# CO2 Balance of Northern Terrestrial Ecosystem

Issue No. 1 April-2010

## SnowCarbo Life+ Project Newsletter

### Special points of interest:

- Snow cover
- $CO_2$ balance
- Carbon modeling
- Satellite remote sensing

### Inside this issue:


| | |
|---|---|
| $CO_2$ balance at northern latitudes | 1 |
| $CO_2$ exchange in between terrestrial ecosystems and the atmosphere | 2 |
| Surface in climate modeling | 2 |
| Earth observation and Land Cover | 2 |
| Regional NEE and $CO_2$ concentration modeling in Snowcarbo | 3 |
| $CO_2$ balance maps and calculator | 3 |
| Project progress | 3 |
| Dissemination | 5 |
| Contact information | 5 |


## $CO_2$ Balance at Northern Latitudes

Today the anthropogenic carbon sources are producing more carbon dioxide into the atmosphere than is being absorbed by carbon sinks in terrestrial ecosystems and the oceans. This contributes towards the instability in the natural balance of carbon dioxide. The excess carbon dioxide warms the atmosphere, as a result causing global warming. In order to formulate environmental legislations, regulations and adaptation strategies to address the issues of climate change, it is essential to monitor and retrieve information on the magnitudes and locations of real natural carbon sources and sinks.

In the northern terrestrial ecosystem, both carbon sources and sinks are affected by seasonal changes in snow cover. Changes in snowmelting times during the spring and soil freezing in the autumn affect the length of the growing season and consequently, the ecosystem net productivity.

As result spatial variability and long-term trends in snow cover distribution and related climate patterns need to be analyzed based on observation data and climate change prediction models. These models predict changes in the spatial and temporal distribution of snow in boreal and arctic terrestrial regions.

The main objective of the SnowCarbo project is to implement and demonstrate a new innovative approach for the net $CO_2$ balance mapping in northern Finland and northern Eurasian region. This approach is based on a combination of different information sources describing snow evolution, phenology, land cover, $CO_2$ fluxes and concentrations. The implemented method combines local in-situ observations and global Earth observation satellite data together with land cover class information in a new way. SnowCarbo aims to produce carbon dioxide balance maps over northern Finland and northern Eurasia by combining both different earth observation data sources and modelling of $CO_2$ balance. The results can be implemented into the European and national adaptation strategies to the impacts of climate change and to support the formulation of the environmental legislations and regulations.

*SnowCarbo project is funded by the European commission (EC) Life+ program*

## $CO_2$ Exchange in Between Terrestrial Ecosystems and the Atmosphere

In the terrestrial ecosystem green plants are able to take in carbon from the atmosphere in the form of $CO_2$. This requires energy that is harvested by the plants from the sunlight in a chemical process called photosynthesis. On the other hand, $CO_2$ is produced in process called respiration that releases energy from carbohydrates in order to provide for the growth and maintenance of living organisms such as plants and bacteria. Respiration rate is sensitive to the availability of water and thermal energy. In terrestrial ecosystems a large fraction of respiration takes place in soils where it is mainly related to activity of living biota, such as bacteria, utilizing dead debris from plants. Figure 1 indicates the respective flows of $CO_2$ in between the vegetated surface and the atmosphere. These two flows of opposing directions – one is adding up to and the other one is reducing the atmospheric $CO_2$ content – are summed up and divided by the respective land area a term giving the **N**et **E**cosystem $CO_2$ **E**xchange (**NEE**) is gained. Process based $CO_2$ balance modeling of terrestrial areas aims at describing the $CO_2$ uptake and release rates by the functional compartments of an ecosystem. When regional or global NEE are of interest the environmental variables driving the uptake and release processes are typically either derived from the measurements or from predictions of climate models.

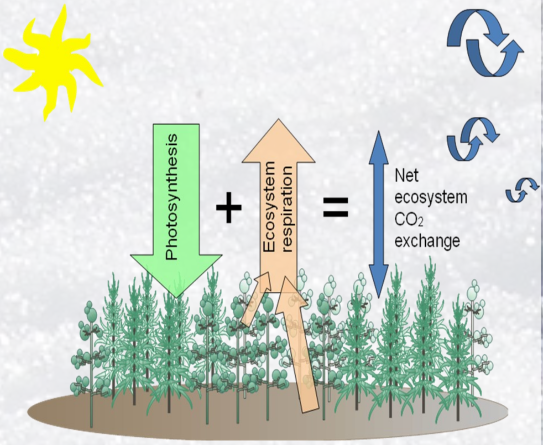



**Figure 1 Carbon dioxide cycle**

## Surface in Climate Models

**G**eneral **C**irculation **M**odels (**GCM)** used to create global climate projections and their regional counterparts are based on the description of physical processes taking place in the atmosphere. A crucial part of these models are the descriptions of land surfaces, i.e. **L**and **S**urface **S**cheme (**LSS**). These descriptions consist of the parameterizations of key processes taking part into the exchange of energy and matter between the atmosphere and the surface. Such parameterizations can be in different degrees of detail depending on the purpose of use of the model. The degree of sophistication of the models is also dependent on the computing power, thus especially first generations of climate models needed to manage on relatively general surface parameterizations. Most up to date models consider the water cycle of terrestrial areas considering the physiological response of vegetation cover to the climatic variables. This requires taking into account the resistance for water vapor exchange due to functioning of water pathways within the plants. It turns out that the most crucial control of water vapor exchange between the vegetation and the atmosphere – stomatal control – restricts the $CO_2$ exchange as well. Thus a model having a sophisticated land surface scheme is readily able to produce reliable $CO_2$ exchange by vegetation. The soil module is central part of a LSS in order to produce a reliable NEE.

## Earth Observation and Land Cover

**E**arth **O**bservation (**EO**) techniques using satellite remote sensing provide simultaneous information on the state of earth's surface for extensive areas, either for instant needs or for long-term analysis. Some of the environmental conditions, affecting NEE, can be accurately measured at any location. The problem is that the local measurements of, for example, snow conditions or the status of vegetation are not representative of the environmental conditions in large scale. This is where satellite remote sensing becomes a valuable tool in EO. The local information from relatively few measurements on the ground can be used together with satellite images to make extensive maps of the snow cover, the amount of water held in the snowpack or the vegetation status of plants and other important variables. With images taken by satellites we can follow the development of the important environmental conditions continuously, extensively over the area of interest and sometimes irrespective of the weather conditions.

The terrestrial NEE can nowadays be measured accurately. Unfortunately the equipment for the measurements is expensive and therefore measurements are carried out only in few locations. The locations have been selected to be representative of common ecosystems in the region of interest. As NEE varies with different ecosystems, we need again means to extend local information to larger areas. Satellite remote sensing cannot offer a straight forward solution to this. But we are able to create a map displaying the environmental conditions, i.e. vegetation type and density or other use of the land by combining satellite remote sensing methodologies (satellite images and interpretation techniques) and other information sources such as databases from other national institutions. This is called land cover or land use classification. Now by assuming that the measured net exchange of $CO_2$ behaves in a similar manner in all areas with the same land cover or land use type, we can estimate the total carbon dioxide exchange for the entire coverage of each land cover or land use type, for which $CO_2$ is measured locally. The EO data acquired in Snowcarbo are; Weekly snow water equivalent (SWEI )n mm, Snow melt onset (date, spring), Snow Clereance (date, spring), Land cover data, MODIS (moderate resolution imaging spectrometer) and AVHRR (Advanced Very High Resolution radiometer).

## Regional NEE and CO2 concentration modeling in Snowcarbo

In Snowcarbo project the present climate is modeled for an area covering Nordic and Baltic countries. For climate modelling, the REgional MOdel (REMO) of Max Planck Institute for Meteorology, Hamburg, Germany is used. As the regional climate model is frequently corrected with the weather observations the modeled weather closely follows the weather observations accurately. In order to estimate the $CO_2$ balance in terms of NEE, the respective LSS area is forced with the high resolution climatic data from the climate model. The land surface module of the general circulation model ECHAM , called JSBACH is used for $CO_2$ flux shown in figure 3. Further, as $CO_2$ concentration is of interest as well the gridded sink and source strengths will be used as boundary information for a transport model that distribute this natural signal from the terrestrial vegetation together with anthropogenic sources and signals from other natural sources into the atmosphere. As the project aims at improving the existing $CO_2$ balance estimates for northern areas, a new land cover map derived with the methods explained above will be used. Moreover, the remote sensing data of snow characteristics and vegetation status will be facilitated in assessing and eventually also in improving the model predictions.

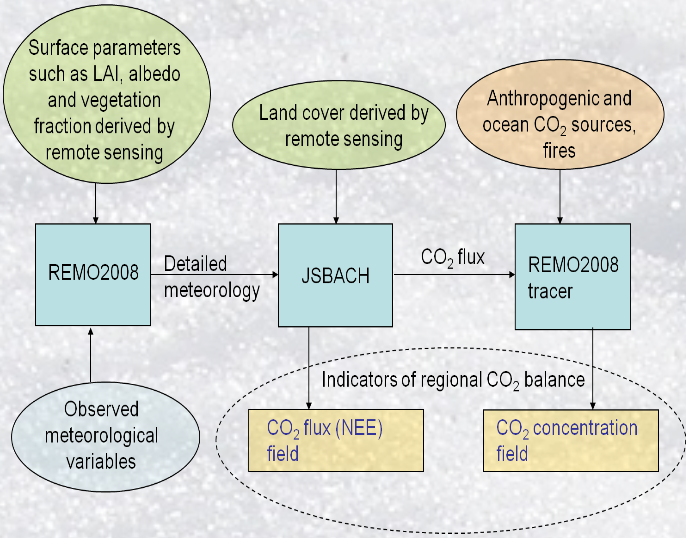



**Figure 3: A schematic presentation of the one-way coupled model runs**

## CO2 Balance Map and Calculator

A $CO_2$ balance map is important to provide accurate information on net carbon balance in the atmosphere in order to assess the real levels of carbon sinks and sources for future climate controlling treaties and policy making and understanding what action should be taken to reduce the rate of $CO_2$ concentration rise. As an example, CarboScope which is an exploring tool for $CO_2$ and $CH_4$ shown in figure 5 on page 4. The $CO_2$ maps will be a collection of NEEs and $CO_2$ concentrations estimated in resolution of 0.1667 degrees for a domain covering Finland, Sweden, Norway and Denmark as whole as well as the Baltic countries: Estonia, Latvia and Lithuania; together with areas from most Northern Germany and Western parts of Russia. The map will cover the target years of the project 2001-2011.

Carbon balance calculator for use of general public will be provided. The calculator will provide a numerical estimate of carbon balance and its inter-annual variation in a specified location using recent climate and land cover information together with state-of-the-art modeling tools.

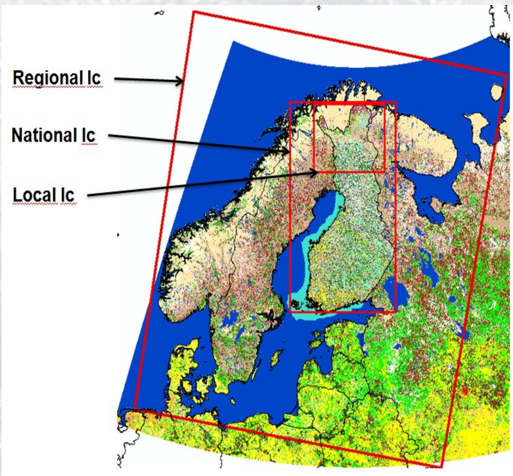



**Figure 4 An example of Land Cover data**

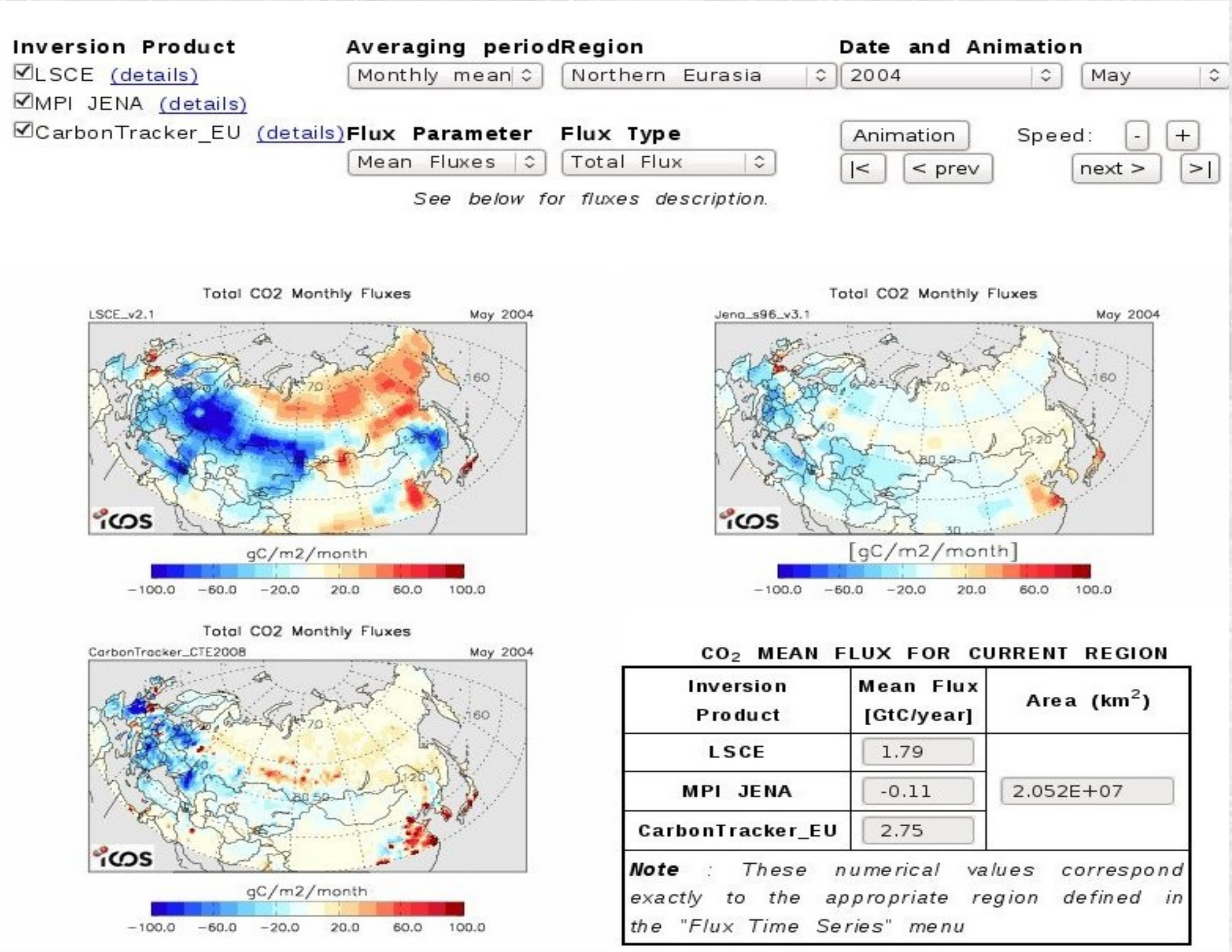
## Project Progress

To address the issue of seasonal changes in snowcover, the Snowcarbo project has developed some software to produce products such as the snow water equivalent grids and snow melt seasonal grids, the examples can be seen from figure 6 on page 4. These products will enable validating and also improving the model results.

Also the Snowcarbo project has collected the 1st version of input data needed for the $CO_2$ modeling. An example of a collected input data set is the land cover shown in figure 4.

The processing of MODIS data for years 2001-2008 has been completed. Produced dataset contains the local MODIS archive with calibrated and rectified top of atmosphere products. Using the top-of-atmosphere data, **N**ormalized **D**ifference **V**egetation **I**ndex (**NDVI**) and **S**now **C**overed **A**rea (**SCA**) estimates, as well as cloud masks were calculated for each preprocessed scene. The produced dataset of environmental variables has been revised and found to be accurate.

The input data, which provides the boundary and initial conditions for the model runs, are collected from various global data sources and they are synthetized to global grids. The validation data (i.e. the in situ data set) such as, $CO_2$ fluxes and concentrations, which will be used for assessing the reliability of the model predictions are routinely measured at several stations maintained.




| Inversion Product | Mean Flux [GtC/year] | Area ($km^2$) |
|---|---|---|
| LSCE | 1.79 | |
| MPI JENA | -0.11 | 2.052E+07 |
| CarbonTracker_EU | 2.75 | |

*Note : These numerical values correspond exactly to the appropriate region defined in the "Flux Time Series" menu*

**Figure 5** $CO_2$ Fluxes from Atmospheric Inversions *[image source: http://www.carboscope.eu/index.php?p=co2_map&rub=r21&smenu=smenuInfo2]*

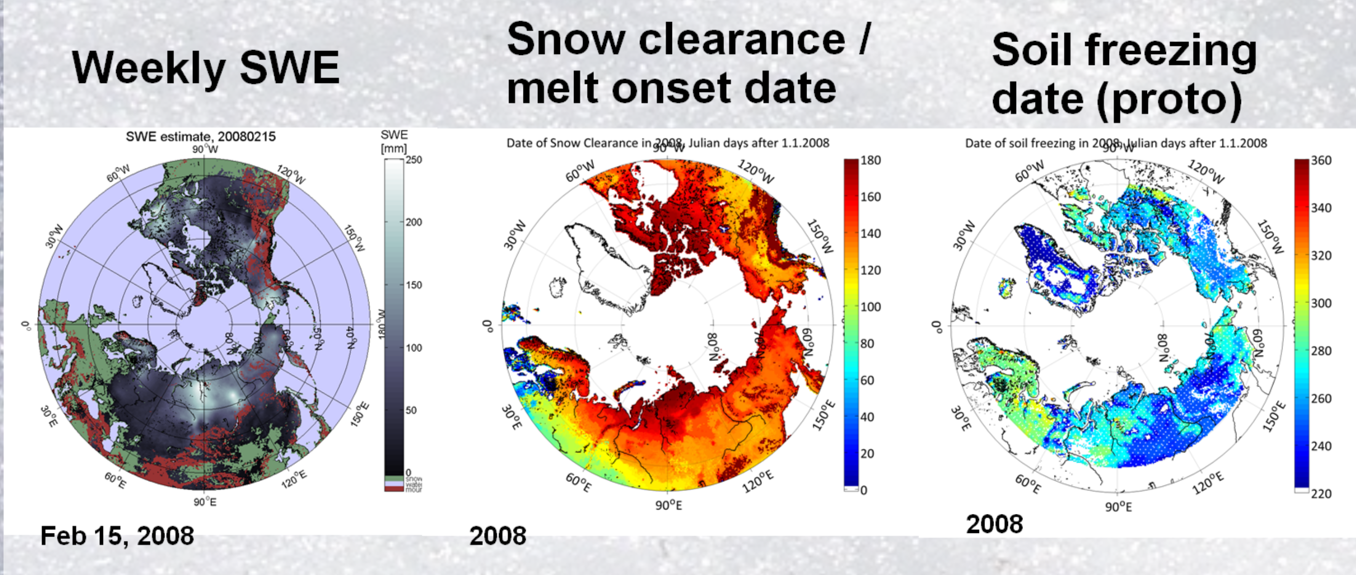



**Figure 6** Examples of some of the Snow Products

SNOWCARBO

## Dissemination

1. SPIE Europe Remote Sensing Conference. 31 August - 3 September 2009, Berlin, Germany.
   Törmä, M., Aalto, T., Hatunen S., Härmä P., Markkanen T. and Pullainen, J. Spatial Data Requirements of Carbon Balance Modelling (conference paper)
2. METIER - Final Conference. 4-6 November 2009, Brussels, Belgium
   Mattila, O-P and Böttcher K. SNOWCARBO - Monitoring and Assessment of Carbon Balance related Phenomena in Finland and Northern Eurasia (poster presentation)
3. 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. SnowCarbo presentation at the life + climate change seminar which was held on the 18-19 January in Helsinki
5. Törmä, Härmä, Markkanen, Hatunen, Arslan: "Revising the land cover and use classification of northern areas for climate modeling", SPIE European Remote Sensing Symposium, September 2010 Toulouse
6. Kari Luojus, Jouni Pulliainen, Chris Derksen, Helmut Rott, Thomas Nagler, Rune Solberg, AndreasWiesmann, Sari Metsämäki, Eirik Malnes and Bojan Bojkov," Investigating the feasibility of the globsnow snow water equivalent data for climate research purposes" IGARSS 2010,July 25-30,2010, Hawai-USA(accepted)

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# SnowCarbo Project Partners

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*The SnowCarbo project is funded by the European commission (EC) Life+ program*