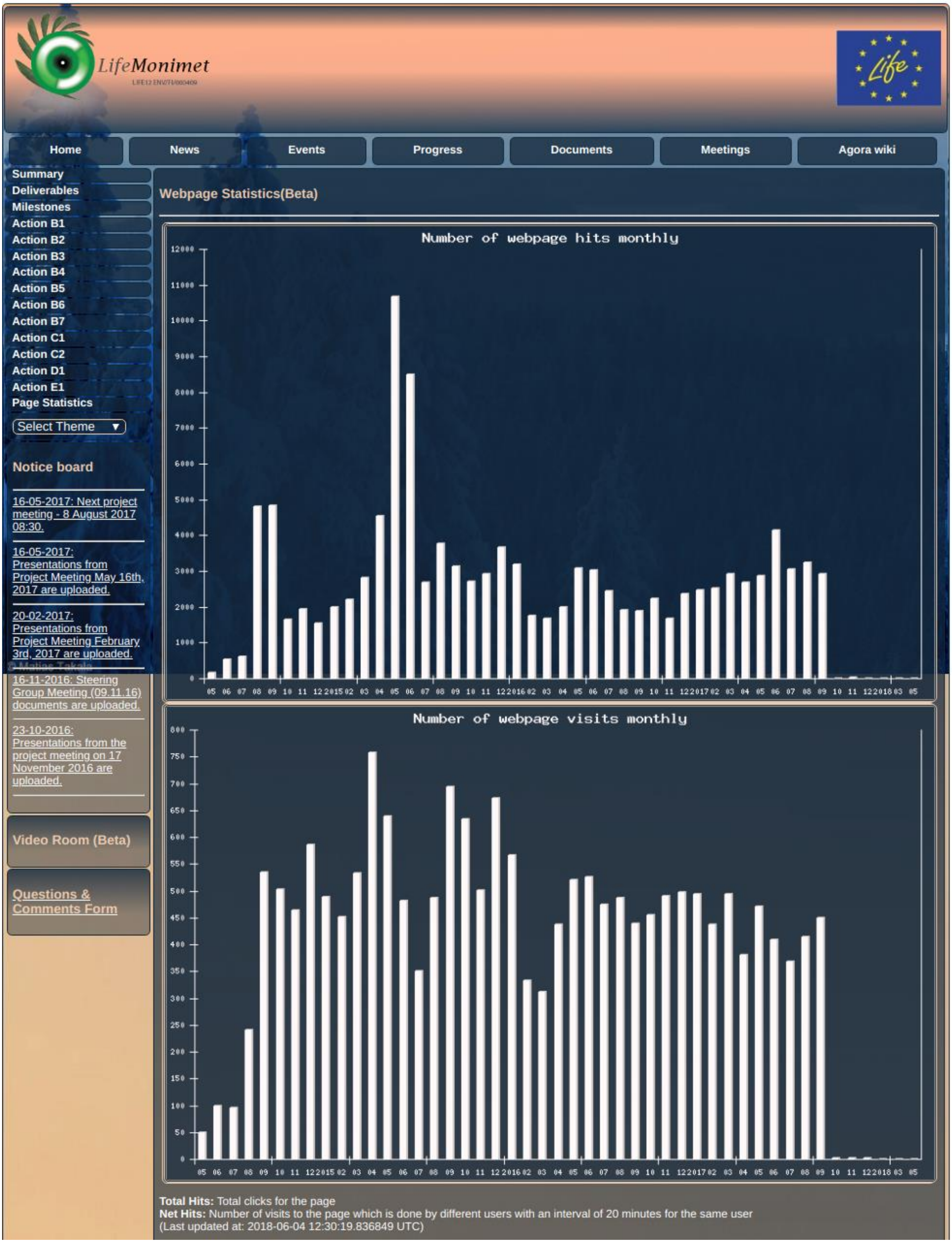
Table 5 - Media and other communication and dissemination work

Type of media	No.
Project website: average number of visitors per month	50
Press releases made by the project	
General public article in national press	
General public article in local press	
Specialised press article	
Internet article	
TV news/reportage	
Radio news/reportage	
Film produced	
Film played on TV	
Film presented in events/festivals	
Exhibitions attended	
Information centre/Information kiosk	
Project notice boards	4
Other (please specify)	
Total incurred cost (€)	

Table 6 - Publications

Type of publication	No. published	No. of copies	Languages
Layman's report	1	200	English
Manuals			
Leaflets			
Brochures	2	200	English
Posters	4		English
Books			
Technical publications	24		English
Other (please specify)			
Total incurred cost (€)			

We monitored the MONIMET webpage from the beginning (http://monimet.fmi.fi) Below it can be seen the statistics below



Webpage Statistics(Beta)

Notice board

16-05-2017: Next project meeting - 8 August 2017 08:30.

16-05-2017: Presentations from Project Meeting May 16th, 2017 are uploaded.

20-02-2017: Presentations from Project Meeting February 3rd, 2017 are uploaded.

16-11-2016: Steering Group Meeting (09.11.16) documents are uploaded.

23-10-2016: Presentations from the project meeting on 17 November 2016 are uploaded.

Total Hits: Total clicks for the page
Net Hits: Number of visits to the page which is done by different users with an interval of 20 minutes for the same user
(Last updated at: 2018-06-04 12:30:19.836849 UTC)

We also implemented Google analytics in June 2016. The statistics are given below.

Users	New Users	Sessions	Number of Sessions per User	Page Views	Pages/Session
2,032	2,032	4,198	2.07	16,156	3.85

Avg. Session Duration	Bounce Rate
00:02:23	41.42%

In both monitoring showed that more than 50 persons (target number at the beginning) have visited the webpage monthly.

7 Financial report and annexes

Financial reports were given in annex as follow

FMI:
1. FMI Financial Reports 02.09.2013-01.09.2017
2. Standard payment request
3. Financial statement of the participant
4. Consolidated cost statement of the project

SYKE:
1. SYKE Financial Reports 02.09.2013-01.09.2017
2. Financial statement of the participant

LUKE:
1. LUKE Financial Reports 02.09.2013-01.09.2017
2. Financial statement of the participant

UHEL:
1. UHEL Financial Reports 02.09.2013-01.09.2017
2. Financial statement of the participant

7.1 Independent Audit Report