LIFE07 ENV/FIN/000133

FINAL Report

Covering the project activities from 01/01/2009 to 31/12/2012

Reporting Date

07/05/2013

LIFE+ PROJECT NAME or Acronym

Monitoring and assessment of carbon balance related phenomena in Finland and northern Eurasia

Data Project

Project location	Helsinki
Project start date:	01/01/2009
Project end date:	31/12/2012
Total Project duration (in months)	48 months
Total budget	2155627 €
EC contribution:	1046759 €
(%) of total costs	
(%) of eligible costs	49.09

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List of abbreviations

AMSR-E	Advanced Microwave Scanning Radiometer – Earth Observing System
ASCAT	Advanced Scatterometer
ASD	Analytical Spectral Device
AVHRR	Advanced Very High Resolution Radiometer onboard NOAA-satellite
CAL-VAL	CALibration VALidation
CEA-LSCE	Commissariat à l'énergie atomique – Laboratoire des Sciences du Climat et de l'Environnement
CO2	Carbon dioxide
CORINE	Coordination of information on the environment
CTE	Carbon Tracker Europe
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ENVISAT	Environmental Satellite
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FGS	Flux Growing Season
FMI	Finnish Meteorological Institute
GAW	Global Atmospheric Watch
GHG	Greenhouse Gases
GMES	Global Monitoring of Environment and Security
GPP	Gross Primary Production
GSE	GMES Services Element
GSSD	Growing Season Start Date
IRS	Indian Research Satellite
JSBACH	Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg
LISS	Low Imaging Sensing Satellite
MERIS	Medium Resolution Imaging Spectrometer
METLA	Finnish abbreviation for Finnish Forest Research Institute
mmu	minimum mapping unit
MODIS	MODerate-resolution Imaging Spectroradiometer

MPI-M	Max Planck Institute for Meteorology
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NEE	Net Ecosystem CO_2 Exchange
NOAA	National Oceanic and Atmospheric Administration
NRT	Near-Real-Time
QuikSCAT	Quick Scatterometer
REMO	Regional Climate Model of MPI
SCA	Snow Covered Area
SMMR	Scanning Multichannel Microwave Radiometer
SPOT	Système Pour l'Observation de la Terre
SSM/I	Special Sensor Microwave Imager
SWE	Snow Water Equivalent
SYKE	Suomen ympäristökeskus (Finnish Environmental Institute)
UNFCCC	United Nations Framework Convention on Climate Change
TER	Total ecosystem respiration includes both autotrophic respiration due to growth and maintenance of living plants and heterotrophic respiration due to decomposition of organic material

1 Executive summary

In SnowCarbo project, net carbon balance maps was provided for national and international organizations and policy makers responsible for 1) climate change investigations 2) inventory of greenhouse gases and 3) international agreements, their implementation and reporting in Finland. The primary stakeholders of the project in Finland include:

- Ministry of Transport and Communications (governing body of FMI)
  - CO_2 net balance information highly relevant for future traffic regulations
- Ministry of Environment (governing body of SYKE)
  - Project results highly relevant for the implementation of national environmental policy
- Statistics Finland
  - Greenhouse gases (GHG) reporting
- Ministry of Agriculture and Forestry
  - CO_2 net balance of forest holdings highly relevant for the national forestry policy, future regulations, and the development of environmentally sustainable forestry industry.
- Finnish Forest Research Institute (METLA)
  - Methods for calculation of GHG balances of forests
- Agrifood Research Finland (MTT)
  - Methods for calculation of GHG balances of agricultural land

For the European Comission the project results are important concerning Green Paper follow up (adaption policy development) and European Climate Change Programme II (ECCP). The products of SnowCarbo project will also support a number of international environmental monitoring activities, such as Arctic Monitoring and Assessment Programme (AMAP) and Sustained Arctic Observing Networks (SAON) initiative of the Arctic Council, and Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO).

In SnowCarbo project a new innovative approach was implemented and demonstrated. A new innovative approach to net carbon balance mapping is based on a combination of different information sources describing snow evolution, phenology, land cover, CO_2 fluxes and concentrations. The information sources include in situ observations and Earth observation (satellite) data. Dedicated models for different land cover classes were applied to describe carbon uptake and respiration.

List of SnowCarbo project key objectives:

- To provide accurate map information on net carbon balance in boreal forest zone in order to assess the real levels of carbon sinks and sources for future climate controlling treaties and policy making

- To provide and demonstrate methodologies to extract anthropogenic influence from natural background CO_2 sources in order to enable the development new legislative means for CO_2 regulation. These methodologies include the use of Earth observation data as a comprehensive data source (together with models and in situ data).

- To provide information for the future needs required in situ, Earth observation and land cover data needs of continental scale carbon balance mapping/monitoring (focusing on northern areas)

1.1 Key deliverables and outputs

1.1.1 A novel earth observation satellite data-aided modelling tool for the monitoring of annual carbon balance

A modelling framework predicting present day land ecosystem CO_2 balance for Nordic countries and surroundings (i.e. for Northern Europe) was developed. The modelling framework consists of regional climate model REMO and land surface model JSBACH accounting for photosynthesis. In the framework of this project a method of coupling between the climate model REMO and the land surface model JSBACH was implemented and tested: 1) the first step is a REMO-run to determine fine scale regional climatic variables such as air temperature, surface pressure, radiation and precipitation; 2) in the second step the JSBACH model is forced with the climatic variables to produce the land vegetation CO_2 exchange rate; and 3) as final step the exchange rate together with mapped data for anthropogenic and ocean CO_2 sources the REMO is driven in a version distributing the tracers to the atmosphere inside the model domain. Both REMO and JSBACH use model specific surface parameter fields (i.e. surface maps or surface libraries) that were modified with data from various actions of this project.

1.1.2 Digital carbon balance maps covering years from 2001 to 2009

Digital carbon balance maps covering years from 2001 to 2009 were produced. The maps of highest degree of detail have been produced with the land cover based on the National Corine data. Deviating from the original listing of the expected results, instead of applying three different resolutions for results, the CO_2 balances, together with other model outputs including all relevant energy balance terms, were calculated for the grid resolution of 0.167 degrees. The time span of the simulated results expands from 2001 to 2009 instead of end 2011. This is due to lack of processes boundary data for the REMO model. For the same reason the scenarios were excluded from the end results. However, the implemented modelling framework provides a tool for modelling CO_2 balance for any period of time there is a suitable climatological boundary data available – either for hind casts or for forecasts. The condition of the validity of the land cover information in the future, that was brought up in the original work plan, can be estimated with models taking into account the land use related policies. Nevertheless, as the impact of such policies is visible with considerable delay, the applicability of the land cover maps utilised in this work will extend to at least a decade onwards from the present. The raw data from the model is given in the rotated latitude-longitude grid with resolution of 0.167 degrees. The time resolution of the raw data is one hour and it comprise all the predicted variables of JSBACH model and a wide selection of 2D and 3D meteorological variables predicted by REMO. The carbon balance related JSBACH output fields, such as GPP, NPP and soil respiration have been stored in daily resolution in the original rotated grid. These files are available for the scientific community by demand. For public, monthly and yearly the CO_2 balance mapped data have been transformed into non-rotated latitude-longitude grid. The data is accessible via Erdas Apollo database. Furthermore, a table of monthly and yearly CO_2 balance values for Finland have been produced for comparison with the National GHG inventories.

1.1.3 Demonstration of carbon balance assessment methodology

Sensitivity analysis among the different modelling schemes and comparison to observation data of different climate related variables are conducted three different evaluation approaches to be applied in the assessment of the performance of the modelling framework. These are 1) model intra-comparison that is performed among the results achieved with different boundary conditions (e.g. various land cover data) by a single model in a certain running mode; 2) model inter-comparison that is comparison between the common variables predicted independently by both REMO and JSBACH and 3) comparison to the observations. The evaluation of the modelling system was performed at CAL-VAL site as well as at regional levels. At site level there is reference data available that represents identically many of the variables predicted by the modelling framework. Consequently, to some degree the model could be calibrated to better produce the seasonality and basic level of both GPP and TER, who are the two large terms contributing to CO_2 balance of land ecosystems. However, the site level data is limited in representativeness to certain land cover type that is typically boreal coniferous forest in Finland. Furthermore, even though in Finland the flux site network is relatively dense, generalization of the site level calibrations is only feasible with a rigorous data assimilation system, which would combine other data sources in addition to flux site data. Existing regional reference data on the other hand has their limitations that hinder decisive conclusions about the precision of the modelling system. Nevertheless, the levels of GPP as well as NEE are within the range predicted by other modelling systems. The main concern of Nordic countries being too often a net CO_2 source, can be to some degree corrected by changing the spin-up procedure for ecosystem carbon storages so that the rise in atmospheric CO_2 concentrations is better accounted for.

1.1.4 Extracting anthropogenic influence from natural background CO_2 sources

Considering the case of remote station Pallas in Northern Finland, long range transported anthropogenic emissions are clearly visible in winter, while in summer biospheric sources and sinks dominate the CO_2 signal. Thus, in order to study the anthropogenic contribution to observed CO_2, it is easier to focus on winter months. High CO_2 concentration of observations event was selected from December to February 2006-2009, and recorded the length of each event in hours. Event started when hourly mean concentration was elevated 1 std over background and ended when the 1 std level was crossed again. Background level was determined by fitting a linear trend + harmonic function to multi-year time series of CO_2. This removes the year-to-year growth as well as the seasonal cycle in CO_2. For the same observation period of CO, highest concentrations were selected until the track record, or sample, became as long as in the case of CO2. Note here that the sample is equally sized for comparability, and the high concentration hours do not necessarily occur at the same time. An atmospheric transport model is able to simulate the anthropogenic component in CO_2 by using emission databases and transport modelling. Global 3D multi-component CO_2 simulation results provided by NOAA/ESRL for TM5 (Carbon Tracker) were utilised, and results were extracted for Pallas station for the before-mentioned observation period. Hours with high anthropogenic component concentration (aCO_2) were selected in the same way as was done for CO. Timing of CO and CO_2 and model aCO_2 were correlated. High CO_2 occurred simultaneously with high CO in 72% of the total number of hours during the observation period. High CO_2 hours coincided with high model aCO2 hours in 76% of the cases. Thus, the model captured the timing of high CO_2 as accurately as the anthropogenic tracer CO.

1.1.5 Satellite data products

The SCA product (snow covered area), from GSE Polar View, describes the fraction of snow cover inside a single satellite image pixel and NDVI product (normalized difference vegetation index), from GSE Land, is related to the amount of the 'green vegetation' in a satellite image pixel were created. Additionally, the cloud coverage was interpreted separately using algorithm developed at SYKE and refined during the SNOWCARBO- project. For all above products the area of interest was covered daily using 1-3 images, therefore the images needed to be composited, i.e. stitched together to gain a daily coverage. Additional weekly composites were created for data-analysis. As the brightness temperature data from AVHRR did not yield desired information, which could be used to input or to validate the model performance without more extensive algorithm development, another vegetation related index, NDWI i.e. Normalized Difference Water Index, was calculated, as it proved to be more informative for wetland than the NDVI. In addition, following three satellite data products were also provided

- Weekly Snow Water Equivalent (SWE) Grids
- Snow Melt Seasonal Grids (Dates of onset of snow melt and snow clearance)
- Date of Soil Freezing Grids

All these products were archived for further use.

1.1.6 Extraction of carbon balance-related indicative features

Time-series of Snow Covered Area (SCA) and Normalized Difference Vegetation Index (NDVI) were produced from Moderate Resolution Imaging Spectroradiometer (MODIS) observations, describing the status of snow cover and vegetation, both of which are important components in the carbon exchange between atmosphere and soil and vegetation. In addition, also Normalized Difference Water Index (NDWI) was calculated, as it was shown to be a good indicator for the greening-up in the boreal region. Cloud masking was applied to SCA, NDVI and NDWI products and daily composites were calculated.

Filtered and interpolated time-series were used to extract features indicating important changes in the carbon exchange, namely:

a) beginning of growing season,

b) seasonal vegetation peak and

c) end of growing season.

1.1.7 Northern-Eurasian land cover information

Land cover classification give the spatial distribution of land cover types and surface parameters allocated for each land cover. These characterize each land cover category used by the models. Several sets of gridded land cover maps were produced in different resolutions (scales) and geographical coverage:

1. Detailed (local) land cover information covering intensive in-situ monitoring areas (flux stations in northern Finland) were produced using satellite data (IRS P6 LISSIII, SPOT 4 XS, LANDSAT 5 TM, KOMPSAT 2) together with ancillary GIS and in-situ data. Employed methods included estimation of land cover variables using rule-based predictive models. Additionally Finnish national CORINE land cover databases were utilized.

2. In standard model versions the surface cover data is a global 1km resolution land cover dataset based on Olson ecosystem classification. Since Olsson data do not describe Nordic land cover properly, alternative land cover information was produced. Different revised land cover data sets recoded into Olsson nomenclature were produced and delivered covering the modelling window in Scandinavia and surrounding areas. Following data were utilized:
    a) GlobCover (regional version 2.2)
    b) European Corine Land Cover (CLC2006)
    c) National Corine Land cover (CLC2000 and CLC2006)
    d) Clusters of MODIS products (MOD15 Leaf Area Index and MCD43 Albedo)

2 Introduction

Seasonal snow has strong effect on the climate in the Northern hemisphere and therefore also to the carbon exchange between vegetation, soil and atmosphere. Until now, the terrestrial natural carbon exchange has been investigated in coarse spatial resolution, or only in the perspective of a single ecosystem. In the SNOWCARBO project, coordinated by the Finnish Meteorological Institute, a modeling framework has been set up for climate and land surface to produce spatially more accurate information on the carbon exchange between vegetation, soil and atmosphere. The modeling is done by implementing REMO climate model and JSBACH modular land surface scheme. In the implementation of the model, mature remote sensing products have been utilized. New land cover data, derived using satellite data, has been take in to use and physical parameters produced by the model have been compared with same parameters derived from satellite images for model validation.
The modeling framework can be utilized in several different ways:

- To support in fulfilling national and international greenhouse gases reporting obligations
    - Emissions in different sectors (forestry, agriculture)
    - The components of natural greenhouse gas exchange (sinks and sources of vegetation and soil)
- To produce estimates for the effects of spatial variability carbon dioxide sinks and sources in regional scale that can be used as an information source
- To use the results in national and international climate change adaptation and mitigation programs and related decision making
    - E.g. In the implementation of emission the trade system of European Union
- Model can also be used to simulate future scenarios for atmospheric carbon balance related to climate change

The areal coverage of the models is currently consisting of Nordic countries, excluding Iceland, and Baltic countries. As the final outcome of the project, it is an atlas of annual carbon balance for years 2001-2011 and the development and calibration of a tool to calculate current (2001-2011) CO_2 balances of Finland and surroundings by combining existing regional climate and land surface models.

Expected longer term results:

Main expected longer term result is a tool applicable for assessing the impacts of climate change on the land vegetation CO_2 balances.

The modeling framework, implemented in SnowCarbo- project, can be used to produce information to support national and international climate policy making and monitoring. The central international conventions and programs in European level, which can utilize the results, are:

- Updating and publishing greenhouse gas inventories (including carbon dioxide) on regular bases to UNFCCC (United Nations Framework Convention on Climate Change),
- **DG CLIMA:** The accounting of greenhouse gas emissions in all sectors of society (e.g. forestry and agriculture) and building mechanisms for restricting emissions,
- **DG ENV:** Imposing emission limits, regulation of emission trade and monitoring of emissions need comprehensive emission accounting and reporting
- **DG ENER:** Emission trade related to energy production; Research and development aiming at reduction of carbon dioxide emissions
- **DG MOVE:** Program for reduction of emissions from land and sea traffic

3 Administrative part

All meetings are planned and organized in close collaboration among project manager from FMI (Finnish Meteorological Institutes) and other representatives from SYKE (Finnish Environment Institute) and CEA-LSCE (Commissariat à l'énergie atomique – Laboratoire des Sciences du Climat et de l'Environnement). Collaboration and communication among partners has been good. The project meetings in Finland are organized by FMI and SYKE respectively. The management & steering meetings are organized by FMI.

3.1 Description of the management system

The management and monitoring of the progress in the SnowCarbo project is carried out by management and steering groups, who will meet regularly during the project. The Management Board of the project is formed by

- Project Principal Investigator (Prof. Jouni Pulliainen, FMI),
- Project Manager (Dr. Ali Nadir Arslan, FMI),
- Partner Coordinators (Mr. Olli-Pekka Mattila, SYKE and Dr. Philippe Ciais, CEA-LSCE),
- Project secretaries (Ms. Riitta Aikio, FMI and Ms. Ulla Haapanen, SYKE),
- Action Managers.

The project Steering Group includes

- Principal Investigator
- Project Manager, Partner Coordinators
- Institute Evaluators (Prof. Yrjö Viisanen, FMI and Dr. Yrjö Sucksdorff, SYKE)
- The representatives of the stakeholders (Statistics Finland, Ministry of Transport and Communications, Ministry of Environment, Ministry of Agriculture and Forestry).

The project teams within the project partners are lead by the Partner coordinators (except at FMI, where the team is lead by the Principal Investigator). The project teams have assigned Action Managers for each action to lead the daily work.

The Management Board and the Steering Groups will meet twice a year. The Steering Group monitors the project progress based on a Progress Report issued by the Management Board. The feedback and recommendations from the Steering group are provided to the project teams through the Management Board. The action personnel of the project will meet at least quarterly to ensure that all project activities are fully coordinated. Small working meeting relevant to ongoing project activities are organised as necessary.

The organigramme of the SnowCarbo project is presented in Figure 3.1.1.

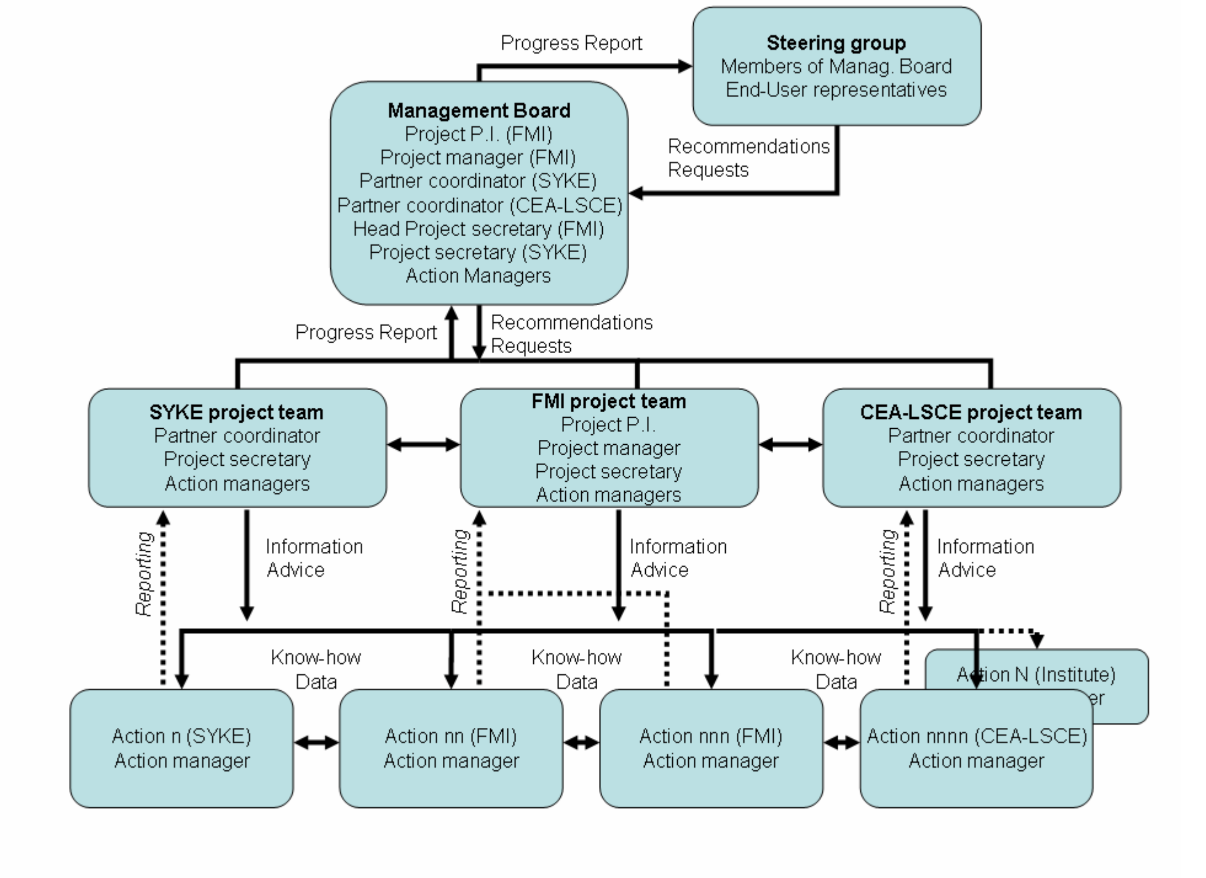

Figure 3.1.1: Organigramme of the SNOWCARBO project

3.2 Evaluation of the management system

Communication between project personnel from different disciplines was challenging in the beginning of the project and improved towards the end of the project. Obvious needs and opportunities for collaboration were recognised. In the future the communication between remote sensing and ecosystem modelling communities among partners is easier.

At the beginning we needed to have meetings monthly which were more often than planned. This was necessary due to number of project personnel involved and also wide diversity of their background. It was also important to revise project objectives and tasks more often at the beginning of the project that we can lead progresses towards to right direction.

Project objectives and defined methodology was well-defined in the revised project plan. This made management system easy. Most of the efforts were used to transmit these objectives and methodology to the project personnel.

The Finnish User Forum started 5/2011 and main aims are (a) to define and validate user needs (products and services) (b) coordination between national public users (c) to inform national users of Copernicus activities (d) to disseminate national user needs to EC and Copernicus User Forum / Committee. The members of Finland User Forum are

- Regional State Administrative Agencies

- Centre for Economic Development, Transport and the Environment
- European Forest Institute
- Finnish Geodetic Institute
- Geological Survey of Finland
- Ministry of Foreign Affairs of Finland
- Finnish Meteorological Institute
- Crisis Management Centre Finland
- Finnish Transport Agency
- MTT Agrifood Research Finland
- Forest Management
- Finnish Forest Research Institute
- Finnish Border Guide
- Game and Fisheries Research
- Finnish Environment Institute
- Rescue Services in Finland
- Radiation and Nuclear Safety Authority
- Aerobiology Unit of University of Turku
- Finnish Government
- Technical Research Center of Finland

Since the project manager of SNOWCARBO project is also the chairman of Finland Copernicus User Forum. That's why the dissemination of the project's result was very effective.

At this level there is no any technical and commercial application planned. This was not planned in the revised project plan. However, the results of the project can be utilized into educational services of the project partners and the stakeholders in format of text books, digital records (CDs, videos) or games.

As continuation of the project, several potential actions arising from co-operation between project partners and project stakeholders has emerged. As a result of this co-operation we have generated a new Life+ proposal (MONIMET) that was submitted 30.9.2012. This proposal, if successful, has significant potential in strengthening seasonal monitoring of carbon balances of forests, and in providing easily understandable information about climate change for the general public and other stakeholders.

4 Technical part

4.1 Actions

4.1.1 Action 1: Project management and monitoring

The activities of Action 1 such as arrangements of the official project meetings, coordination and monitoring of the project progress, preparation of the project deliverables, and monitoring of the project expenses are completed successfully.

The Management Board and the Steering Group meetings have been very successful with good discussions and exchange of opinions between the project managers and the representatives of the stakeholders. Project team meetings and working meetings between project team members have been used to ensure coordination of the project work and clarify any issues related for example to the deliverables between project Actions.

4.1.2 Action 2: Satellite data processing by FMI

Following three satellite data products were provided

- Weekly Snow Water Equivalent (SWE) Grids
- Snow Melt Seasonal Grids (Dates of onset of snow melt and snow clearance)
- Date of Soil Freezing Grids

Datasets for weekly gridded SWE are available for 30 year dataset (1978-present). In Figure 4.1.2.1, an example of the product in EASE grid projection is presented. A full dataset of 30 years (1978 – 2008) has been created. The product has been verified and validated in a journal publication (Takala et al., 2009). In Figure 4.1.2.2, Gridded date of Snow Clearance for Northern Hemisphere in 2008 is shown as an example. The Snow Clearance product is formed as a gridded (0.25 degree EASE grid) value corresponding to the date (counted as days from Jan1) in the respective year, when the snow clearance threshold (90%) is passed. The soil freezing grids are based on available historical scatterometer observations. The default instruments are the NASA QuikSCAT/SeaWinds scatterometer (Ku-band). A prototype dataset for the year 2008 has shown in Figure 4.1.2.3.

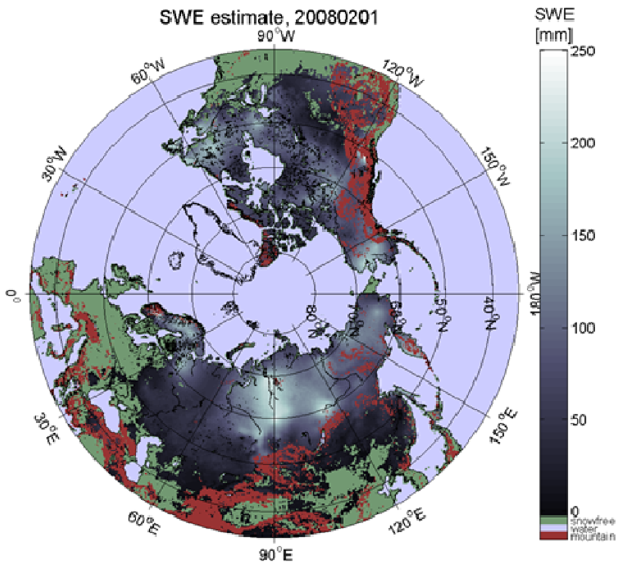

Figure 4.1.2.1: A visualization of the SWE product (in 0.25 degree EASE-grid) over the Northern hemisphere. The lower limit for the latitude is 35° and the upper limit 85°.

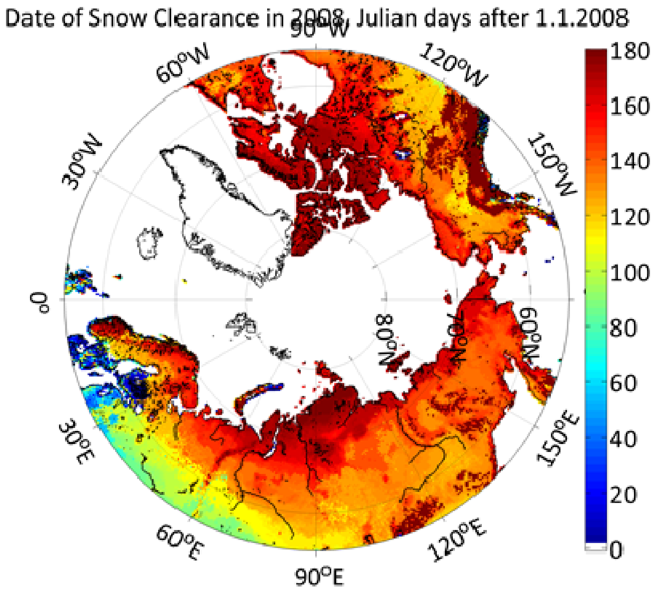

Figure 4.1.2.2: A visualization of the Date of Snow Clearance product (in 0.25 degree EASE-grid) for Eurasia in 2008. Color codes represent amount of days from Jan 1 2008.

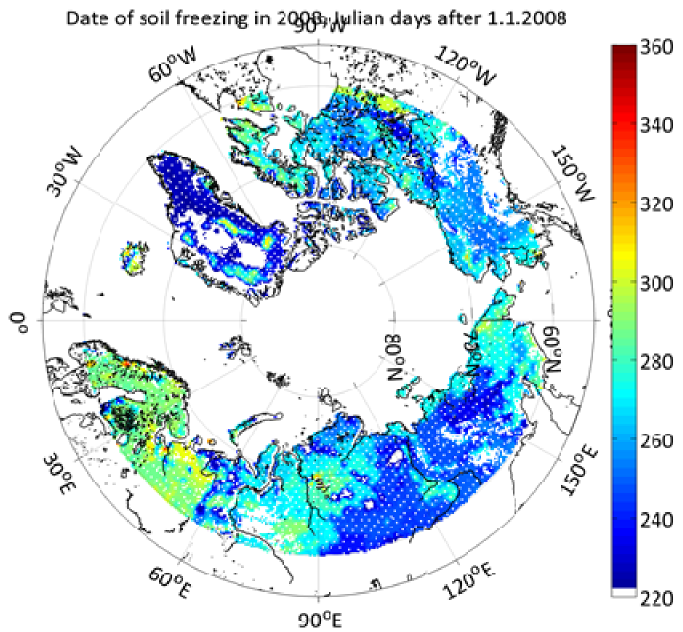

Figure 4.1.2.3: Visualization of experimental soil freezing date product for 2008. Color codes represent days after 1.1.2008

References:

Takala, M., Pulliainen, J., Metsämäki, S., and Koskinen, J. (2009). Detection of Snowmelt Using Spaceborne Microwave Radiometer Data in Eurasia From 1979 to 2007. IEEE Trans. Geosci. and Remote Sensing, 47:2996-3007.

4.1.3 Action 3: Acquisition and extension of GMES-services GSE Polar View and GSE Land

The Earth Observation (EO) products used in this project are based on near-real-time (NRT) environmental monitoring services, which were set up in the development stage of GMES services. In the two test services at SYKE of GSE (GMES Service Element) Polar View and GSE Land, the first focused on snow monitoring and in the latter a methodology was developed for monitoring vegetation. From the two, GSE Polar View led to a continuous NRT- service, whereas the methodology from the GSE Land was used on ad hoc bases. The data gathered and methodology developed in the development phase was used in SNOWCABRO- project to obtain a harmonized dataset of 10 years of information on snow cover and vegetation from the MODIS/Terra (Moderate- resolution Imaging Spectroradiometer onboard NASA Terra satellite)- instrument. Reference information of the surface temperature was obtained from the AVHRR/NOAA (Advanced Very High Resolution Radiometer/ National Oceanic and Atmospheric Administration- satellites). MERIS (Medium Resolution Imaging Spectrometer)- was seen as back up sensor if the other two were to fail. The final MODIS and AVHRR- datasets are described in Table 4.1.3.1 and in more detail in the deliverable of the action (SNOWCARBO Action 3, 2009 and 2010).

The NRT- snow service has run at SYKE since 2007 for Northern-Europe using MODIS-data. To acquire harmonized and uniform dataset the data needed to be filled for the summers, where the GSE Land methodology had not been exploited. The years 2001-2007 were collected from online- image catalogue/database LAADS (Level 1 and Atmosphere Archive and Distribution System by NASA). The AOI (Area of Interest) was also extended from the NRT- service extents to cover the entire modeling region, requiring collecting additional images.

The raw data was run through a pre-processing chain based on the NRT- service, but modified to account changes in the processing region and in the algorithm constricting parameters and to facilitate processing through the large dataset when algorithms are refined. The pre-processing chain consisted of calibration of the raw data, geo-correcting, cropping for AOI and according to other constricting parameters (e.g. sun elevation angle and satellite viewing angle) and distribution in the database.

Two end products were calculated from the pre-processed satellite data. The SCA (snow covered area; Metsämäki et al., 2005 and 2012), from GSE Polar View, describes the fraction of snow cover inside a single satellite image pixel and NDVI (normalized difference vegetation index), from GSE Land, is related to the amount of the ‘green vegetation’ in a satellite image pixel. Additionally, the cloud coverage was interpreted separately using algorithm developed at SYKE and refined during the SNOWCARBO- project. For all above products the area of interest was covered daily using 1-3 images, therefore the images needed to be composited, i.e. stitched together to gain a daily coverage. All these products were archived for further use. Additional weekly composites were created in Action 7 for data-analysis. Examples of the satellite images and the data products are shown in Figure 4.1.3.1. As the brightness temperature data from AVHRR did not yield desired information, which could be used to input or to validate the model performance without more extensive algorithm development, another vegetation related index, NDWI i.e. Normalized Difference Water Index, was calculated, as it proved to be more informative for wetland than the NDVI.

Quality control for products and clouds was done during the processing of time-series. Time-series of observations, combined with cloud information were used to develop the methodology for detecting carbon cycle related phenomena (done in Action 7). From the time-series clear errors in the processed test data could be detected easily, e.g. the cloud algorithm was producing too covered images. The algorithm was revised by operator analysis and tuned for better cloud detection. Due to the harmonized and documented dataset, with the archived intermediate top-of-the-atmosphere reflectances, the re-processing of the data was relatively easy, considering the size of the dataset. Also, as the monitoring area was expanded during the course of the project to be corresponding with the modeling region the dataset was re-processed partly.

Data was archived at SYKE and backed-up with external hard-drives, which was also available if the entire dataset would have been needed to be transferred to other partners. As the plan indicates, the data was mainly processed at SYKE, but samples of the data were transferred to project partners via email and via the FTP-server set up finally at FMI for the project.

The data from Action 3 was central part for the project. Therefore the measure for action performance was to get the data available for the other actions (especially Actions 7 and 9) as soon as possible. Also if the data needed refinement, the re-processed data needed to be delivered quickly to keep the other actions on track. The data was reported in a deliverable together with Action 2 and updated after completing the dataset

The dataset was available for the project partners in the schedule of the project. The re-processing needed extra time due to the large size of the dataset. But experimental data could always be given for the other actions to start testing and preparing for further analysis during the re-processing.

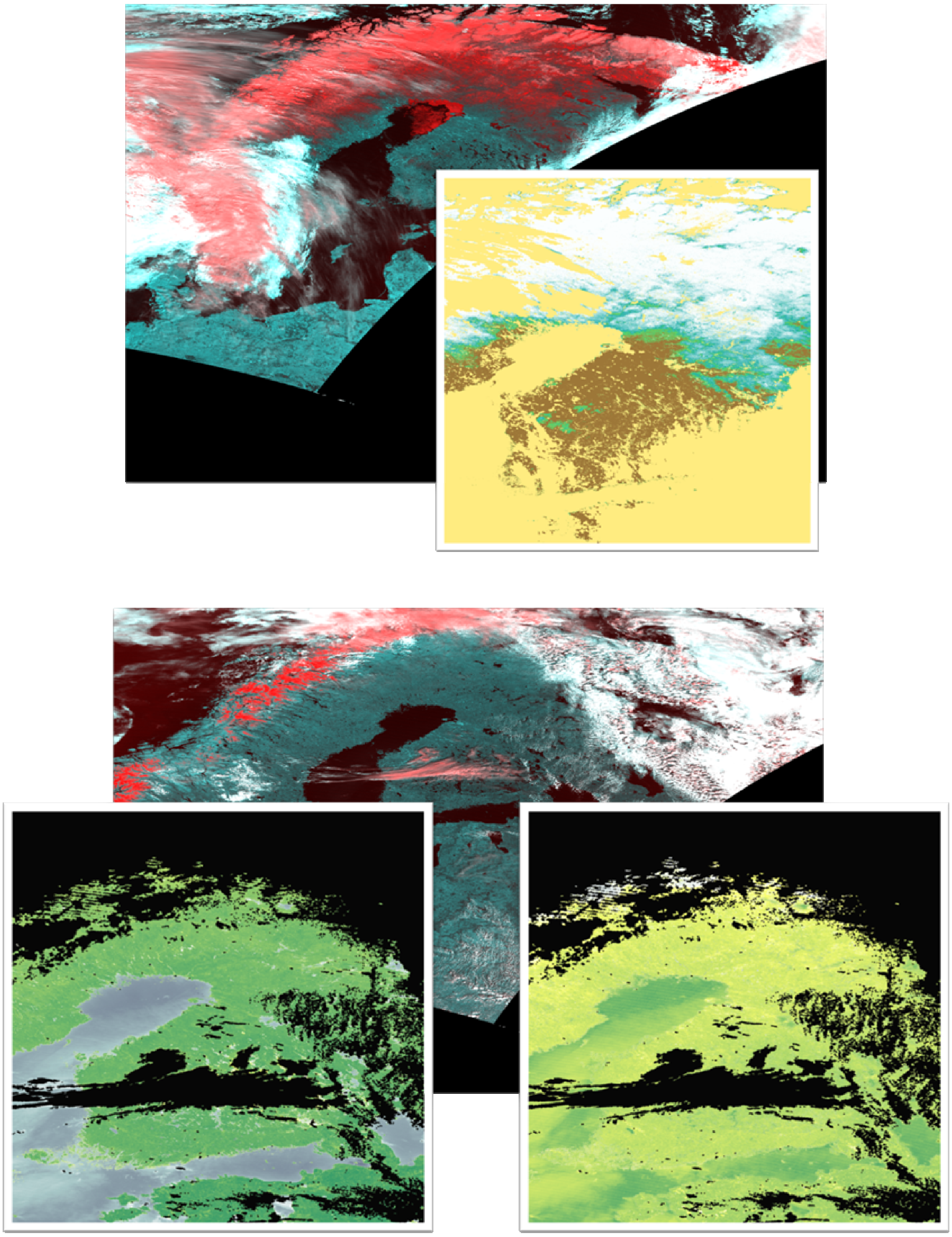

Figure 4.1.3.1: MODIS Satellite image and related SCA- product 2007-04-22 (top) MODIS Satellite image and relaged NDVI (bottom left) and NDWI (bottom right)-products.

Table 4.1.3.1. Summary of the work planned and performed in Action 3

Dataset	Planned	Performed	Notes
MODIS			
MODIS RAW	Daily coverage for 2001-2011	Daily coverage for 2001-2011, excluding days of nearly total cloud cover	The existing dataset was extended in spatial domain to cover the entire modeling grid. This required additional data requests from web- catalogues as well as additional processing.
MODIS TOA Reflectances	Daily coverage for 2001-2011	Daily coverage for 2001-2010 and winter 2011; model data available only for years 2001-2010	Includes also thermal emissive channel (MODIS Ch-11) that could be used instead of AVHRR data. Some images could not be processed due to file corruption and some were left out due to extensive cloud cover.
MODIS SCA	Daily coverage for 2001-2011	Daily coverage for 2001-2011	Years 2001-2008 re-processed with corrected algorithm and extended area
MODIS NDVI	Daily coverage for 2001-2011	Daily coverage for 2001-2010; model data available for years 2001-2010	Years 2001-2008 re- processed with extended area
MODIS NDWI	Not anticipated in the original plan	Daily coverage for 2001-2010	
MODIS Clouds	Daily coverage for 2001-2011	Daily coverage for 2001-2010 and winter 2011;	Years 2001-2008 re-processed with corrected algorithm and extended area
AVHRR			
AVHRR RAW – available archive	Daily coverage for 2001-2010	Daily coverage for 2001-2010	The REMO-JSBACH model produces more reliable surface temperature data and therefore AVHHR- data was not used further in the analysis of model performance or as input.
AVHRR TOA Brightness temperatures– available archive	Daily coverage for 2001-2010	Daily coverage for 2001-2010	The dataset had no further use, for the modeling provided better estimate for surface temperature
MERIS			
MERIS- data was not needed (acted as a backup for MODIS)			

References

Metsämäki, S., S. T. Anttila, M. J. Huttunen and J. M. Vepsäläinen. 2005. A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model. Remote Sensing of Environment, Vol. 95, p.77-95. 2005.

Metsämäki, S., O.-P. Mattila, J. Pulliainen, K. Niemi, K. Luojus and K. Böttcher. 2012. An optical reflectance model-based method for fractional snow cover mapping applicable in continental scale. Remote Sensing of Environment, Vol. 123, p. 508-521, 2012.

4.1.4 Action 4: In-situ data collection and processing by FMI

The general objective of Action 4 (In-situ data collection and processing by FMI) was to prepare two data sets for the modelling purposes: the input data and the validation data. The input data set needed for weather and tracer transport simulations consists of initial and boundary forcing data. This input data for the models (REMO2008, ECHAM5 and JSBACH) are given in the form of meteorological fields and as maps of surface properties. In addition to the standard meteorological fields such as air temperature, liquid water content and 3D velocity fields we also need the initial atmospheric CO_2 concentration fields, fire information, anthropogenic sources and sea ecosystem CO_2 exchange for estimating the CO_2 balance. Various possibilities for the initial and boundary forcing data fields were explored. The selected data sources are presented in Table 4.1.4.1.

The initial and boundary fields for meteorology were taken from the ECMWF (The European Centre for Medium-Range Weather Forecasts) ERA-Interim data set. TM3 model results from The Atmospheric Tracer Transport Model Intercomparison Project (TransCom) were used as CO_2 concentration boundaries. The Emissions Database for Global Atmospheric Research (EDGAR 4.0) provided gridded global past and present day anthropogenic emissions of greenhouse gases and air pollutants. The oceanic CO_2 emissions were obtained from the Takahashi database.

Table 4.1.4.1. Datasources of the initial and boundary forcing data for the models (REMO2008, ECHAM5 and JSBACH)

Name of the dataset	*Included data types*	*Limitations/ Drawbacks*	*Spatial/Time resolution*	*Time coverage*
ECMWF ERA-INTERIM	Detailed meteorology derived from observations	-	0.167° Six-hourly	2001-2009
TM3	3D concentration fields due to all the relevant surface fluxes	-	1.875° Six-hourly	2001-2009
EDGAR4.0	Surface fluxes due to fires and anthropogenic sources	Limited time coverage	0.1° Annual	2001-2008
Takahashi database	Oceanic CO2 fluxes	-	4° × 5°	Present (2000)

The validation data set was based on the CO_2 flux and concentrations measurements from various flux and concentration measurement stations of Finnish Meteorological Institute. The flux measurements were conducted by the eddy covariance (EC) technique which provides a direct measurement of the net exchange of CO_2, water vapour and sensible heat between the biosphere and the atmosphere. The measurements at Finnish flux sites Kaamanen wetland, Sodankylä Scots pine forest, Kenttärova Spruce forest and Lomplojänkkä wetland continued throughout the project as planned. The background CO_2 concentration measurements were conducted at Pallas-Sodankylä GAW station on top of Sammaltunturi hill (67°58'24"N, 24°06'58"E, 565m above sea level), about 100m above the tree-line. In addition to the FMI sites, data was obtained from a southern Scots pine forest Hyytiälä (University of Helsinki). In addition to the actual CO_2 exchange data the flux stations provided additional meteorological data which were used for evaluating the representativeness of gridded meteorological data products at the chosen flux measurement sites (Sodankylä, Kenttärova and Hyytiälä.

Mast-based field spectrometer measurements for the validation of applied optical satellite data products were conducted at Sodankylä. An ASD field spectroradiometer was installed in a 30-m tower on a 4.5-m horizontal pole. This rotating pole enabled measurements of two separate land covers: a sparse Scots pine forest and a deforested area covered by lichen and heather. In nominal operating mode the spectroradiometer was planned to perform scheduled measurements automatically once per hour. Due to problems with the measurement and control software, the measurements have been performed mainly manually during sunny weather conditions.

In addition to the data obtained directly from measurements, some further processed data was also produced in Action 4. Carbon balance related features, like growing season beginning and end dates, were analysed from the CO_2 flux data for different sites for a comparison with similar information extracted from satellite data time (Action 7) and from models (Action 8).

4.1.5 Action 5: In-situ data collection and processing by SYKE

Finland is acting as the main area for testing and validating the different methodologies used in the project. This is due to availability of suitable and extensive in-situ monitoring networks and datasets. The quality of information derived from satellite images depends strongly on the in-situ and ground truth information available for interpretation, algorithm development and validation.

The existing data from SYKEs own databases and information from other research institutes were collected and made easily available for further use in other Actions of the project. Dedicated field campaigns were organized to fill in information gaps, especially in the optical spectral data from melting snow surface and ground vegetation (Figure 4.1.5.1a and 4.1.5.1b), but also to collect reference data (e.g. snow characteristics form snow pits, Figure 4.1.5.1c) for the spectral data and for validation of land cover information (e.g. forest parameters). There were altogether five field campaigns of which four were carried out in the Sodankylä Cal-Val Super-site of Finnish Meteorological Institute and one in Inari area.

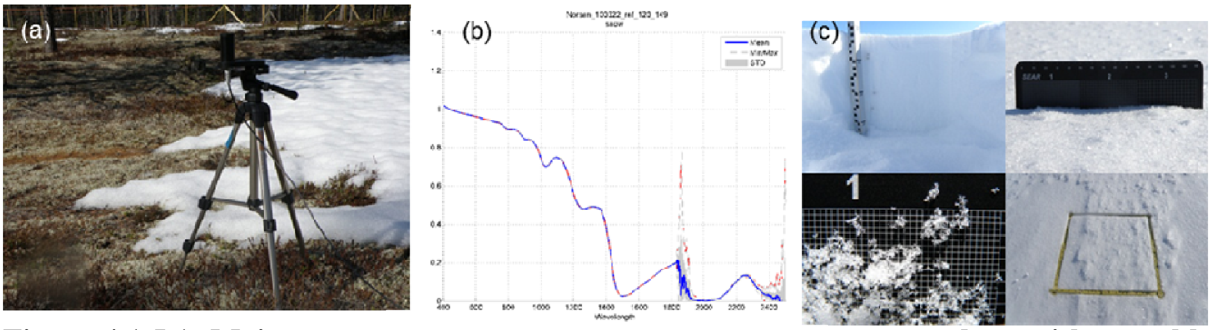

Figure 4.1.5.1: Main measurements during the field campaigns were done with portable spectrometer (a), which produced spectral reflectance signal from the target (b). The measurements were always accompanied with snow pit observations (c): snow depth, layer structure and grain size, surface roughness and a photograph of the surface.

From the existing monitoring network of SYKE for snow cover, information is available from several decades, including the years 2001-2010. The information was made available for use in Actions 7 and 9 by creating necessary software tools to collect data time-series of snow observations from the databases for given sites and given time span. The data was used in creating the algorithm to detect phenological events from satellite data.

Dataset of occurrence dates of phenological events was purchased from Finnish Forest Research Institute (METLA). The data was evaluated and discrepancies with other available information were reported to METLA, after which a corrected dataset was received. Data was used as reference information in the methodology development to observe phenological events from satellite data time-series in Action 7.

The database of ground based measurements of the behavior of optical signal, seen by satellites (e.g. the MODIS- satellite used in this project), was complemented during four of the five field campaigns. The dataset lacked the information from the late stages of melting, which is a very short period of time and therefore difficult to capture, especially with the optical measurements, where weather conditions rarely permit good measurements. Measurements were also made in the vicinity of Helsinki to try to bridge this gap. After the field campaigns the data needed pre-processing before including it in the spectral dataset. Together with the mast based spectral measurements, with similar instrument, conducted at Sodankylä Cal-Val Super-site, the field measurement data provided new information for interpretation of the satellite signal, but did not yet result in altering the satellite algorithm, as this requires more research and development. Yet, recent analysis of the ground and mast-based measurements (Niemi et al., 2012) and of high-resolution satellite images (Metsämäki et al., 2012) have revealed that the used optical algorithm (Metsämäki et al., 2005) is performing well and clearly is the best available for snow area monitoring and can be also applied in continental scale.

Different land cover datasets used as input for the carbon modeling framework was generated in Action 11. The datasets were evaluated against each other, but also against ground based observations of vegetation from field campaigns. Spatially higher resolution analysis was planned to be done for Sodankylä area from aerial images archive available from National Land Survey. This was replaced with more recent very high resolution satellite images from Sodankylä area, which came available through collaboration in the field activities and allowed the area to be classified with higher spatial resolution. This information is useful in site-wise analysis of the carbon modeling results. The main indicator for following the progress of the Action was the reporting and data made available for other Actions. All three reports were completed and no gaps in the datasets were found, which would have hindered the method development in Action 7 and analysis of results in Action 9. Complementing of the spectral dataset was very much a weather dependent activity and therefore as resources were still available, due to collaboration with other projects, additional field campaign was carried out in the spring 2011.

References

Metsämäki, S., S. T. Anttila, M. J. Huttunen and J. M. Vepsäläinen. 2005. A feasible method for fractional snow cover mapping in boreal zone based on a reflectance model. Remote Sensing of Environment, Vol. 95, p.77-95. 2005.

Metsämäki, S., O.-P. Mattila, J. Pulliainen, K. Niemi, K. Luojus and K. Böttcher. 2012. An optical reflectance model-based method for fractional snow cover mapping applicable in continental scale. Remote Sensing of Environment, Vol. 123, p. 508-521, 2012.

Niemi, K., S. Metsämäki, J. Pulliainen, H. Suokanerva, K. Böttcher, M. Leppäranta and P. Pellikka. 2012. The behaviour of mast-borne spectra in a snow-covered boreal forest. Remote Sensing of Environment, Vol. 124, p. 551-563, 2012.

Table 4.1.5.1. Summary of the work planned and performed in Action 5.

Expected result	Tasks/work planned	Performed
Data processing		
Collecting and processing snow course data	- Making the data easily available from the different storages of information	- Software tools created for extracting time-series of snow information from selected sites and time-intervals
Obtaining and processing phenological data	- Purchase phenological data from METLA - Collect similar information during fieldwork for additional data from selected sites	- Purchased phenological data from METLA - Evaluated the dataset and feedback sent to METLA →received corrected dataset - The monitoring of phenological sites requires continuous visits to the observation stations. Therefore the spatial distribution of leaf yellowing was observed in spatial domain instead during a field campaign.
Fieldwork campaigns		

Field observations of reflectance spectrum of snow cover	- Two field campaings in the spring 2009 and 2010 planned for obtaining optical reflectance spectrum measurements from late stages of snow cover during melting season.	- The two measurement spring measurement campaings of 2009 and 2010 were carried out as planned in Sodankylä Super-site (FMI) for optical measurements of snow cover. - Additional campaign was carried out in 2011 to obtain more measurements from the late melting period.
Field observations of physical properties of snow	- Simultaneous measurements of snow properties during optical measurements.	- Measurements of snow properties carried out together with optical measurements.
Field observations of reflectance spectrum of vegetation	- Two field campaigns in autumns 2009 and 2010 planned for obtaining optical reflectance measurements from different vegetation targets.	- Optical measurements of vegetation were carried out during autumn 2010, when Inari area was visited. - Resources were directed toward snow observations, where additional campaign in 2011 was carried out.
Reference data collection for vegetation spectrum	- Obtain reference information for vegetation spectrum measurements	- Measurements were conducted as planned together with land cover validation in Inari area.

Reporting

1st, 2nd and 3rd In-situ Data Document	- Three reports documenting the fieldwork activities	- Completed as planned

4.1.6 Action 6: Methodology development and implementation by FMI

A modelling framework predicting present day land ecosystem CO_2 balance for Nordic countries and surroundings (i.e. for Northern Europe) was developed. The modelling framework consists of regional climate model REMO and land surface model JSBACH accounting for photosynthesis. In the framework of this project a method of coupling between the climate model REMO and the land surface model JSBACH (Figure 4.1.6.1) was implemented and tested: 1) the first step is a REMO-run to determine fine scale regional climatic variables such as air temperature, surface pressure, radiation and precipitation; 2) in the second step the JSBACH model is forced with the climatic variables to produce the land vegetation CO_2 exchange rate; and 3) as final step the exchange rate together with mapped data for anthropogenic and ocean CO_2 sources the REMO is driven in a version distributing the tracers to the atmosphere inside the model domain. Both REMO and JSBACH use model specific surface parameter fields (i.e. surface maps or surface libraries) that were modified with data from various actions of this project.

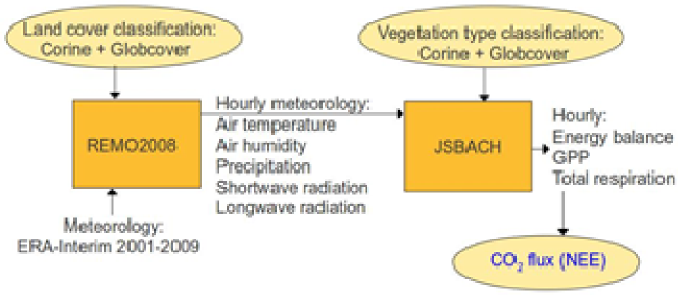

Figure 4.1.6.1: Modelling framework showing the one-way coupling between the models. JSBACH does not feedback to REMO.

The regional climate model REMO was implemented on FMI's system in the beginning of the year 2009 and consequently on CSC's environment in an updated version REMO2008. The version that takes tracer transport into account was installed and debugged on CSC system and was found to run reliably by autumn 2009.

Pre-processing steps that include fixing the domain and creating the surface libraries according to the standard land use maps were taken in 2009 and the surface libraries based on up to date land cover data from Action 11 were created in 2010. Consequently the tools for substituting the surface library fields of the boundary data with new ones were created and applied to ECMWF operational data in 2010 and in 2011 to ERA-Interim based data covering years 2001-2009. Subsequent to creating the ECMWF operational data based meteorological boundary fields for different land cover data sets. REMO was run in climate mode over the 9 years of existing data in 2010.

Since beginning of 2010 both models REMO and JSBACH have been running also at FMI super-computing facilities. Running scripts for the two REMO running modes were coded and tested for three optional land cover data in 2010.

In the beginning of year 2011 the instantaneous JSBACH offline version better suited for the purposes of this project was adopted. The surface libraries with standard and National Finnish Corine based land cover data were created. First site level runs with site specific meteorological data were performed and methods for determining growing season start from the model results were scripted. REMO production runs were performed with the original land cover data of USGS and regional hourly forcing for JSBACH were extracted from the data.

The JSBACH version applied in the production of end products was received in the beginning of year 2012. It was subsequently implemented to FMI supercomputer as well as on PC's. REMO with National Finnish Corine based land cover data with consequent post processing steps for producing JSBACH input. For consistency, the meteorological drivers from this

REMO run were selected as input for JSBACH regardless of the surface library applied in JSBACH.

Separate JSBACH sub model for soil carbon accumulation into stationary state with present day climate was implemented and tested both with regional and site level meteorological data. Regional and site-level JSBACH production runs with required spin-up runs for stabilizing soil carbon pools were performed with USGS land cover data as well as with National Corine data.

Delay in getting the climate data pre-processor from MPI-met, Hamburg and CSC, Hamburg, limited the time extension of the target years between 2001-2009. The pre-processor is presently running in FMI facilities and the CO_2 balances of the remaining planned target years can be produced post Snowcarbo.

Decision to wait for the development of truly instantaneous JSBACH offline model up to beginning of 2011 postponed the start of production runs. The beta-version was adopted soon after its development but last necessary updates were still released in the beginning of 2012.

This was the major obstacle that delayed the production runs. However, adopting the truly instantaneous JSBACH offline version made the coupling between REMO and JSBACH models much more direct. Because there is no need for generating daily cycle of hourly meteorological data out of daily means. This is especially important in modelling CO_2 exchange that is strongly controlled by light availability.

Because of the abovementioned delays the intended REMO tracer run with JSBACH derived CO_2 balance as source data was not performed. Even though the required supplementary source and background data was collected in due time and the REMO tracer modelling system was implemented and run for a short period with test boundary data, there was not time enough to set up the runs with data produced in Snowcarbo.

1_{st} Progress Report on Methodology: describes the models, their current status and the state of implementation to the FMI facilities, the required input data and possible running modes. It further gives an overview of the intended method of coupling between the models, the intended manipulation of surface boundary data and the plan for runs to be performed in the project. The report also discusses possibilities for evaluating model results and shows examples of the first results produced with REMO with different land cover data.

2_{nd} Progress report on methodology: updates the status of the modelling framework. Specifically it reflects the changes due to the implementation of the instantaneous JSBACH version. The report illustrates the sequence of model runs in more detail, it introduces the concept of local JSBACH runs with locally observed meteorology, demonstrates the importance of spin-up of JSBACH boundary conditions in order to stabilise the soil carbon pools and shows the first regional carbon balance results for the whole regional domain.

4.1.7 Action 7: Methodology development and implementation by SYKE

Time-series of SCA and NDVI for the years 2001-2010 in a gridded form

In Action 7 time-series were produced from Moderate Resolution Imaging Spectroradiometer (MODIS) observations, describing the status of snow cover and vegetation, both of which are important components in the carbon exchange between atmosphere and soil and vegetation. Time-series of Snow Covered Area (SCA) and Normalized Difference Vegetation Index (NDVI), in a gridded form, were processed for the years 2001-2010 according to project plan. In addition, also Normalized Difference Water Index (NDWI) (Gao, 1996) was calculated, as it was shown to be a good indicator for the greening-up in the boreal region (Delbart et al., 2005). Cloud masking was applied to SCA, NDVI and NDWI products and daily composites were calculated.

Processing and characteristics of the products were described in deliverable of Action 3: "2nd EO-data document (years 2001-2010)" (Reporting date 30/11/2010).

Filtered and interpolated time-series of snow cover and vegetation index

The raw satellite-derived time-series were post-processed in order to fill gaps due to cloud cover and reduce the effect of noise. Firstly, a literature review was conducted in order to develop the most suitable filtering, interpolation and feature extraction techniques for SCA and vegetation index time-series.

In order to facilitate the generation of time-series from homogenous sites of selected land cover types, the fraction of each land cover class within a MODIS pixel was calculated from CORINE Land Cover 2000 (Härmä et al., 2005) for Finland. NDVI, NDWI and SCA time-series were extracted from homogenous areas around in situ measurement sites (phenological sites and CO2 flux-measurement sites). Time-series of NDVI were interpolated and smoothed using the software TIMESAT version 2.3 (Jönsson and Eklundh, 2004). Time-series of SCA were gap-filled and smoothed by fitting a sigmoid function to the temporal profile. In order to allow comparisons between satellites derived indices (and/ or derived carbon-balance related features) and modelling results (Action 6), methods for spatial aggregation of time-series to the modelling grid were developed and implemented.

Filtered and interpolated time-series for selected areas of interest describing a) the extent of snow cover during the melting period and b) the vegetation status during the growing season were processed for the years 2001-2010. Methods for the smoothing and gap-filling of SCA and NDVI time-series were described in detail in the following deliverables of Action 7: "Progress report on filtered time-series (2001 – 2008)" (Reporting date 31/05/2010) and "2nd progress report on filtered time-series (2001-2008)" (Reporting date 30/11/2010).

Extraction of carbon balance-related indicative features

Filtered and interpolated time-series were used to extract features indicating important changes in the carbon exchange, namely:

a) beginning of growing season,

b) seasonal vegetation peak and

c) end of growing season.

In agreement with Action 6, we used the start and end of growing season (referred here as flux growing season, FGS) calculated from CO_2 flux measurements (Action 4) as reference for the calibration of remote sensing estimates. For methodology development, we compared satellite-derived time-series from coniferous forests and wetland areas with in situ dates of the beginning and end of FGS for three coniferous sites (Sodankylä, Kenttärovä and Hyytiälä) and two wetland sites (northern boreal fens: Kaamanen and Lompoljänkkä). Figure 4.1.7.1 and Figure 4.1.7.2 show examples of the comparison of time-series with the date of the start of FGS for sites Sodankylä and Kaamanen, respectively.

FGS in coniferous forest begins during the snowmelt, when first snow-free patches appear (Figure 4.1.7.1 a). In contrast, the FGS in wetland areas starts after complete snowmelt and is indicated by a rise of the NDWI (Figure 4.1.7.2 c).

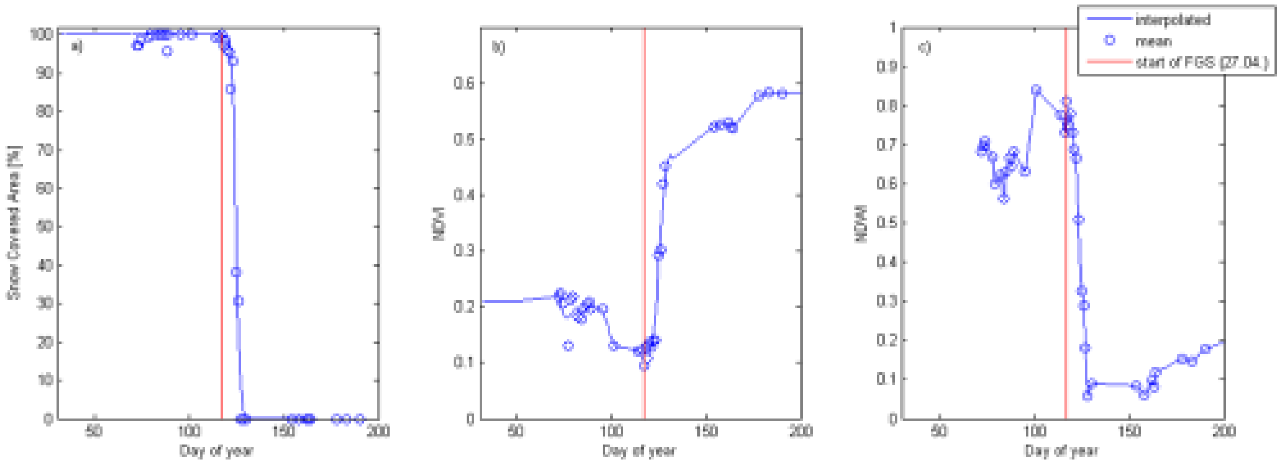

Figure 4.1.7.1: Time-series of (a) Snow Covered Area, (b) NDVI and (c) NDWI in comparison with start of flux growing season (FGS) at Sodankylä (February to July 2006).

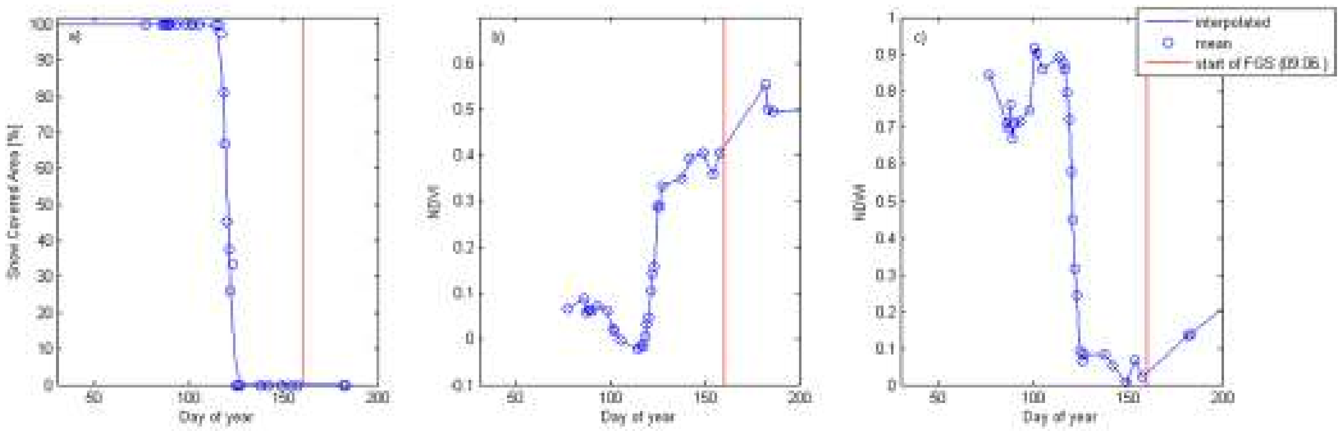

Figure 4.1.7.2: Time-series of (a) Snow Covered Area, (b) NDVI and (c) NDWI in comparison with start of flux growing season (FGS) at Kaamanen (from February to July 2006).

For the retrieval of carbon-balance related features, we focussed on coniferous forests as it is the dominant vegetation type in the boreal zone. A method for the detection of start of FGS was developed for this vegetation type based on time-series of NDVI and SCA. Comparisons of satellite-derived start of FGS for the period 2001 - 2010 with in situ dates revealed high correspondence for the three coniferous sites in Finland (Figure 4.1.7.3), with slightly better performance of the method based on SCA. Maps of SCA-derived start of the FGS in coniferous forest in Finland were therefore used for the evaluation of REMO-JSBACH model results (Action 9).

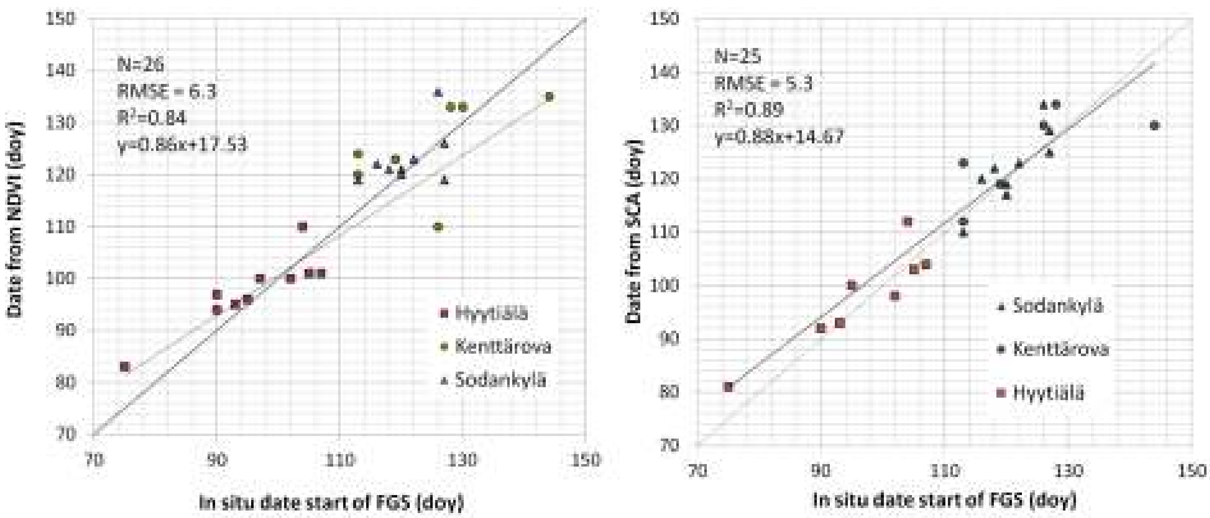

Figure 4.1.7.3: Comparison of in situ measurements of start of growing season (flux growing season, FGS) for years 2001-2010 with satellite estimates: from NDVI (left) and from SCA time-series (right). Doy is day of year.

In addition to comparisons with in situ observations from flux measurement sites, we compared satellite-derived time-series with phenological observations of bud-burst of birch trees and the beginning of height growth of pine trees.

Start of growing season of broadleaved deciduous forest and wetland sites was determined from time-series of Normalised Difference Water Index (NDWI), applying the method by Delbart et al. (2005). The beginning of height growth of new shoots in coniferous forest was extracted from NDWI time-series for four phenological observation sites. Methods for the calculation of the beginning of growing season were documented in deliverable: "Progress report on extracted features (2001-2008)" (date 31/08/2010).

The seasonal vegetation peak (maximum NDVI) and the end of season were determined from NDVI time-series for selected coniferous forest sites. NDVI-based end of growing season estimates showed low correspondence with in situ observations of end of FGS and could therefore not be used for the evaluation of model results. Methods for the calculation of seasonal vegetation peak and end of growing season were documented in deliverable: "Final progress report on extracted features (2001-2010)" (date 31/12/2011).

References

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Table 4.1.7.1. Summary of the work planned and performed in Action 7.

Expected result	Tasks/work foreseen	Performed
Inter-annual and intra-annual dedicated time-series of daily-weekly observations describing: a) The extent of snow cover b) Vegetation status	- Generation of time series of NDVI and SCA (2001-2010) - Literature review - Filtering of time-series - Extraction of time-series for selected land cover categories	Completed and reported. In addition the NDWI was calculated.
Definition, documentation and communication on data and methods for deriving carbon-balance related indicative features for Action 6 (in preliminary phase progress report)	- Discussion with modeling (FMI, Action 6), in situ data (FMI, Action 4) and remote sensing group(SYKE, Action 3 and 7) - Literature review	Completed and reported. Agreement about definition of carbon-balance related features to be used for model evaluation.
Carbon-balance related indicative features extracted from time-series a) date of beginning of growth season b) date of seasonal vegetation peak c) date of end of growth season d) dates of soil freeze	- Comparison of filtered time-series with *in situ* observation of carbon-balance related features - Extraction of carbon-balance related features from time-series (2001-2010)	Completed and reported. A new method for the extraction of the beginning of the growing season of coniferous forest was developed and implemented since it was not available from literature. The dates of soil freeze were provided by Action 2.
Delivery of results to Action 9 for validation purposes	- Delivery of dedicated time-series - Delivery of carbon-balance-related features	Completed.

4.1.8 Action 8: Demonstration and validation by FMI

The CAL-VAL site model evaluations were performed against in situ data of CO_2 fluxes and snow cover. Site level evaluations revealed disagreements in model performance that were partly possible to correct for each specific site by calibrating both the level of winter time soil respiration as well as the photosynthetic capacity (Figure 4.1.8.1). The evaluation revealed also disagreement in timing of processes that could not be corrected for by any straightforward calibration of the model parameters as the seasonality of carbon cycle is superposition of several processes acting in different time scales (Figure 4.1.8.2).

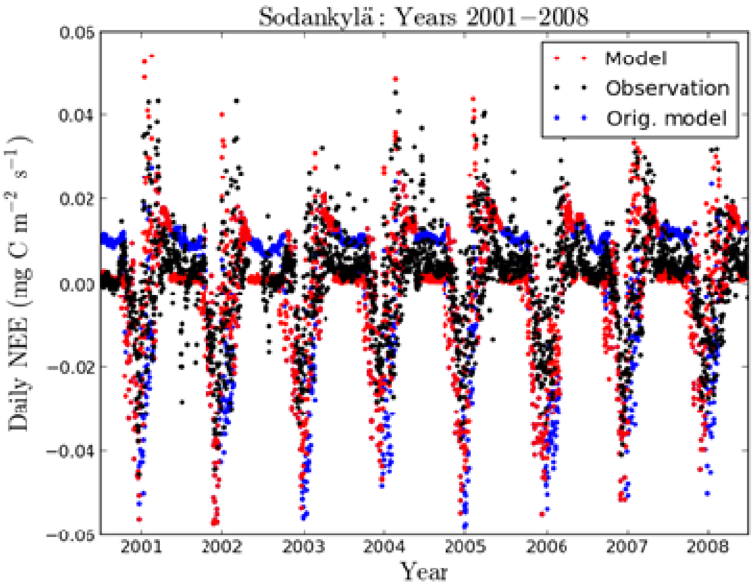


Figure 4.1.8.1: The daily NEE at Sodankylä in 2001-2008. The observation is in black, the original model in blue and the modified model in red.

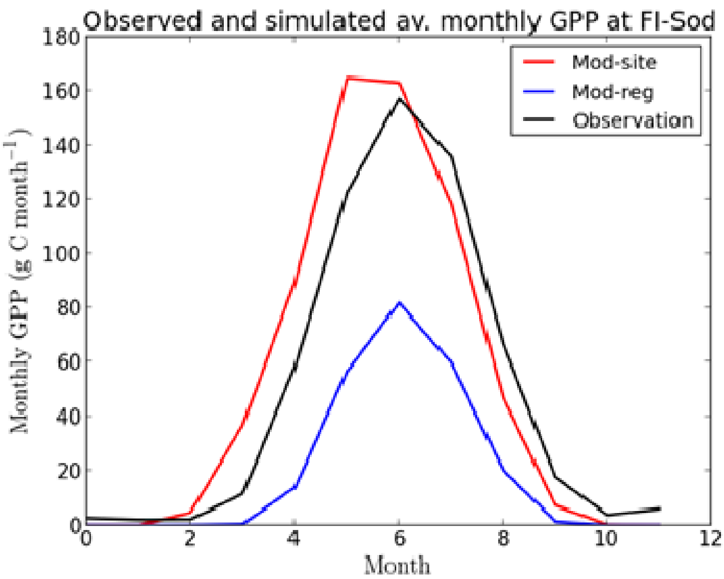


Figure 4.1.8.2: Mean monthly modeled and measured GPPs at Sodankylä in 2001-2009. The JSBACH results forced with REMO meteorology is in blue, the JSBACH result forced with local measurement is in red and the black line is direct observation by EC. Note that months run from 0 to 11.

Comparisons between the site level runs and JSBACH and ORCHIDEE models were performed for a southern Finnish site of the University of Helsinki, Hyytiälä. This comparison showed that the net balance over nine simulated years was best produced by the version of ORCHIDEE adjusted specifically for arctic ecosystems. However, both the soil respiration dominated winter net CO_2 releases as well as the photosynthesis dominated growing season CO_2 uptake levels were highly overestimated. The standard ORCHIDEE that was calibrated with the first year of the data series predicted both summer and winter levels relatively well, while uncalibrated JSBACH overestimated soil respiration in winter time, and underestimated uptake in summer time, thus producing too small net CO2 balance over the nine year period (Figure 4.1.8.3).

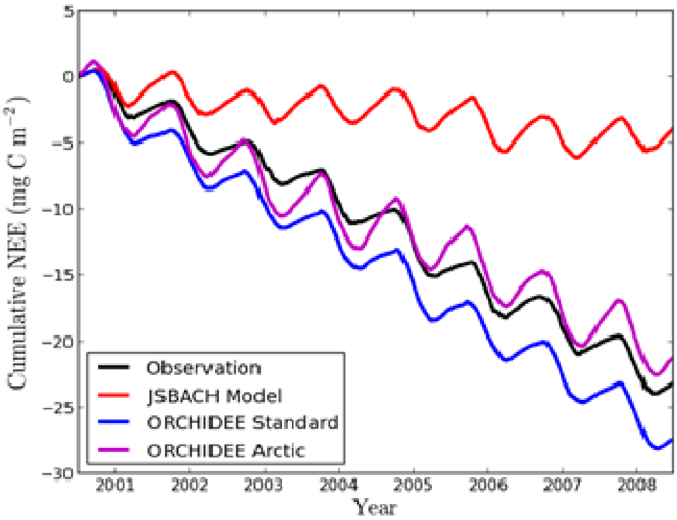


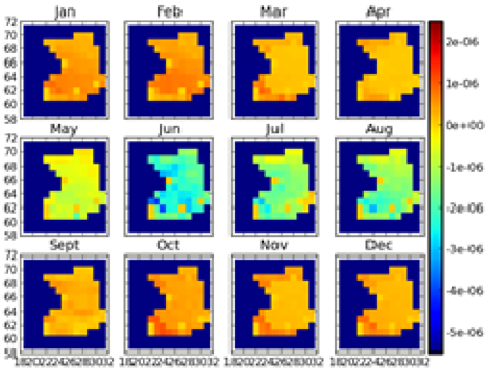
Figure 4.1.8.3: The cumulative NEE values at Hyytiälä in 2001-2009: observations (in black), JSBACH model (in red), ORCHIDEE model (in blue), ORCHIDEE Arctic model (in magenta).

Regionally the predicted CO_2 balances of Finnish territory were evaluated against another regional model result – CarbonTracker Europe - as well as against the National GHG inventories. CarbonTracker Europe is intended for producing atmospheric inversion results for 'ecoregions' of rather large a scale, not for extracting sub-areas such as individual countries as the reliability of the results is not sufficient. However, within Finnish territory the monthly levels show that the seasonality and the range of variability match relatively well between the two different modeling approaches (Figure 4.1.8.4). Concerning the National GHG inventories, the ecosystem fraction of the National balance is intended to reflect the variations in the GHG source/sink stenght due to human activities. Thus the small time scale climatic variations are dampend by using mean climatic variables of the past years in forcing the ecosystem modules. All in all, neither of the available reference data comes without pre-conditions. However, general conclusions can be drawn about the functionality of the modeling system implemented in this work.

Generally the completion of this action was delayed up to 9 months because of delays in the Methodology development and implementation by FMI in Action 6. All the proposed tasks were completed by the end of the project. The biggest deviation from the original work plan was the selected resolution of modeling grid: On one hand, while in the work plan it was said that grids of various resolutions will be modeled (0.25, 0.05 and 0.01 degrees), we only modeled a grid of intermediate resolution of 0.167 degrees. This is because the lower limit of applicability of the regional climate model REMO is around 0.1 degrees and thus the climate data as well as certain surface fields that were adopted for JSBACH from REMO were available in the 0.167 degree resolution of climate runs. On the other hand, we did not run the models separately for Finland and Baltic domains but the domain included all the area of interest at once.

Preliminary demonstration report by FMI explains the intended evaluations of some central variables together with outline of the methods. Additionally, some preliminary evaluation results are shown.

Demonstration report by FMI describes the results of the evaluations of the modeling framework. It specifies the approaches taken, explains the characteristics of the applied reference data, describes the runs setting and finally reports the outcome of the validations. Following validation steps were taken: 1) comparison of the site-level simulations run with local meteorology with flux measurements, 2) comparison of the previous with the ORCHIDEE model runs, 3) comparison of the site-level results extracted from the regional simulations with flux site data and 4) comparison of the regional results to national forest inventories and inverse model results.



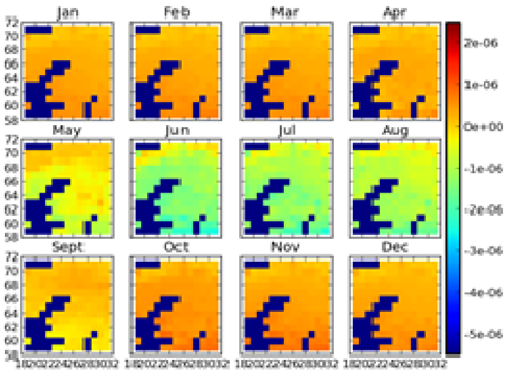


Figure 4.1.8.4: Monthly CO_2 balance of Finland in 2002 predicted by CTE (left) and SnowCarbo modeling framework (right). The horizontal resolution is 1^o and the unit is µmol/m^{2}s.

4.1.9 Action 9: Demonstration and validation of EO services

Action 9 was used to gather data from the other actions focusing on in-situ data (Actions 4 & 5), satellite derived data (Actions 3 & 7) and the land cover data (Action 11) and use the data to support the development of REMO-JSBACH carbon balance modelling framework and validate the outcome from the model. For this purpose data transfers between partners and project team members were established in Action 9 together with Finnish Meteorological Institute (FMI).

For communicating the data within the project several different approaches were used. The full satellite dataset from SYKE was archived on two sets of external hard-drives to be transferable to project partners if need should arise. For subsets of intermediate and final products an FTP-server was set-up to be used between the partners for data exchange. Additionally internal- pages were set-up at the project website to account for document exchange between the partners, but to also allow access to the monitoring organization of Life+.

Operational EO (Earth Observation)-services can provide highly useful data for climate modeling as the satellite era starts to span over several decades and observations are spatially extensive and usually conducted daily. In Action 9 EO- Services developed at SYKE in the GMES Service Element (GSE)- program are used to improve the carbon cycle modelling and to help validate the model performance. The satellite dataset was built on the existing services at SYKE, although the processes were changed and improved, and the spatial extent expanded and product selection improved to better serve the purposes of SNOWCARBO- project. This work was done in Action 3.

Indicators based on time-series of snow covered (SCA) area and normalized difference vegetation index (NDVI) related to changes in annual carbon cycle were derived and validated in Action 7. Using the developed methodology, the phenological events could be mapped in larger scale. This was done in Action 9 for Finland, where abundant reference information was available. The methodology for deriving carbon balance related indicator of growing season start date (GSSD) was derived and validated in Action 7. Comparison with modelling results, by deriving same indicator from the modelling results and using Finland as the area for comparison, showed GSSD of 17 days delay on average for the modelling results compared to those derived from satellite data. Inter-annually the results varied from 8-30 days, always showing earlier GSSD for the satellite data. Spatially the results show good correspondence, when considering the systematic bias. Comparison of the mean GSSD, both form from the modelling results and the satellite data, from 2003-2008 in Finland is shown in Figure 4.1.9.1. The result suggests that the model is producing reliable estimates on the start of the growing date, but there is some process that makes the vegetation start strong photosynthesis earlier than in reality. Also the peak of the growing season and end of growing season were derived from satellite data, in Action 7, but the analysis showed that the NDVI was not sufficiently sensitive to the changes in vegetation to produce reliable results to be compared with model data. For peak of the growing season the maximum in NDVI was not sufficiently strong to be unambiguously defined. For end of the growing season, the NDVI is not sensitive for coniferous forests and then low sun angle during the end of the growing season was restricting the use of optical satellite data.

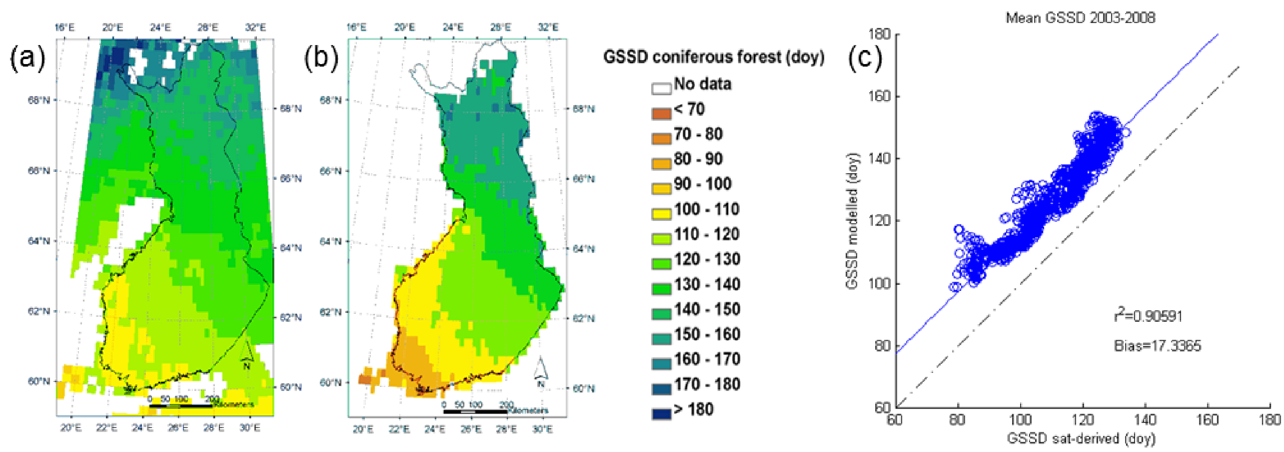


Figure 4.1.9.1: Mean GSSD from modeling data (a) and from satellite data (b) and scatter-plot from the estimates from the area of Finland (c) shows good correlation between the two datasets, but with a systematic bias.

One of the tasks considered was the direct input of the satellite data into the REMO-JSBACH modelling framework. To directly feed the model process flow with remote sensing data proved to be more difficult than anticipated and therefore the main use of the optical satellite data was to use it for model parameter and result validation. The input of remote sensing derived data was accomplished with land cover data, where there was a relatively straight forward way to modify the dataset and use one of the pre-processors used by the REMO-model to input the modified dataset into the dataflow of the model.

A global land cover dataset previously used with REMO- model was the global ecosystem classification by United States Geological Survey (USGS, Olson 1994a and 1994b). The original dataset was created by combining satellite data and hard and soft copies of existing ecosystem classifications. The regional and global land cover (and ecosystem) classifications have improved since then and the land cover has gone through changes, therefore it was clear that improved land cover classification would provide more reliable carbon balance estimates from the models. The classes themselves were covering wide range of land cover/land use types, but the spatial distribution of the classes was not accurate. In Action 11, different land cover datasets were re-classified to the USGS classification system to give more reliable spatial distribution of land cover. The optimal land cover was obtained by combining several existing datasets from the area under investigation. The land cover datasets used were: Finnish National CORINE, European CORINE and ESA GlobCover. In the analysis of land cover effects on the modelling parameters and results were evaluated by comparing the USGS land cover classification ant the combination land cover.

The effects of land cover data on the modelling results were investigated in Finland in two ways during the project. First the effects of land cover on the modelled snow cover produced by the REMO- model, which influenced the local climate used for modelling the carbon balance. The increase in other land cover/land use types from the USGS land cover to the combination land cover seemed to increase the snow depth in general (Figure 4.1.9.2). The changes were most pronounced in the areas where the land cover was changed from forest types (evergreen deciduous, which does not really exist in Finland and coniferous) were changed to wetlands. The surface energy balance changes between different land cover types and therefore affects the snow melt rate.

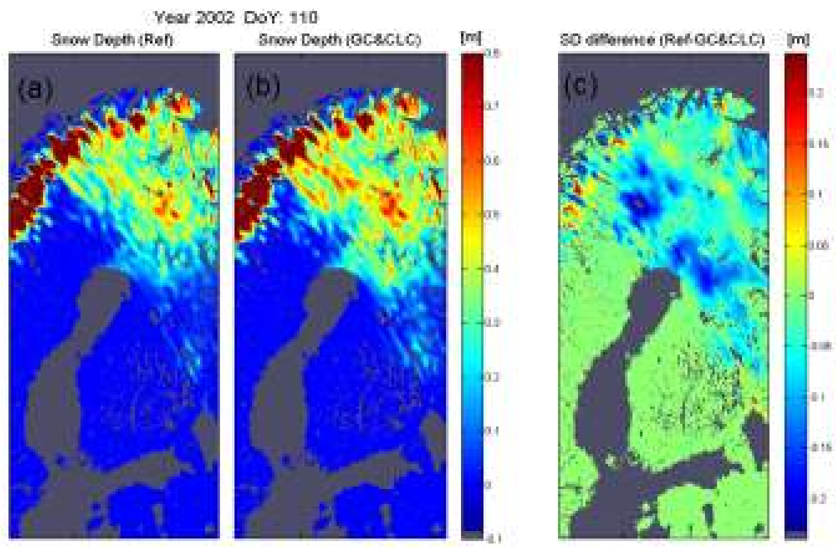


Figure 4.1.9.2: Example of the effect of land cover on model parameters. (a)Snow cover from REMO- model run with USGS land cover and (b)with the combination land cover (Finnish National CORINE-land cover, European CORINE land cover and GlobCover) (c) and the difference in snow depth.

The carbon balance results show that the coniferous forests have a significant role in the carbon balance of Northern- latitudes (Figure 4.1.9.3). The USGS classification over estimates the amount of coniferous forests and therefore produces on average a net-sink for the annual carbon balance. Using the improved land cover data, the Scandinavia and Finland stay close to zero balance, but the Baltic countries, Western-Russia and Belarus, display as annual sources of carbon-dioxide, the main differences between the two datasets in these areas being the over estimation of coniferous forests in areas of summer-green vegetation by USGS classification.

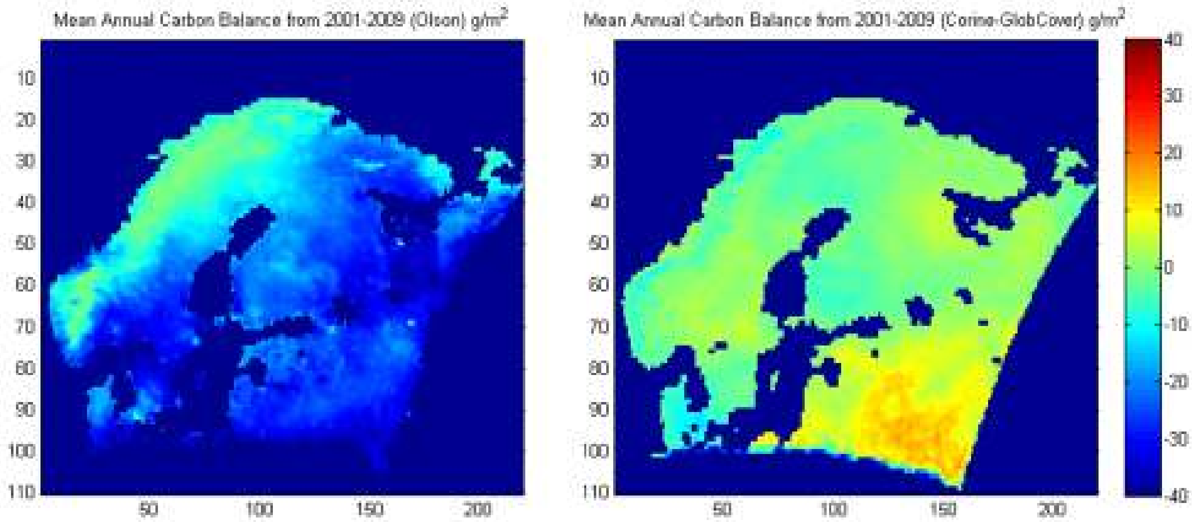


Figure 4.1.9.3: Carbon balance estimates with two different land cover datasets from 2001-2009. USGS land cover data (left) and Corine-GlobCover combination dataset (right).

During the course of the model development, snow parameters produced by the REMO climate model were compared with satellite derived and in-situ snow data. The model seemed to develop too thin snow cover which disappeared 10-20 days earlier than in reality. The ECMWF- input data was reviewed and some clear errors in the snow cover were observed. Also the findings of the snow cover representation and the discrepancies observed in the GSSD (see above) supported the model development process where some adjustments were made to the surface temperature representation.

Table 4.1.9.1. Summary of the work planned and performed in Action 9

Expected result	Tasks/work planned	Performed
Data sharing		
Setting up web-site for document exchange	Website set up in Action 12. The documentation will be passed through the site for external access also.	SNOWCARBO- webs te http://snowca·bo.fmi.fi was set up and had open directory project deliverables and nternal page for e.g. meeting notes and presentations. Life+ monito· had access to both general and internal pages.
Bulk dataset (MODIS and AVHRR Raw, Intermed ate and product data)	To be set up on two sets of hard drives for delivering the entire dataset to project partner and as backup.	As planned.
Results and subset of the main dataset	FTP- set up for delivering results and smaller subsets of the main dataset, with access for all partners.	FTP- was set up in the FMI- premises due to easier set-up.
Use of GMES EO-service		
The EO datasets are in use to support the model framework development	EO based services are in use and feedback is collected.	GSE PolarView snow service was operational during the entire course of the project. The snow data was extensively used in the model development, whe·e comparisons were made with the model parameters and results. GSE Land products (NDVI) were also collected and used in when selecting the appropr ate method for carbon balance indicator development. Land cover data was used as input to the models.
Climate sensitive indicators for model validation		
Satellite data collection	In Action 3	See Action 3.
In-situ data collection	In Action 5	See Action 5.
Method development	In Action 7	See Action 7.
Combining data sources	Combining data sources for method development	Although written in Action 9 in the plan, the combinat on of data sources is important part of method development and therefore done n Action 7. (See Action 7).
Reporting		
Data exchange document	Document on data exchange methods	Completed as planned.s
Prelim nary Demonstration report	Document on first evaluation of the modeling framework	Completed as planned.
Demonstration report	Document on model evaluation	Completed delayed due to delayed availability of model ng data.

4.1.10 Action 10: Generation of carbon assessment end-products

This action has produced the digital carbon balance maps covering years from 2001 to 2009. The maps of highest degree of detail have been produced with the land cover based on the National Corine data (Action 11). The raw data from the model is given in the rotated latitude-longitude grid with resolution of 0.167 degrees. The time resolution of the raw data is one hour and it comprise all the predicted variables of JSBACH model and a wide selection of 2D and 3D meteorological variables predicted by REMO. The carbon balance related JSBACH output fields, such as GPP, NPP and soil respiration have been stored in daily resolution in the original rotated grid. These files are available for the scientific community by demand.

For public, monthly and yearly the CO_2 balance mapped data have been transformed into non-rotated latitude-longitude grid. This has been provided to Action 12 that made the data accessible via Erdas Apollo database. Furthermore, a table of monthly and yearly CO_2 balance values for Finland have been produced for comparison with the National GHG inventories.

Deviating from the original listing of the expected results, instead of applying three different resolutions for results, the CO_2 balances, together with other model outputs including all relevant energy balance terms, were calculated for the grid resolution of 0.167 degrees. The time span of the simulated results expands from 2001 to 2009 instead of end 2011. This is due to lack of processes boundary data for the REMO model. For the same reason the scenarios were excluded from the end results. However, the implemented modelling framework provides a tool for modelling CO_2 balance for any period of time there is a suitable climatological boundary data available – either for hind casts or for forecasts. The condition of the validity of the land cover information in the future, that was brought up in the original work plan, can be estimated with models taking into account the land use related policies. Nevertheless, as the impact of such policies is visible with considerable delay, the applicability of the land cover maps utilised in this work will extend to at least a decade onwards from the present.

In the following the CO_2 balance mappings in rotated grid are shown both in yearly (Figure 4.1.10.1) and monthly (Figure 4.1.10.2) time resolutions of 2001-2009. The colour scheme of the figures has been selected to distinguish between sink and sources of CO2 that are shown in green and red, respectively. The units are given either in grams of carbon per square meter ($g(C)/m^2$) or in million tons of CO_2 per country. These units are in accordance with conventional practice of research in atmospheric sciences and forestry, on one hand, and GHG inventory reporting on the other. The sign convention is conventional for NEE: negative values indicate removal from the atmosphere by surface sinks and positive values indicate release of CO_2 to the atmosphere.

From the yearly maps (Figure 4.1.10.1) it can be seen that the balance vary strongly both from year to year and among different regions. The strong variation is because NEE is a balance in between two big terms - net assimilation by plants and soil respiration – whose responses to climatic variables are non-linear and response times vary among processes. The impact of climatic drivers has been discussed in Demonstration report by FMI of Action 8.

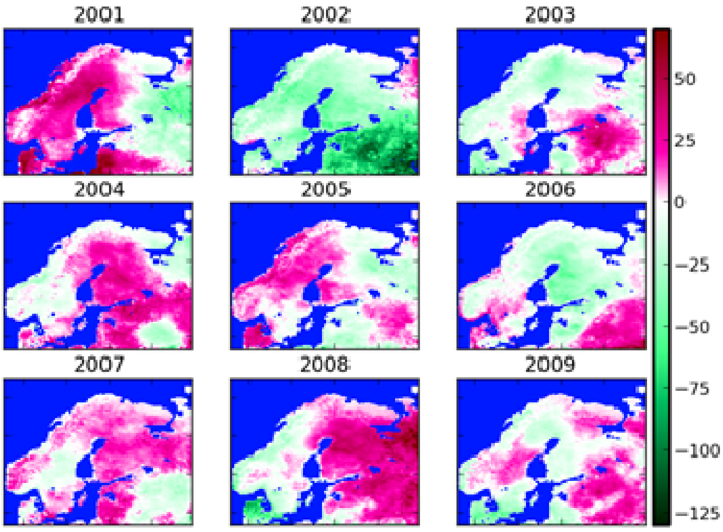


Figure 4.1.10.1: Yearly CO_2 balance of years 2001-2009 in the original model grid with the resolution of 0.167 degrees. Ecosystem sources of CO_2 are indicated in red and sinks in green. The values are given in terms of grams of carbon per area (g(C)/m^2).

Figure 4.1.10.2: Monthly CO2 balance in 2001-2009. The domain specifications, colour scheme and units same are as in Figure 4.1.10.1.

4.1.11 Action 11: Evaluation of required Northern-Eurasian land cover information

Land cover classification give the spatial distribution of land cover types and surface parameters allocated for each land cover. These characterize each land cover category used by the models. The information needs and content in carbon balance modelling (REMO and JSBACH) have been studied together with service providers of land cover information at SYKE and modelling group at FMI (see separate report Land Cover Data Needs for Carbon Balance Mapping). According to the information needs several sets of gridded land cover maps were produced in different resolutions (scales) and geographical coverage:

3. Detailed (local) land cover information covering intensive in-situ monitoring areas (flux stations in northern Finland) were produced using satellite data (IRS P6 LISSIII, SPOT 4 XS, LANDSAT 5 TM, KOMPSAT 2) together with ancillary GIS and in-situ data. Employed methods included estimation of land cover variables using rule-based predictive models. Additionally Finnish national CORINE land cover databases were utilized.
4. In standard model versions the surface cover data is a global 1km resolution land cover dataset based on Olson ecosystem classification. Since Olsson data do not describe Nordic land cover properly, alternative land cover information was produced. Different revised land cover data sets recoded into Olsson nomenclature were produced and delivered covering the modelling window in Scandinavia and surrounding areas. Following data were utilized:
    - e) GlobCover (regional version 2.2)
    - f) European Corine Land Cover (CLC2006)
    - g) National Corine Land cover (CLC2000 and CLC2006)
    - h) Clusters of MODIS products (MOD15 Leaf Area Index and MCD43 Albedo)

Additionally feasibility of surface parameters (Forest ratio and LAI) allocated to each land cover category was evaluated using local estimates of crown cover and LAI in Nordic conditions. Reliable characterization of forests is essential in Scandinavia, where conifer boreal forests cover the most of land areas. It was found that local estimates of LAI and forest ratio deviate significantly from corresponding original values allocated to Olsson land cover categories in Scandinavia. This information was utilized when revising land cover data for modelling. This work is reported in separate document (Land Cover Data for Carbon Balance Mapping).

Figure 4.1.11.1: Combination of CORINE Land Cover 2006 and GlobCover

When considering feasibility of land cover information for carbon balance modeling in terms of thematic accuracy of data, European and national version of Corine Land Cover 2006 should be used as input data source for land cover information over Scandinavia. In the areas where CORINE land cover data does not exist (territory of Russia) GlobCover can be used. These data describes well the spatial distribution of land cover categories in Nordic areas. Combination of CORINE land cover and GlobCover data was produced covering the modelling window in Nordic areas and these data were used to replace the old Olsson land cover data original used by the models (see Figure 4.1.11.1).

Allocation of constant value of surface parameters for each land cover category does not always correspond properly to the situation in the field, where surface characteristics vary also within single land cover category. This is the case for example in the land cover category boreal coniferous forest, where density of forest (crown coverage) varies significantly from south to north. The crown coverage in coniferous boreal forests in Southern Finland reaches over 80%, while in northern-most Finland the crown coverage is less than 30%. Also surface parameter leaf area index (LAI) has significant variation within the same land cover category due to climate conditions. Thus land cover categories should be further divided into subcategories, or preferably, whenever possible surface characteristics should be provided to the models as continuous fields of each surface parameter. This information is available globally, provided for example in the global component of Gio land as part of GMES programme.

Table 4.1.11.1. Summary of the work planned and performed in Action 11

Expected result	Tasks/work foreseen	Performed
Evaluation of land cover information needs for spatial carbon balance mapping	-Discussions with the modeling and remote sensing groups at FMI and SYKE. -Litterature survey.	Done and reported
Evaluation of the suitability of global land cover products for spatial carbon balance mapping and monitoring.	-Download recent global and regional land cover data (GlobCover, GlobCorine, Corine2006). -A new land cover data was produced with the aid of MODIS geophysical products and existing land cover data. -Suitability was assessed in terms of thematic accuracy and feasibility of global surface parameters in Nordic conditions. -Allocation of land cover gategories into Olsson nomenclature and surface parameters	Alternative land cover data sets were completed and provided for the modeling. Combination of Finnish national version of CORINE2006, EU version of CORINE2006 and Globcover was proposed as input for the modeling.
Extrapolation of pointwise field information of carbon balance for large areas	Production of continuous fields of surface characteristics for validation purposes	not done, since pointwise field data was preferred for validation purposes.
Production of detailed land cover information covering intensive monitoring areas using novel, new satellite data together with ancillary GIS and in-situ data.	-Land cover mapping in northern Finland in different scales and using multiple satellite instruments (IRS LISS, KOMPSAT)	Land cover maps were produced and provided covering the surroundings of Sodankylä cal/val site and whole of North-Finland
Accuracy assessment of produced information with the aid of field data.	-The thematic accuracy of selected, alternative land cover data sources was assessed using existing data sources.	Done

4.1.12 Action 12: Dissemination

Objectives of Action 12 primarily include the distribution of end-product produced in Action 10 to stakeholders and general public. Following activities produced and delivered during 4 years' time of the SnowCarbo project from 2009-2012 and future dissemination plans:

a) Project brochures and leaflets
b) SnowCarbo project website
c) Notice boards
d) FMI Erdas Apollo
e) The carbon balance atlas
f) Scientific publications
g) Dissemination workshops of SnowCarbo project
h) The synthesis report on the results of SnowCarbo project results

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 also planned to publish to scientific refereed journals.

Detailed information related to Action 12 was given under chapter 4.4 Dissemination issues.

4.1.13 Action 13: Auditing

This action was performed and detailed information given under chapter 6.Comments on the financial report.

4.1.14 Action 14: Project advisory co-operation

Within Action 14, the CEA advisory co-operation with FMI and SYKE mainly focused on **modelling aspects**, a field of expertise of the CEA. Discussion and exchanges concerned:

- Model required **input parameters** (soil properties, vegetation, and snow) and model **sensitivity** to them
- Model results **interpretation**
- Assessment of **consistent** model behaviours.

The partnership between CEA and FMI focused on two main points. The first one deal with the role of snow cover in driving the soil carbon distribution. The second one is devoted to the analysis of snow cover variations induced by aerosol deposition.

1/ First point: snow-cover and soil carbon distribution

Co-operation on the first point involved cross-model simulations at the study-sites selected for the SnowCarbo project, most notably Hyytiälä. There, the carbon balance for the 1997-2009 period was simulated by the land surface and carbon model ORCHIDEE, developed by the CEA and especially suited for high-latitudes regions ; the results were compared with simulations carried out with the FMI modelling-line including REMO and JSBACH. The results of this comparison are mentioned in Action 8.

The understanding of the modelled carbon balance sensitivity to parameters such as land-cover data fostered closer investigations by the CEA, which took the form of a publication in the Journal of Geophysical Research (Gouttevin et al., 2012), with following resume:

We demonstrate the effect of an ecosystem differentiated insulation by snow on the soil thermal regime and on the terrestrial soil carbon distribution in the pan-Arctic area. This is done by means of a sensitivity study performed with the land surface model ORCHIDEE, which furthermore provides a first quantification of this effect. Based on field campaigns reporting higher thermal conductivities and densities for the tundra snowpack than for taiga snow, two distributions of near-equilibrium soil carbon stocks are computed, one relying on uniform snow thermal properties and the other using ecosystem-differentiated snow thermal properties. Those modeled distributions strongly depend on soil temperature through decomposition processes. Considering higher insulation by snow in taiga areas induces warmer soil temperatures by up to 12 K in winter at 50 cm depth. This warmer soil signal persists over summer with a temperature difference of up to 4 K at 50 cm depth, especially in areas exhibiting a thick, enduring snow cover. These thermal changes have implications on the modeled soil carbon stocks, which are reduced by 8% in the pan-Arctic continental area when the vegetation-induced variations of snow thermal properties are accounted for. This is the result of diverse and spatially heterogeneous ecosystem processes: where higher soil temperatures lift nitrogen limitation on plant productivity, tree plant functional types thrive whereas light limitation and enhanced water stress are the new constrains on lower vegetation, resulting in a reduced net productivity at the pan-Arctic scale. Concomitantly, higher soil temperatures yield increased respiration rates (+22% over the study area) and result in reduced permafrost extent and deeper active layers which expose greater volumes of soil to microbial decomposition. The three effects combine to produce lower soil carbon stocks in the pan-Arctic terrestrial area. Our study highlights the role of snow in combination with vegetation in shaping the distribution of soil carbon and permafrost at high latitudes.

Figure 4.1.14.1 illustrates the impact of increased insulation by snow in taiga biomes on the soil C respiration rates. It underlines one critical aspect of the use of precise and reliable land-cover map for soil carbon modelling, as well as the need of model development in the representation of snow-vegetation interactions.

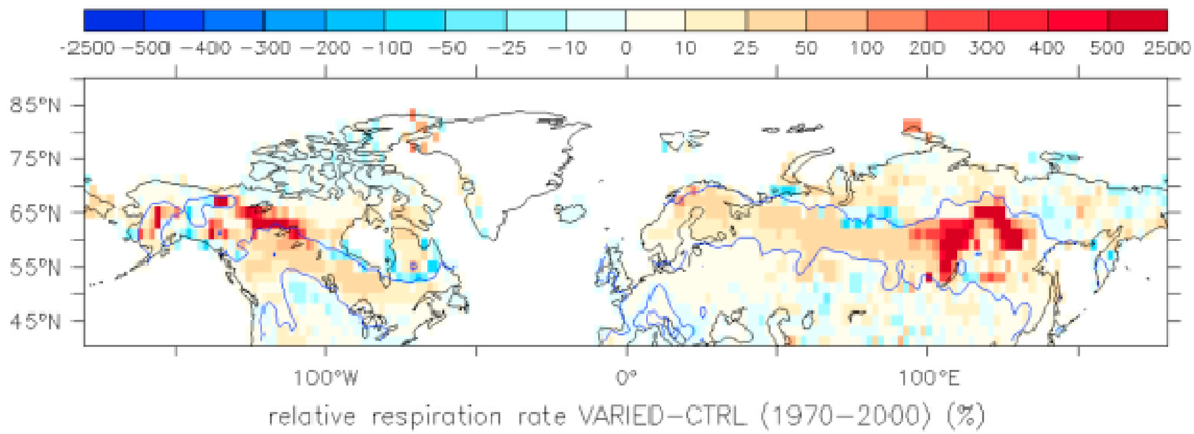


Figure 4.1.14.1 : Relative difference in respiration rate (fraction of annually respired total soil carbon) between a simulation where taiga snow is more insulative than tundra snow, minus a simulation where both snow types are treated as tundra snow, e.g. poorly insulative. The blue line contours taiga ecosystems in the model.

2/ Snow cover variations induced by aerosol deposition

A paper is currently in revision for The Cryopshere (Ménégoz et al., 2012), with following resume:

We used a coupled climate-chemistry model to quantify the impacts of aerosols on snow cover north of 30°N both for the present-day and for the middle of the 21st century. Black carbon (BC) deposition over continents induces a reduction in the Mean Number of Days With Snow at the Surface (MNDWS) that ranges from 0 to 10 days over large areas of Eurasia and Northern America for the present-day relative to the pre-industrial period (Figure 4.1.14.3a). This is mainly due to BC deposition during the spring, a period of the year when the remaining of snow accumulated during the winter is exposed to both strong solar radiation and large amount of aerosol deposition induced themselves by a high level of transport of particles from polluted areas (Figure 4.1.14.2a). North of 30°N, this deposition flux represents 222 Gg BC month-1 on average from April to June in our simulation. A large reduction in BC emissions is expected in the future in all of the Representative Concentration Pathway (RCP) scenarios (Figure 4.1.14.3b). In particular, considering the RCP8.5 in our simulation leads to a decrease in the spring BC deposition down to 110 Gg month-1 in the 2050s. However, despite the reduction of the aerosol impact on snow, the MNDWS is strongly reduced by 2050, with a decrease ranging from 10 to 100 days from present-day values over large parts of the Northern Hemisphere (Figure 4.1.14.3b). This reduction is essentially due to temperature increase, which is quite strong in the RCP8.5 scenario in the absence of climate mitigation policies. Moreover, the projected sea-ice retreat in the next decades will open new routes for shipping in the Arctic (Figure 4.1.14.2c). However, a large increase in shipping emissions in the Arctic by the mid 21st century does not lead to significant changes of BC deposition over snow-covered areas in our simulation. Therefore, the MNDWS is clearly not affected through snow darkening effects associated to these Arctic ship emissions (Figure 4.1.14.3c). In an experiment without nudging toward atmospheric reanalyses, we simulated however some changes of the MNDWS considering such aerosol ship emissions (Figure 4.1.14.4a). These changes are generally not statistically significant in boreal continents, except in the Quebec and in the West Siberian plains, where they range between -5 and -10 days. They are induced both by radiative forcings of the aerosols when they are in the snow and in the atmosphere, and by all the atmospheric feedbacks. These experiments do not take into account the feedbacks induced by the interactions between ocean and atmosphere as they were conducted with prescribed sea surface temperatures. Climate change by the mid 21st century could also cause biomass burning activity (forest fires) to become more intense and occur earlier in the season (Figure 4.1.14.2d). In an idealized scenario in which forest fires are 50% stronger and occur 2 weeks earlier and later than at present, we simulated an increase in spring BC deposition of 21 Gg BC month-1 over continents located north of 30°N. This BC deposition does not impact directly the snow cover through snow darkening effects (Figure 4.1.14.3d). However, in an experiment considering all the aerosol forcings and atmospheric feedbacks, except those induced by the ocean-atmosphere interactions, enhanced fire activity induces a significant decrease of the MNDWS reaching a dozen of days in Quebec and in Eastern Siberia (Figure 4.1.14.4b).

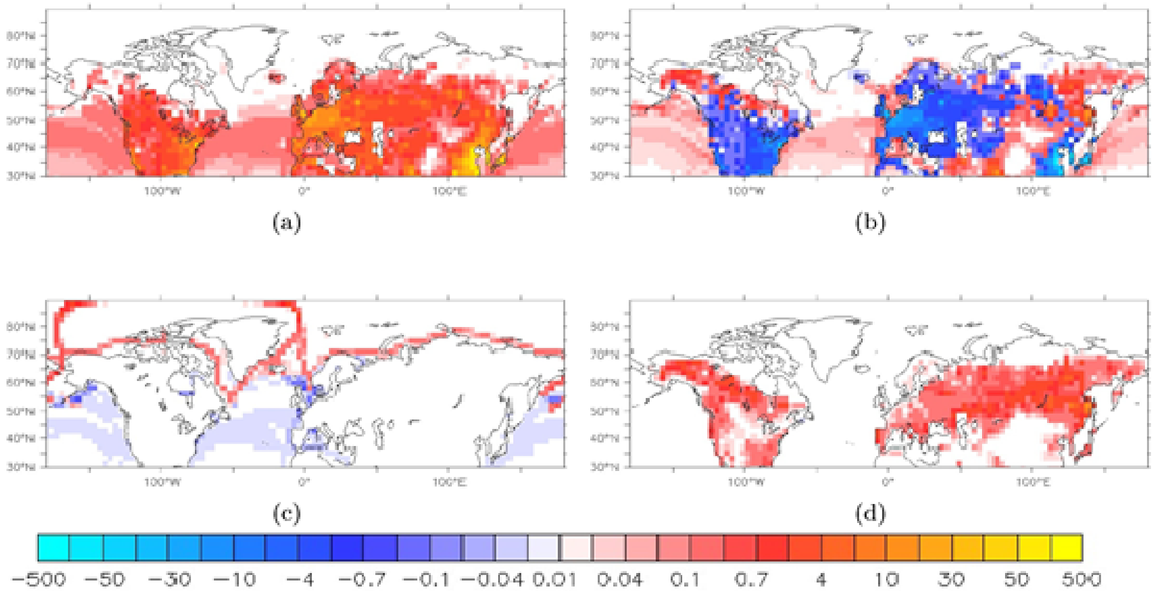


Figure 4.1.14.2: Annual mean of BC emissions (mg m-2 month-1); (a): Current emissions (S1, total=2878 Gg/yr); (b): difference between 2050 RCP8.5 scenario and current emissions (S2-S1; difference= -1588 Gg/yr); (c): difference in 2050 ships emissions in a scenario with a large ship traffic over the Arctic region (Corbett et al.; 2010) with the 2050 RCP8.5 projected ship traffic scenario (S3-S2, difference=+3.9 Gg/yr); (d): difference in 2050 fire emission between a scenario with lengthened biomass burning season (constructed after Flanningan et al. ; 2009a, 2009b) and the 2050 RCP8.5 scenario projected fire emissions (S4-S2, difference=+235.9 Gg/yr).

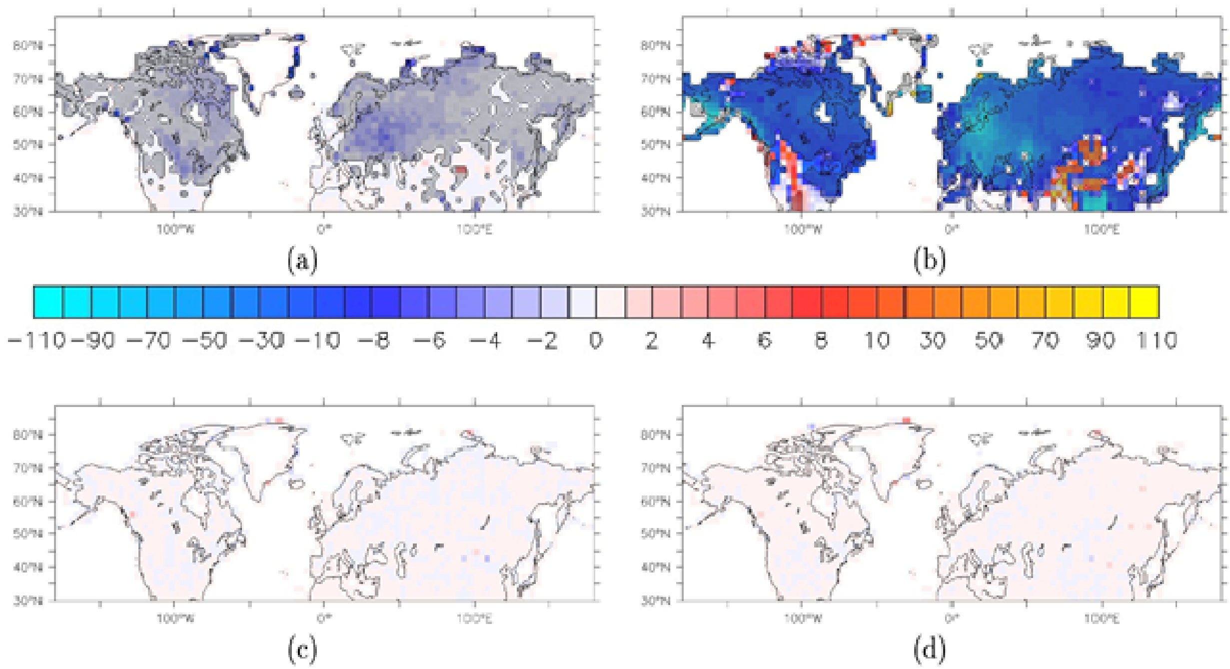


Figure 4.1.14.3: Mean number of days per year with snow at the surface (MNDWS); (a):Present-day MNDWS difference induced by BC deposition on snow; S1-S1B. (b):

MNDWS difference between 2050 climate with RCP8.5 emission scenario and present-day simulation (S2_N-S1); (c): MNDWS difference between a 2050 scenario with higher ship traffic in the Arctic in comparison with 2050 RCP8.5 scenario (S3_N-S2_N); (d): MNDWS difference between a 2050 scenario with increased biomass burning activity in comparison with 2050 RCP8.5 scenario (S4_N-S2_N). Note that future simulations are nudged toward the S2_N future simulation. Areas with statistically significant differences, according to a two-sample t-test, are shaded in grey. Note that the changes shown in (a) and (b) are statistically significant over the major part of the domain.

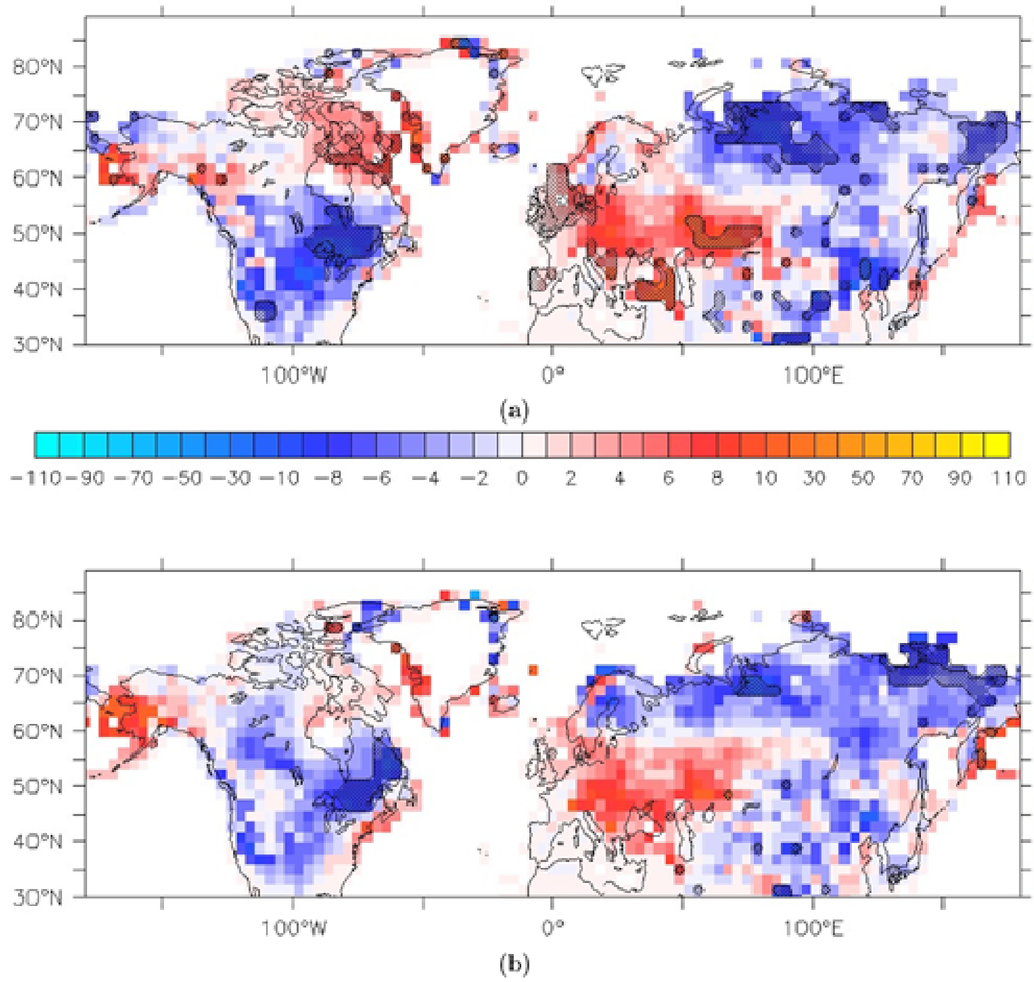


Figure 4.1.14.4: Mean number of days per year with snow at the surface (MNDWS); (a): MNDWS difference between a 2050 scenario with higher ship traffic in the Arctic in comparison with 2050 RCP8.5 scenario (S3-S2); (d): MNDWS difference between a 2050 scenario with increased biomass burning activity in comparison with 2050 RCP8.5 scenario (S4-S2). Simulations S2, S3 and S4 are not nudged. Areas with statistically significant differences, according to a two-sample t-test, are shaded in grey and contoured.

References:

Gouttevin, I., Ménégoz, M., Dominé, F., Krinner, G., Koven, C., Ciais, P., Tarnocai, C., Boike, J.: How the insulating properties of snow affect soil carbon distribution in the continental pan-Arctic area, Journal of Geophysical Research, 117: G02020. DOI: 10.1029/2011JG001916, 2012.

Ménégoz, M., Krinner, G., Balkanski, Y., Cozic, A., Boucher, O., and Ciais, P.: Boreal snow cover variations induced by aerosol emissions in the middle of the 21st century, The Cryosphere Discuss., 6, 4733-4769, doi:10.5194/tcd-6-4733-2012, 2013, in rev. for The Cryosphere

4.1.15 Action 15: After Life+ Communication plan

The detailed plan for communications and actions after the end of the Life+ project were made and can be found under chapter 4.4.3 After-LIFE Communication plan.

4.2 Evaluation

Main activities of this project can be listed as follow

1. Development of a novel Earth observation satellite data-aided system for the monitoring of annual carbon balance by applying observations of hydrological phenomena, phenology, CO_2 fluxes and CO_2 concentration.
2. Use of snow melt information together with GIS land cover data and CO_2 flux/concentration measurements to assess the annual carbon balance with a high spatial resolution.
3. Use of dedicated models for different soil/vegetation types and CO_2 together with a climate model are applied for the determination of carbon sinks and sources

And expected result out of these activities were

- Maps of carbon uptake by terrestrial vegetation, soil respiration and net carbon balance in different land use and cover classes
- Demonstration of the mapping of carbon sources and sinks in boreal forest zone (northern Finland, northern Eurasia) and the assessment of natural background sources from the anthropogenic influence
- Evaluation of the required performance characteristics of Eurasian land cover information for the needs of net carbon balance mapping/monitoring

The methodology developed and implemented in this project is discussed in detail in Action 6. In Action 6, the success and failures of the methodology applied in the Snowcarbo project are explained in detail in Action 6, 8,9,10 and 14.

The evaluation of the modelling system was performed at CAL-VAL site as well as at regional levels. At site level there is reference data available that represents identically many of the variables predicted by the modelling framework. Consequently, to some degree the model could be calibrated to better produce the seasonality and basic level of both GPP and TER, who are the two large terms contributing to CO_2 balance of land ecosystems. However, the site level data is limited in representativeness to certain land cover type that is typically boreal coniferous forest in Finland. Furthermore, even though in Finland the flux site network is relatively dense, generalization of the site level calibrations is only feasible with a rigorous data assimilation system, which would combine other data sources in addition to flux site data. Existing regional reference data on the other hand has their limitations that hinder decisive conclusions about the precision of the modelling system. Nevertheless, the levels of GPP as well as NEE are within the range predicted by other modelling systems. The main concern of Nordic countries being too often a net CO_2 source, can be to some degree corrected by changing the spin-up procedure for ecosystem carbon storages so that the rise in atmospheric CO_2 concentrations is better accounted for. The detail of evaluation of the modelling system is reported in Demonstration Report of Action 8 (30.09.2013).

The simulated concentrations can be marked for example for contributions coming from anthropogenic, biogenic, fire and oceanic sources. The contributions can be plus or minus signed depending if a source or sink is acting on background concentration.

Considering the case of remote station Pallas in Northern Finland, long range transported anthropogenic emissions are clearly visible in winter, while in summer biospheric sources and sinks dominate the CO_2 signal. Thus, in order to study the anthropogenic contribution to observed CO_2, it is easier to focus on winter months. We selected the high CO_2 concentration event observations from December to February 2006-2009, and recorded the length of each event in hours. Event started when hourly mean concentration was elevated 1 std over background and ended when the 1 std level was crossed again. Background level was determined by fitting a linear trend + harmonic function to multi-year time series of CO_2. This removes the year-to-year growth as well as the seasonal cycle in CO_2. For the same observation period of CO, highest concentrations were selected until the track record, or sample, became as long as in the case of CO_2. Note here that the sample is equally sized for comparability, and the high concentration hours do not necessarily occur at the same time. An atmospheric transport model is able to simulate the anthropogenic component in CO_2 by using emission databases and transport modelling. Global 3D multi-component CO_2 simulation results provided by NOAA/ESRL for TM5 (Carbon Tracker) were utilised, and results were extracted for Pallas station for the before-mentioned observation period. Hours with high anthropogenic component concentration (aCO_2) were selected in the same way as was done for CO. Timing of CO and CO_2 and model aCO_2 were correlated. High CO_2 occurred simultaneously with high CO in 72% of the total number of hours during the observation period. High CO_2 hours coincided with high model aCO_2 hours in 76% of the cases. Thus, the model captured the timing of high CO_2 as accurately as the anthropogenic tracer CO.

The absolute values of wintertime CO and CO_2 and modelled aCO_2 were also studied. CO_2 and CO time series were pre-processed in a similar way by removing the species-dependent year-to-year growth trend and seasonal cycle. In Figure 4.2.1 wintertime observed CO_2 concentrations are plotted against modelled total CO_2 ($R=0.83$). Cases when modelled total CO_2 had highly elevated anthropogenic contribution (> 1std over background) are shown in red. The modeled anthropogenic component was correlated with observed CO_2 ($R=0.78$) and with CO ($R=0.75$).

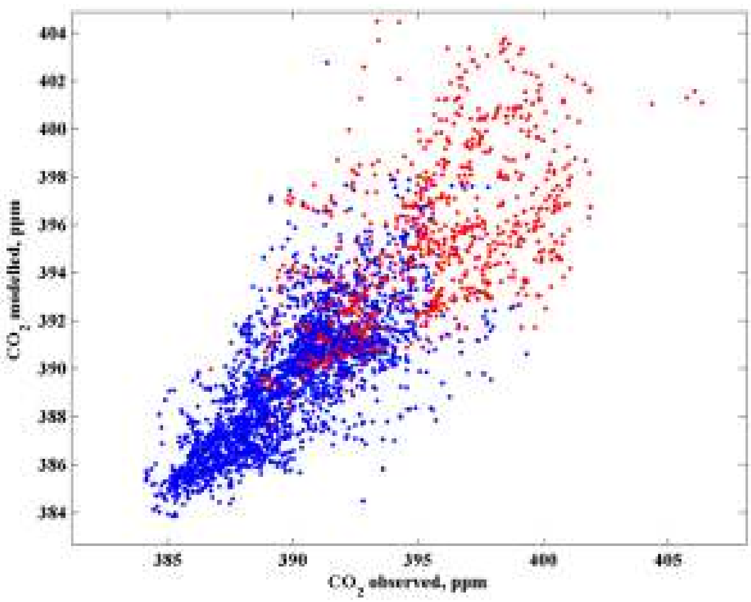


Figure 4.2.1: Wintertime (Dec-Feb) observed CO_2 concentrations vs. modelled CO_2. Red dots refer to cases when modelled CO_2 had a notable anthropogenic contribution.

4.3 Analysis of long-term benefits

Climate change indicators are simple ways of presenting difficult information to the public. In order to map the climate change indicators related to boreal ecosystems, we must use modeling tools. The models will enable projections to the future. The magnitude of climate change is dependent on the atmospheric load of the two most important greenhouse gases, carbon dioxide and methane. The terrestrial biosphere plays an important role in the global carbon balance, and boreal forests and peatlands are an important part of the global carbon cycle. Global carbon balance of the terrestrial ecosystems is known in an accuracy of about +-35% based on atmospheric concentration increase and versatile use of other observational and modeling methods. The uncertainty increases in the regional level, and obtaining accurate figures of country based carbon balances and their future development is a challenge.

To obtain reliable regional carbon balance estimates and accurately predict their future development, spatial coverage of observations should be increased and models calibrated with observations referring to the target region. To interpret and evaluate the results we need knowledge of the regions studied and their specific features. Thus, the contribution of the northern regions to the global carbon balance requires input from researchers who have first-hand knowledge on the climatological conditions and carbon cycling in the boreal zone. In regional modelling it is essential to have up-to-date high-resolution land cover maps and to use vegetation types which correctly correspond to land cover classes. Regional uncoupled models such as developed in SnowCarbo project are important to efficiently develop the processes and scaling approaches. Using regional approach, extreme weather events and their effects and importance on the regional carbon balances can be better quantified.

Main expected longer term benefit from SnowCarbo project is a tool applicable for assessing the impacts of climate change on the land vegetation CO_2 balances for Nordic countries and surroundings. SnowCarbo project provides a tool to assess natural and potential natural CO_2 source and sink strengths. The tool can be also applied in assessing changes of sources and sinks due to land use change or under climate deviating from present.

SnowCarbo project results will make a contribution to GEOSS (The Global Earth Observation System of Systems) and thereby also to (environmental) policies of the European Union. GEOSS addresses 9 areas of critical importance to people and society (www.earthobservations.org/geoss.shtml). Other long-term benefits are

- Increase of knowledge about carbon balances and their projected changes for boreal areas
- Benefit to global model-based assessments of the GHG balances especially wetlands (44% of global wetlands occur in Northern latitudes).

The modeling framework, implemented in SnowCarbo- project, can be used to produce information to support national and international climate policy making and monitoring. The central international conventions and programs in European level, which can utilize the results, are:

- Updating and publishing greenhouse gas inventories (including carbon dioxide) on regular bases to UNFCCC (United Nations Framework Convention on Climate Change),
- **DG CLIMA:** The accounting of greenhouse gas emissions in all sectors of society (e.g. forestry and agriculture) and building mechanisms for restricting emissions,
- **DG ENV:** Imposing emission limits, regulation of emission trade and monitoring of emissions need comprehensive emission accounting and reporting
- **DG ENER:** Emission trade related to energy production; Research and development aiming at reduction of carbon dioxide emissions
- **DG MOVE:** Program for reduction of emissions from land and sea traffic

4.4 Dissemination issues

Objectives of dissemination plan primarily include the distribution of end-product produced in Action 10 to stakeholders and general public. Following activities produced and delivered during 4 years' time of the SnowCarbo project from 2009-2012 and future dissemination plans:

a) Project brochures and leaflets
b) SnowCarbo project website
c) Notice boards
d) FMI Erdas Apollo
e) The carbon balance atlas
f) Scientific publications
g) Dissemination workshops of SnowCarbo project
h) The synthesis report on the results of SnowCarbo project

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 also planned to publish to scientific refereed journals.

Also as part of dissemination SnowCarbo 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.

4.4.1 Dissemination per activity

Project brochures and leaflets: Following project brochures and leaflets were produced by all project partners:

1. SnowCarbo 1st brochure
2. Snowcarbo Newsletter issue No.1 April-2010: CO_2 Balance of Northern Terrestrial Ecosystem
3. Snowcarbo Newsletter issue No.2 December-2010: Progress & Preliminary Achievements
4. SnowCarbo 1st brochure update
5. FMI Erdas Appollo: Reliable Data Dissemination and Spatial Data Discovery and Services
6. SnowCarbo final brochure: Key results & outputs

All these brochures and leaflets were disseminated via SnowCarbo project webpage (http://snowcarbo.fmi.fi), by emails to stakeholders and interested partners. Hardcopies of these material were distributed at scientific meetings/conferences and two dissemination stakeholder workshops. 100 hard copies were produced.

SnowCarbo project website: SnowCarbo project website was updated regularly. From October 19, 2009 the project website layout has been revised. This was based on information or feedback from the users and external monitors. The website now contains only internal password protected pages and public pages. The user protected pages where eliminated. An internal document library page was established for internal purposes of sharing and exchanging files. Also to support the data exchange, an ftp server was set up. On October 20 2009, users where supplied 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 and Stakeholder dissemination workshops material can be found at the website. The SnowCarbo project website was maintained by FMI. All other partners contributed contents of the website. SnowCarbo website will be kept as long as needed. Each partner will advertise and give a link to SnowCarbo website at their SnowCarbo related new projects websites.

Notice boards: Each partner placed Notice boards related to SnowCarbo project at strategic places accessible and visible to the public

FMI Erdas Apollo: FMI Erdas Apollo is data dissemination interface where users can browse, view, and download data and products using OGC standards. It is implemented on a geospatial platform that enables high performance OGC web services. Some of the services include; web map services (WMS), web coverage services (WCS) and web feature services.

The carbon assessment end-products were archived to the Sodankylä data centre. Using the Erdas Apollo data manager, the products is then be cataloged and managed to the Erdas Apollo geospatial server. Erdas Apollo uses the International Standards Organisation (ISO) 19115 for the generating metadata. Thus for SnowCarbo, the Inspire metadata editor is used to generate and validate the metadata template. The carbon assessment end product metadata is in XML format validated using the INSPIRE metadata validator.

The data is then be delivered using Erdas Apollo OGC Services (that is web coverage service wcs and web map service wms). The end-users of the products are able to have direct access to the data products using an out of the box Erdas Apollo web client.

The carbon balance atlas: Digital carbon balance maps covering years from 2001 to 2009 are produced. The maps of highest degree of detail have been produced with the land cover based on the National Corine data. Deviating from the original listing of the expected results, instead of applying three different resolutions for results, the CO_2 balances, together with other model outputs including all relevant energy balance terms, were calculated for the grid resolution of 0.167 degrees.

Scientific publications: During the SnowCarbo projet time (1.1.2009-31.12.2012) many results of SnowCarbo project had been published as journal articles and conference proceedings. The list of the publications was found below. The most important step was final results of SnowCarbo project will be published in the journal of Boreal Forest Research (www.borenv.net) as a special issue, entitled, "Monitoring and Modelling of Snow, Water and Carbon Balance Related Phenomena in Northern Latitudes". The journal (Impact Factors 2011: 1.803 (two-year) and 1.878 (five-year)) publishes original, previously unpublished research reports, reviews and commentaries on various aspects of the boreal environment and its natural resources, in particular: environmental problems, their assessment, understanding and management, as well as the sustainable use of natural resources. Boreal is interpreted in a wide sense, i.e. including polar, subpolar and northern temperate conditions, biomes or ecosystems. The journal is a forum for emphasizing a holistic approach to environmental sciences, linking pressures via sources of pollution to the impacts on the environment through the processes occurring in various media.

Following publications and presentations were disseminated from SnowCarbo project:

1. Ménégoz, M., Krinner, G., Balkanski, Y., Cozic, A., Boucher, O., and Ciais, P.: Boreal snow cover variations induced by aerosol emissions in the middle of the 21st century, The Cryosphere Discuss., 6, 4733-4769, doi:10.5194/tcd-6-4733-2012, 2013, in rev. for The Cryosphere
2. Gouttevin, I., Ménégoz, M., Dominé, F., Krinner, G., Koven, C., Ciais, P., Tarnocai, C., Boike, J.: How the insulating properties of snow affect soil carbon distribution in the continental pan-Arctic area, Journal of Geophysical Research, 117: G02020. DOI: 10.1029/2011JG001916, 2012.
3. Arslan A.N., Mattila O-P., Markkanen T., Böttcher K., Susiluoto J., Törmä M., Lemmetyinen J., Metsämäki S., Aurela M., Kervinen M., Takala M., Härmä P.,

Pulliainen J., SNOWCARBO: Monitoring and assessment of carbon balance related phenomena in Finland and northern Eurasia, Geoscience and Remote Sensing Symposium (IGARSS), 2011.

4. Arslan A., Mattila O-P., Markkanen T., Böttcher K., Susiluoto J., Törmä M., Lemmetyinen J., Metsämäki S., Aurela M., Kervinen M., Takala M., Härmä P., Pulliainen J.,SNOWCARBO: CO2 Balance of Northern Terrestrial Ecosystem, AGU, December 13-17, 2010, San Francisco, USA.

5. Markkanen T., Susiluoto J., Törmä M., Härmä P., Arslan A., Mattila O-P., Pulliainen J.,Impact of Refined Land Cover Data on Regional Climate and CO2 Balance, ESA-iLEAPS-EGU Earth Observation for Land-Atmosphere Interaction Science Conference, 3-5 November 2010, ESA-ESRIN, Frascati, Italy, 2010.

6. Arslan A., Mattila O-P., Markkanen T., Böttcher K., Susiluoto J., Törmä M., Lemmetyinen J., Metsämäki S., Aurela M., Kervinen M., Takala M., Härmä P., Pulliainen J.,SNOWCARBO: CO2 Balance of Northern Terrestrial Ecosystem,ESA-iLEAPS-EGU Earth Observation for Land-Atmosphere Interaction Science Conference, 3-5 November 2010, ESA-ESRIN, Frascati, Italy, 2010.

7. Pulliainen J., Laaksonen A., Laurila T., Luojus K., Rautiainen K., Aurela M., Lemmetyinen J., Vehviläinen J., Kontu A., Arslan A., Aalto T., Markkanen T., Susiluoto J., Böttcher K., Törmä M., Mattila O., Metsämäki S., Kervinen M., Härmä P., Mapping Of CO2/CH4 Annual Fluxes At High Latitude Continental Areas Applying Microwave Radiometer Observations, ESA-iLEAPS-EGU Earth Observation for Land-Atmosphere Interaction Science Conference, 3-5 November 2010, ESA-ESRIN, Frascati, Italy, 2010.

8. Böttcher,K., Kervinen, M, Aurela, M., Mattila, O-P.,Determination of spring events of boreal coniferous forest from MODIS time-series,Finnish Remote Sensing Days,4-5.11.2010, Helsinki, Finland

9. Törmä M., Arslan A., Hatunen S., Härmä P., Markkanen T., Susiluoto J., Pulliainen J., Revising the land cover and use classification of Northern areas for climate modeling, SPIE European Remote Sensing, Toulouse-France, 20-23.09, 2010.

10. Pulliainen J., Lemmetyinen J., Kontu A., Arslan A., Wiesmann A., Nagler T., Rott H., Davidson M., Schuettemeyer D., Kern M., Observing seasonal snow changes in the boreal forest area using active and passive microwave measurements, Geoscience and Remote Sensing Symposium (IGARSS), 2010, pp. 2375 - 2378. DOI 10.1109/IGARSS.2010.5653105, 2010.

11. Takala M., Pulliainen J., Luojus K., Lemmetyinen J., Kangwa M., Metsämäki S., Koskinen J., Combined hemispherical scale SWE and snow clearance monitoring Geoscience and Remote Sensing Symposium (IGARSS), 2010. Digital Object Identifier: 10.1109/IGARSS.2010.5650728 Publication Year: 2010 , Page(s): 1765 – 1768, 2010.

12. Metsämäki S., Mattila O., Kärnä J., Pulliainen J., Luojus K., New approach for the global mapping of fractional snow coverage in boreal forest and tundra belt applicable to various sensors, International Geoscience and Remote Sensing Symposium (IGARSS), 2010.

13. Luojus K., Pulliainen J., Takala M., Derksen C., Rott H., Nagler T., Solberg R., Wiesmann A., Metsämäki S., Malnes E., Bojkov B., Investigating The Feasibility Of

The GlobSnow Snow Water Equivalent Data For Climate Research Purposes, Geoscience and Remote Sensing Symposium (IGARSS), 2010.

14. SnowCarbo presentation at the Life+ Climate Change Seminar, 18-19 January, 2010, Helsinki, Finland.

15. Takala, M., Pulliainen, J., Metsämäki, S., and Koskinen, J., Detection of Snowmelt Using Spaceborne Microwave Radiometer Data in Eurasia From 1979 to 2007, IEEE Trans. Geosci. And Remote Sensing, 47:2996-3007.

16. Mattila, O-P., Böttcher K., SNOWCARBO:Monitorung and Assessment of Carbon Balance related Phenomena in Finland and Northern Eurasia, METIER-Final Conference, 4-6 November 2009, Brussels, Belgium.

17. Törmä, M., Aalto, T., Hatunen, S., Härmä, P., Markkanen, T., and Pulliainen, J., Spatial Data Requirements of Carbon Balance Modelling, SPIE Europe Remote Sensing Conference, 31 August-3 September 2009, Berlin, Germany.

Dissemination workshops of SnowCarbo project: Two dissemination meetings was organized (1) SnowCarbo project end-users/stakeholder consultation meeting (14.12.2011) (2) SnowCarbo project dissemination meeting (09.01.2013).

The SnowCarbo project end-users/stakeholder meeting was successful. The agenda and presentations can be found in SnowCarbo website: http://snowcarbo.fmi.fi .The registered participants were 45 but there were also unregistered participants so there were about 55. The meeting was successful in terms of informing people about the SnowCarbo project and results so far produced and networking. In discussion session many questions asked to audience related the stakeholder's needs in terms of SnowCarbo project results and products like what kind of information needed and what form the information should be delivered. This ouput of the discussion gave us a path and guidelines how we should have continued the project and what information, to whom and what form should have been delivered. It had also been discussed on dissemination final results of SnowCarbo project. There were many good suggestions. One of them we agreed to disseminate our result via http://ilmasto-opas.fi which is another Life+ project.

The SnowCarbo project dissemination meeting was held on 09.01.2013. We had opportunity to combine the SnowCarbo project dissemination meeting with other national organization such as COPERNICUS (GMES) Finland user forum (http://blog.fmi.fi/gmes/) and international organizations DORIS_Net (The European network of Copernicus-GMES Regional Contact Offices- http://www.doris-net.eu/) and NEREUS (Network of European Regions Using Space Technologies- http://www.nereus-regions.eu/). This gave us a big opportunity to disseminate the SnowCarbo project result to wider end-users/stakeholders and public network than the end-users/stakeholders and public network of the SnowCarbo project. This was very important for the SnowCarbo project how we continue disseminating and utilizing the SnowCarbo project results further and especially after project ended. The dissemination meeting organized in 5 sessions and we had 21 presentations (given in the SnowCarbo website) and more than 80 participants. The sessions were

a) Introduction to European COPERNICUS (GMES) services
b) COPERNICUS (GMES)/GEO services in Finland
c) Using COPERNICUS (GMES) services in net carbon balance mapping in SnowCarbo
d) User experiences of COPERNICUS (GMES) services

e) COPERNICUS (GMES) user forum

The synthesis report on the results of SnowCarbo project results: This report was given separately as a deliverable report of Action 12.

4.4.2 Layman's report

This report was given separately as a deliverable report of Action 12.

4.4.3 After-LIFE Communication plan

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

- A novel earth observation satellite data-aided modelling tool for the monitoring of annual carbon balance was developed in SnowCarbo project will be available for all interested partners. FMI is committed to use and develop the modelling system further analysis and problems regarding climate change scenarios and policies.
- Statistics Finland is a Finnish governmental unit which is in charge of reporting national greenhouse inventories to national policy makers and further reported to UNFCCC (United Nation Framework Convention on Climate Change). Results of Snowcarbo project have been delivered to Statistics Finland as a tool for evaluation and validation of inventories. The work will be continued with them.
- The snow products of Snowcarbo project have been used and will be used in the operational hydrological forecasting system and numerical weather prediction (NWP) of the Finnish Environment Institute which is used for flood warning system. These products are global products which can be adapted into all operational hydrological forecasting systems and NWP systems.
- The results of SnowCarbo will be available and utilize for educational purposes on Climate Change. We have already organized a seminar (01.03.2013) at FMI with the students who were Innolukio's winner of a weekly task which was " How can one reduce carbon footprint of studies or the whole school climate burden using information technology or social media". Innolukio (http://innolukio.fi/fi/english/) is a project that is funded by the Finnish National Board of Education for the development of a learning environment that encourages upper secondary school students towards creative thinking and provides them with the knowledge and skills that are required in future work tasks. The essential goal of the project is to create a connection between upper secondary school students, businesses and universities, while utilising the creativity of the students as a national resource. This type of collaboration and work will be continued and developed further.
- SnowCarbo website and notice boards will be kept as long as needed and possible. Each partner will advertise and give a link to SnowCarbo website at their SnowCarbo related new projects websites.
- The results of SnowCarbo project such as net carbon balance maps will be utilized in Climateguide.fi which was created in an EU Life+ project (LIFE07 INF/ FIN/000152 CCCRP). This portal offers practical climate change information.

- The development of FMI Erdas Apollo data dissemination interface will continue. The data and net carbon balance maps are / will be delivered using Erdas Apollo OGC Services (that is web coverage service wcs and web map service wms). The end-users of the products are able to have direct access to the data products using an out of the box Erdas Apollo web client.
- The final results of SnowCarbo project will be published in the journal of Boreal Forest Research (www.borenv.net) as a special issue, entitled, “Monitoring and Modelling of Snow, Water and Carbon Balance Related Phenomena in Northern Latitudes”.
- As continuation of the SnowCarbo project, several potential actions arising from co-operation between project partners and project stakeholders has emerged. As a result of this co-operation a new Life+ proposal (MONIMET) was submitted 30.9.2012. This proposal, if successful, has significant potential in strengthening seasonal monitoring of carbon balances of forests, and in providing easily understandable information about climate change for the general public and other stakeholders.

5 Comments on the financial report

5.1 Costs Incurred

PROJECT COSTS INCURRED				
	Cost category	Total cost according to the Commission's decision*	Costs incurred from the start date 1.1.2009 to 31.12.2012	%**
1.	Personnel	1 817 616 €	1 927 800 €	106 %
2.	Travel	30 000 €	20 721 €	69,1 %
3.	Outside assistance	30 000 €	21 558 €	71,9 %
4.	Durables: total non-depreciated cost			
	- Infrastructure sub-tot.			
	- Equipment sub-tot.	46 000 €	0	
	- Prototypes sub-tot.			
5.	Consumables	0 €	9 780 €	
6.	Other costs	106 000 €	5 855 €	5,5 %
7.	Overheads	126 011 €	126 011 €	100 %
	SUM TOTAL	**2 155 627 €**	**2 111 725 €**	98 %

5.2 Accounting system

The project's accounts were run within the beneficiaries' routine wise accountancy framework.

5.3 Partnership arrangements (if relevant)

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

5.4 Auditor's report/declaration

Auditing is still in progress.

6 Annexes

All annexes were categorized in 3 parts as follows

1. Deliverables
2. Financial reports
3. Dissemination materials

All annexes were delivered to European Commission and the external monitor of the project by a memory stick (USB) together with the final report by mail.

6.1 List of deliverables

List of Deliverables 1.1.2009-31.12.2012		
Action 1: Project management and monitoring		
Activity	**Due date**	**Completion (%)**
• 1st Project brochure	30/03/2009	100%
• Inception report	30/06/2009	100%
• 1st Monitoring Report	27/11/2009	100%
• First-year progress report	31/12/2009	100%
• 2nd Monitoring Report	29/04/2010	100%
• 18 month progress report	30/06/2010	100%
• 3rd Monitoring Report	29/10/2010	100%
• Midterm progress report	31/01/2011	100%

• Carbon footprint report (first contributions)	31/12/2010	100%
• 4th Monitoring Report	28/04/2011	100%
• 30 month progress report	30/06/2011	100%
• 5th Monitoring Report	07/11/2011	100%
• Report on end-user/stakeholder consultation workshop	11/01/2012	100%
• Third year progress report	27/02/2012	100%
• 6th Monitoring Report	17/05/2012	100%
• 42 month progress report	29/06/2012	100%
• 7th Monitoring Report	25/10/2012	This was removed it is considered not necessary
• Carbon footprint report	31/12/2012	100%
• Final report	31/01/2013	100%
Action 2: Satellite data processing by FMI		
Activity	**Due date**	**Completion (%)**
• Contribution to the 1st EO- data document (years 2001-2008)→1st EO-data document	30/11/2009	100%
• Contribution to the 2nd EO- data document (years 2009-2010)→ 2nd EO-data document	30/11/2010	100%
Action 3: Acquisition and extension of GMES-services GSE Polar View and GSE Land		
Activity	**Due date**	**Completion (%)**
• 1st EO- data document	30/11/2009	100%
• 2nd EO- data document	30/11/2010	100%
• Contribution to final report	30/11/2012	The contribution to final report was done directly. Not extra report produced
Action 4: In situ data collection and processing by FMI		
Activity	**Due date**	**Completion (%)**
• 1st Data document	31/12/2009	100%
• 2nd Data document	31/12/2010	100%
• 3rd Data document	31/12/2011	100%
• Contribution to the final report	30/11/2012	The contribution to final report was done directly. Not extra report produced

Action 5: In-situ data collection and processing by SYKE		
Activity	**Due date**	**Completion (%)**
• 1st in-situ data document	30/11/2009	100%
• 2nd in-situ data document	30/11/2010	100%
• 3rd in-situ data document	30/11/2011	100%
Action 6: Methodology development and implementation by FMI		
Activity	**Due date**	**Completion (%)**
• 1st Progress report on methodology	31/05/2010	100%
• 2nd Progress report on methodology	31/08/2011	100%
Action 7: Methodology development and implementation by SYKE		
Activity	**Due date**	**Completion (%)**
• The unfiltered time-series, in the gridded form, of snow covered area (SCA) and normalized difference vegetation index (NDVI), years 2001-2008 (incorporated into the deliverable from Action 2 & 3, entitled, "**1st EO-data document**")	30/11/2009	This deliverable was incorporated into Action 2 & 3, entitled, "1st EO-data document"
• Progress report on filtered time-series (years 2001-2008)	31/05/2010	100%
• Progress report on extracted features (2001-2008)	31/08/2010	100%
• 2nd progress report on filtered time-series (2001-2008)	30/11/2010	100%
• Final progress report on extracted features (2001-2010)	31/12/2011	100%
Action 8: Demonstration and validation by FMI		
Activity	**Due date**	**Completion (%)**
• Preliminary demonstration report	31/12/2010	100%
• Demonstration report	30/09/2012	0%
Action 9: Demonstration and validation of EO services		
Activity	**Due date**	**Completion (%)**
• Documentation of the data exchange method	30/11/2009	100%
• Preliminary demonstration report	30/11/2010	100%
• Demonstration report	30/09/2012	0%
Action 10: Generation of carbon assessment end-products		
• Report on carbon balance mappings (FMI)	31/08/2012	0%
Action 11: Evaluation of required Northern-Eurasian land cover information		
Activity	Due date	Completion (%)

• Report on land cover data needs	31/08/2009	This was reported together with the report on data production and accuracy
• Report on data production and accuracy	31/10/2010	100%
• Report on suitability of global land cover datasets for carbon balance modeling	31/10/2010	100%
Action 12: Dissemination		
Activity	**Due date**	**Completion (%)**
• 1st project brochure	30/03/2009	100%
• 1st project brochure (updated)	29/06/2012	100%
• Layman's Report	31/12/2012	100%
• 1st project brochure (final)	31/12/2012	100%
• Carbon balance atlas for Finland and Baltic EU	31/12/2012	100%
• Synthesis report of project results for stakeholders and policy makers (in Finnish and English)	31/12/2012	100%

6.2 Financial Reports

Financial reports were given in annex as follow

FMI:

1. FMI Financial Reports 2009-2012
   a. Standard payment request
   b. Financial statement of the participant
   c. Consolidated cost statement of the project
2. Employee Cost
3. Salary Specifications
   a. Arslan 2011, 2012
   b. Kangwa 2009, 2010, 2011, 2012
   c. Pulliainen 2009, 2010

SYKE:

1. SYKE Financial Reports 2009-2012
    a. Financial statement of the participant
2. Salary Specifications
    a. Attila
    b. Harma
    c. Sucksdorff
3. Worktime Record 2009

CEA:

1. CEA Financial Reports 2009-2012
    a. Financial statement of the participant

6.3 Dissemination materials

- 1st Brochure
- 1st Brochure update
- Snowcarbo newsletter issue 1
- Snowcarbo newsletter issue 2
- Snowcarbo final brochure