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Action 9 – Demonstration and validation of EO services (SYKE)

LIFE+ PROJECT NAME or Acronym

SNOWCARBO

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List of key-words and abbreviations

EC	Eddy covariance
ECMWF	European Centre for Medium Range Weather Forecast
FMI	Finnish Meteorological Institute
FSC	Fractional Snow Cover
GPP	Gross primary production
GSSD	Growing season start date
JRC	Joint Research Centre
JSBACH	Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
REMO	Regional Climate Model
STD	Standard deviation
SWE	Snow Water Equivalent
SYKE	Finnish Environment Institute

1 Summary

This document describes the results of work concerning the demonstration of using Earth-observation data in carbon modelling. Actions 4 and 5 were used to collect together the existing in-situ datasets and to conduct field campaigns to complement those datasets. In-situ data was used to help develop remote sensing methodologies for observing phenological events related to natural carbon exchange between surface and atmosphere. During the field campaigns also ground truth information was collected to verify the land cover dataset, which was used in the carbon modelling. Satellite data was available from existing GMES services, but additional images were collected in Actions 2 and 3 from open web services to get continuous annual datasets for years 2001-2010. In Action 7, the remote sensing methodologies were developed, using the in-situ information, to map spatially extensively the phenological events that could be related to the final results derive with the REMO-JSBACH modelling framework (Developed in Action 6). The final carbon estimates were generated in Action 8.

The first demonstration report displayed the comparison between the observed in-situ; satellite derived and modelled snow information. The conclusion was that there were, in some occasions, relatively large differences between the modelled and observed snow conditions. This should be kept in mind while assessing the final modelling results. Additionally the report presented the first results from the methodology of using phenology (vegetation or snow) related indicators to map the start of the growing season from optical satellite data.

Here we have collected together comparisons of carbon balance modelling results with two different land cover datasets, i.e. Olson classification (Olson 1994), which has been used global carbon cycle simulations and Corine (Haakana et al., 2008)-GlobCover (GLOBCOVER, 2009) dataset, which is a combination of the best available land cover data from the modelling region. The model runs using these two datasets are used to display the importance of correct land cover information and to look at the effect on inter-annual and intra-annual variability of carbon balance. Close examination of the land cover dataset, i.e. the Olson classification, originally applied in global climate modelling and used in REMO-climate model revealed large errors in the distribution of land cover types in the region of interest in SNOWCARBO, i.e. the Northern Europe. Therefore it has become obvious that the improvement of the land cover datasets would give more reliable estimates of carbon balance from modelling. The two model runs display large differences in the carbon balance, which can be attributed to the distribution of land cover/land use types and the effects of changes in both the climate and the carbon cycle. The carbon results will be reviewed more closely in Actions 8 and 10.

Another issue, with the relatively recently developed models used to estimate the carbon balance over land areas, is the lack of information for assessing or verifying the final results. There exists only sparse network of in-situ measurement sites for CO_2-exchange. The remote sensing methodology, developed in Action 7, to give phenological information from ground has now been applied to all years in question (2001-2010) and can be used to compare to same parameters derived from modelling results to assess the performance of the models. Here the results from comparison of start of growing season derived from model and satellite data are given. The method shows a bias for later start of the growth, of coniferous forests, in the model compared to the start of growth from satellite data. The bias is relatively systematic although the difference is stronger further North in the

modelling region. Correlation between the two datasets is strong and therefore the spatial distribution is very similar. The bias will be still further investigated in Actions 8 and 10.

Overall the importance of correct land cover is shown here and the Corine-GlobCover combination will be used to provide the final carbon Atlas results. Also the possibility of using remote sensing techniques in verifying the model results are proven and the first results indicate that the model is performing well, but needs tuning before the final results are produced.

2 Data sources

REMO Regional climate model

The regional climate model REMO is used in SNOCARBO to produce the weather patterns in regional scale for the area of interest in Northern-Europe. The model is run in *forecast* mode to produce actual climate. Here REMO is forced with daily weather data from European Centre for Medium Range Weather Forecasting (ECMWF) and the model is producing hourly climate data for input in JSBACH.

JSBACH Land Surface Scheme

JSBACH is a land surface model, which is used together with climate models to describe the interaction between surface vegetation and atmosphere. JSBACH has been developed in Jena Institute, Wienna, Austria, and has been here coupled (off-line, i.e. there is no feedback from JSBACH to REMO climate model) with REMO, to describe the exchange of carbon-dioxide (CO_2) using the regional weather data produced with REMO model. The calculation for CO_2- exchange has been done hourly. The results presented here have been averaged to produce annual means and monthly means for years 2001-2009.

Land cover data

The distribution of land cover/land use in global Olson ecosystem, produced by the USGS (United States Geological Survey, Olson 1994, referred here as the Olson classification), which has been used in climate modelling for ground-atmosphere interaction processes, by giving each ecosystem type a list of surface parameters influencing the atmospheric system. The classification is based on classification of satellite imagery, using existing maps and datasets (in 1994) of ecosystems as reference. In SNOWCARBO- project the Olson classification in REMO climate model to produce the meteorological forcing for JSBACH. The JSBACH has a pre-processor for the land cover dataset used in REMO to relate the classes in Olson classification to the plant functional types used in JSBACH model. Therefore the underlying distribution of land cover/land use in both models originates from the same dataset.

To improve the land cover/land use description of the modelling framework we use a combination of other land cover/land use data considered to be more accurately describing Northern-Europe. The Finnish national Corine dataset (Haakana et al., 2008) is 25m raster and represents detailed description of the land cover/land use in Finland. In European scale the Corine vector dataset has minimum mapping unit of 25 ha (CORINE, 2006). The classification is to large degree the same as in the national dataset. Additionally, where Corine land cover data was not available (i.e. in parts of Russia, Poland and Belarus), the GlobCover dataset (GLOBCOVER, 2009), produced by European Space Agency (ESA) and Joint Research Centre (JRC) was used to fill the modelling grid. All the land cover datasets in the combination are also based on satellite imagery, but Corine datasets have also more accurate national datasets as reference. The combination datasets are also referenced to the same grid as the original Olson classification. The two land cover datasets, Olson classification and Corine-GlobCover combination, are presented in more detail in Action 11 deliverable: "Report on produced land cover datasets and Report on data production and accuracy assessment" (SNOWCARBO A11, 2010). In the creation of the new land cover dataset for REMO and JSBACH models, i.e. the Corine-GlobCover combination, the surface parameters related to the classes in the Olson classification, were redistributed by finding corresponding classes between Olson and Corine-GlobCover datasets. The new dataset is further processed in JSBACH to give each carbon modelling grid point 4 dominating land cover types. We consider the Corine-GlobCover dataset to be the most accurate description of land cover available freely from the modelling region.

Growing season onset from eddy covariance measurements
In boreal coniferous forests the beginning of the growing season can typically be recognised as sudden increase of gross primary production (GPP). At a forest plot level, GPP can be derived from eddy covariance (EC) measurements. Here, a fixed fraction of peak growing season GPP (15%) was used as a threshold value for the growing season onset (growing season start date, GSSD) at EC measurement sites Hyytiälä and Sodankylä for years 2001-2010 (provided by action 4).

Start of season from JSBACH model results
The growing season onset of boreal coniferous forest was predicted by the land surface scheme JSBACH using the same criterion as applied for the *in situ* observations (see above). In the following analysis, a stand alone JSBACH version was used offline (i.e. there is no true coupling between REMO and JSBACH). JSBACH was forced with regional meteorological data in hourly time resolution generated with the regional model REMO. Era-INTERIM data of the ECMWF was used as boundary for the regional model. Additionally, JSBACH has been driven with local meteorological data from EC flux sites Hyytiälä and Sodankylä.

Satellite-derived start of season
Start of growing season (GSSD) for coniferous forest in Finland was calculated from MODIS time-series of Fractional Snow Cover (FSC) using the methodology developed in Action 7 see deliverable: "Progress report on extracted features (2001-2008)" (SNOWCARBO A7, 2010). Growing season onset derived from *in situ* observations at EC sites were used as reference date for the definition of GSSD from satellite observations ($GSSD_{sat}$). $GSSD_{sat}$ was determined for homogenous areas around EC sites Hyytiälä and Sodankylä. Furthermore, maps of GSSD covering Finland were derived at 0.25 x 0.25 degree resolution for comparisons with regional JSBACH model results. For the mapping of $GSSD_{sat}$ only pixels with a dominant fraction of coniferous forest were considered.

3 Results

Following comparison will give some indication of the range of carbon balance values and the spatial distribution in the light of changes with the two different land cover datasets from the years 2001-2009. Further analysis of the carbon balance and flux results will be done in Actions 8 and 10.

3.1 Effect of land use data to carbon estimates

Spatial differences in the land cover datasets

Annual carbon balance was modelled, using REMO-JSBACH modelling framework (Actions 6 & 8). The modelling region of Northern Europe was described with two different land cover datasets: 1) the Olson ecosystem classification and 2) A combination of Finnish National Corine land cover 2006, the European Corine land cover 2006 and GlobCover, where Corine land cover was not available. Figure 1 displays the modelling region from the two datasets to illustrate some of the differences. Both datasets have been used with the same spatial resolution of 1 km and the colour coding is the same for both images.

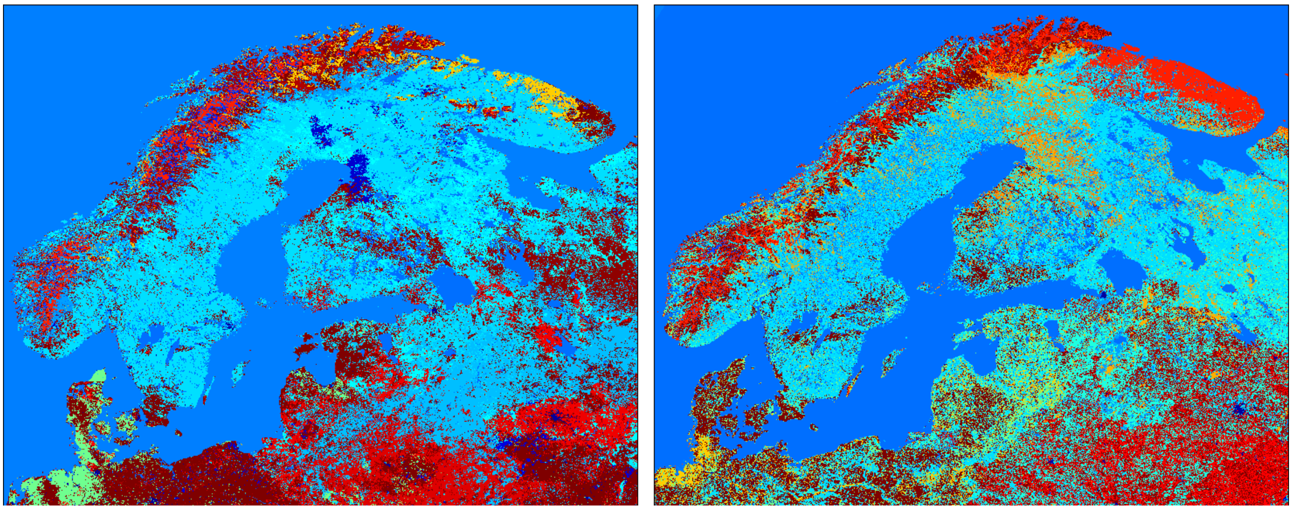

Figure 1. The two land cover datasets used in REMO-JSBACH modeling framework. Olson ecosystem classification (left) and Corine-GlobCover combination (right). The color coding is the same for both datasets. (red - colors) Low vegetation, high-lands; (cyan – colors) coniferous dominated forests; (brown/dark red, green) agricultural areas; (yellow-orange) grasslands-wetlands; (light-blue) water; (dark blue)

The Olson classification somewhat over estimates the forest areas in Northern Europe, when compared to Finnish National and European Corine land covers datasets (Haakana et al., 2008). Also it classifies most of the Northern parts of Scandinavia and Finland as coniferous forest, when in reality the forests are more mixed and getting more dominated by deciduous vegetation in further North. The agricultural areas are somewhat misplaced, both in Finland and in Sweden and, on the other hand, over represented in parts of Baltic countries, Poland and Northern Germany. Also, the Olson classification does not account any wetlands for the modelling region, when they are relatively common in Northern parts of Scandinavia, Finland and North-Western Russia. There are also vegetation classes like the deciduous needle leaf around the Bay of Bothnia that does not really belong to the environment.

In general the Olson classification creates larger homogenous areas, where some land cover/land use categories are clearly misplaced. This is a problem arising from the interpretation of the optical satellite images with limited temporal and spectral resolution. The optical spectral response of the surface varies, especially strong in the boreal region, where the summer green vegetation displays the annual growing cycle. The Corine-GlobCover shows much more heterogeneous structure which is apparent especially in Finland, where the land cover/ land use is small featured. The ~10 year difference between the datasets is also important to realize with land cover/land use changing especially in densely populated areas.

Mean annual balances

The mean annual carbon balances for years 2001-2009 are shown for the two land cover datasets in Figure 2. Although the general level of annual carbon balance is not the same for both datasets, it is apparent that the areas dominated by coniferous forests are showing the most intake of atmospheric carbon. Whereas the areas with summer green vegetation, especially visible in the Corine-GlobCover run, are acting as stronger source of CO_2. The high altitude and low vegetation areas are showing close to zero balance as expected.

The mean annual balance with Olson classification varies between < -40 g/m^2 to slightly positive balance. The results using Corine-GlobCover dataset shows much more positive annual mean balance (i.e. acting as the source of atmospheric CO_2), with CO_2-balance ranging between -40 – 40 g/m^2, but is dominated by annual release of CO_2. The differences in extent of coniferous forest, which was most dominant feature in comparison of Olson and Corine-GlobCover classifications is one of the clear reasons for the difference. This is highlighted in Easter parts of the modelling region, which shows the strongest differences (Figure 2).

The largest differences naturally fall to the areas with the most different description of land cover, but looking at the general level of the carbon balance, it should also be kept in mind that the climate data used for the two runs are also affected by the land cover dataset, as the surface interaction in REMO-model is controlled by the land cover dataset used. The changes in the climate due to changes in the land cover dataset are analyzed elsewhere.

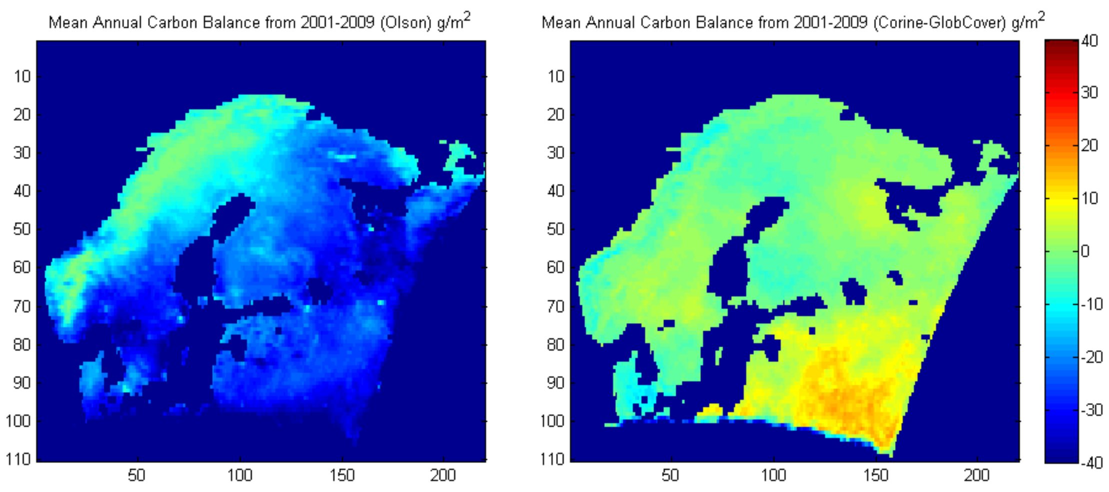

Figure 2. Mean annual carbon balances g/m2 for years 2001-2009 for Olson classification (left) and Corine-GlobCover dataset (right).

Differences in the annual carbon balances

The inter-annual variability, and the differences between the two land cover datasets, is examined here by looking at the standard deviation (STD) of the annual carbon balances during the years 2001-2009.

From the results the first observation is that the evergreen forests display the lowest inter-annual variability (Figure 3). This is natural as the seasonal variability in biomass in deciduous trees, grasses, shrubs and agricultural vegetation, and even mires, is much stronger than in coniferous trees. Additionally, the high mountain and fell areas, with little or no vegetation, display small inter-annual variation. For the Olson classification the highest inter-annual variability is located around the Bay of Bothnia, where the classification has placed large areas of needle-leaf forest (deciduous), which in Corine-GlobCover classification is largely fen type of mires surrounded by shrub lands. The same area shows locally higher variability also with Corine-GlobCover dataset. Another area displaying strong inter-annual variability in both datasets is Denmark, which is to large extent covered by agriculture, therefore the length of the growing season and growing conditions for crops during the summers play a major role in the carbon balance.

The Corine-GlobCover dataset shows strongest inter-annual variation in the region covering Belarus and Western parts of Russia. Here the Olson classification is relatively homogenous, with mainly classes of evergreen forests; whereas the data from GlobCover gives much more variety in classes, with mixture of summer and evergreen forests and crops, class of mires and class of green crops. Again the summer green vegetation is much more sensible to the climate conditions, therefore displaying larger variability through out the 9 years.

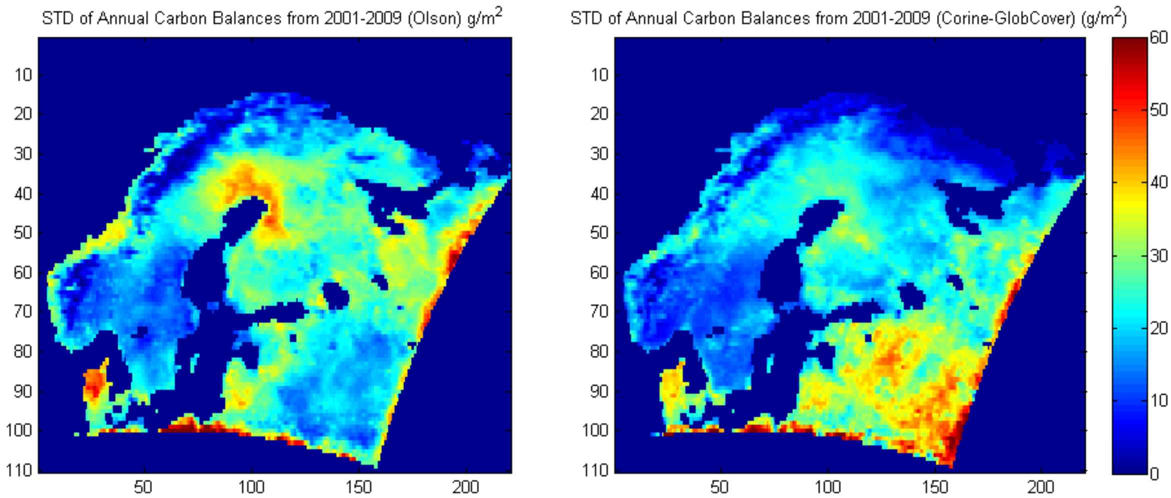

Figure 3. Standard deviation of carbon balances for years 2001-2009 from JSBACH with two different land cover datasets. Olson ecosystem classification (left) and Corine-GlobCover land cover combination (right).

Differences in the monthly carbon balances

In general view of the effect of land cover datasets on intra-annual variability, the standard deviation from monthly carbon balances was calculated for each year (2001-2009) and the mean STD for the years 2001-2009 is displayed in Figure 4.

Olson classification, which displays larger areas of homogenous land cover, shows higher intra-annual variability. The Finland and Sweden where the difference is most pronounced are mainly classified as boreal coniferous forest, whereas in Corine-GlobCover land cover Finland and Sweden have also abundant mires and fens, mixed summer green and evergreen forests as well as lower vegetation over the fells. Again areas of higher elevation naturally display lower intra-annual variability. Also, the areas with concentrated agricultural land in South-Western Finland, in Southern Sweden and especially in Denmark show reasonable behaviour, with pronouncedly higher intra-annual variability.

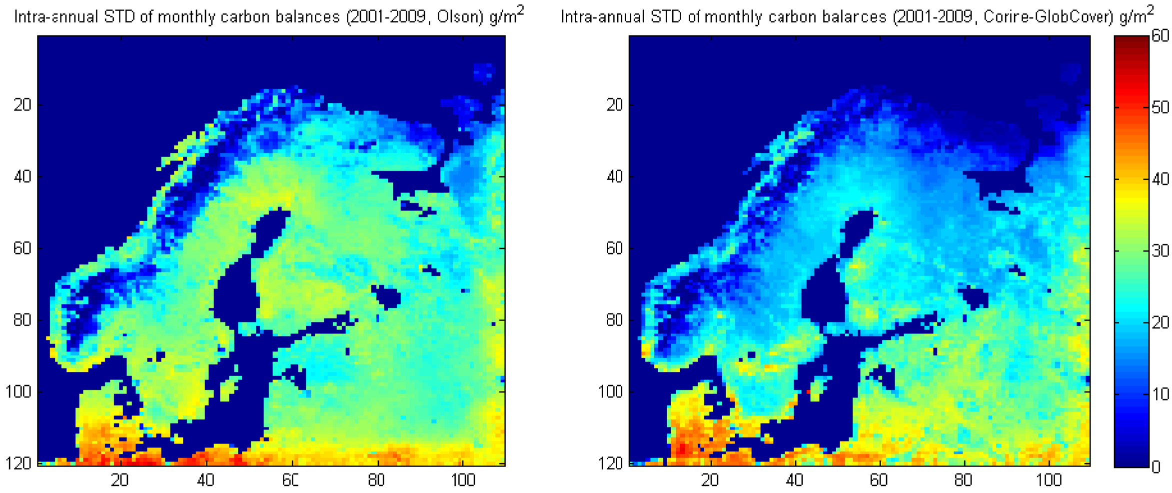

Figure 4. The STD for monthly carbon balances was calculated for each year in 2001-2009. The mean STD is displayed for Olson ecosystem classification (left) and for Corine-GlobCover dataset (right).

3.2 Start of growing season determined from satellite and carbon modelling

Comparison at CO_2 flux measurement sites in Finland

$GSSD_{sat}$ for sites Hyytiälä and Sodankylä showed good correspondence with *in situ* observations for the period 2001-2010. No systematic difference in performance of $GSSD_{sat}$ was found between the northern (Sodankylä) and southern (Hyytiälä) site. The JSBACH modelled growing season onset at site level was in general ahead of its measured value (Figure 5).

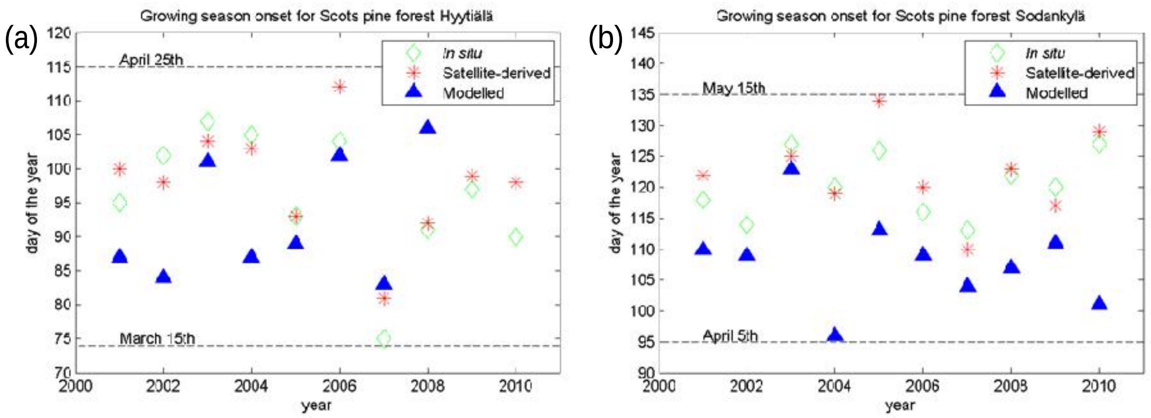

Figure 5. Comparison of in situ measurements of growing season start date (GSSD, determined from CO2 flux-measurements) with satellite-derived estimates and model simulations with JSBACH (period 2001–2010) in (a) Hyytiälä, Southern Finland and (b) Sodankylä, Northern Finland.

Regional comparison

The regional JSBACH modelling results for Finland showed generally a later occurrence of GSSD (about 25 days, Figure 6 and Figure 7) than satellite-derived estimates, which is in contrast to results for the local sites Hyytiälä and Sodankylä. Reasons for the delay of the modelled GSSD are still under investigation, but are most likely due to too low air temperatures provided to JSBACH by the regional climate model REMO.

The average modelled GSSD for years 2003-2008 was well correlated with $GSSD_{sat}$ (Figure 7) and similar patterns for the distribution of GSSD were observed in both maps (Figure 6). The delay of GSSD is stronger for the northern areas. This may be due to the fact that in the model the same temperature parameterization for the recovery of photosynthetic processes in evergreen coniferous forest is applied for the whole region, although it has been found that the response of photosynthetic recovery to air temperatures seems to be slower in the Northern than in the in Southern Boreal zone (Suni et al. 2003; Thum et al. 2009).

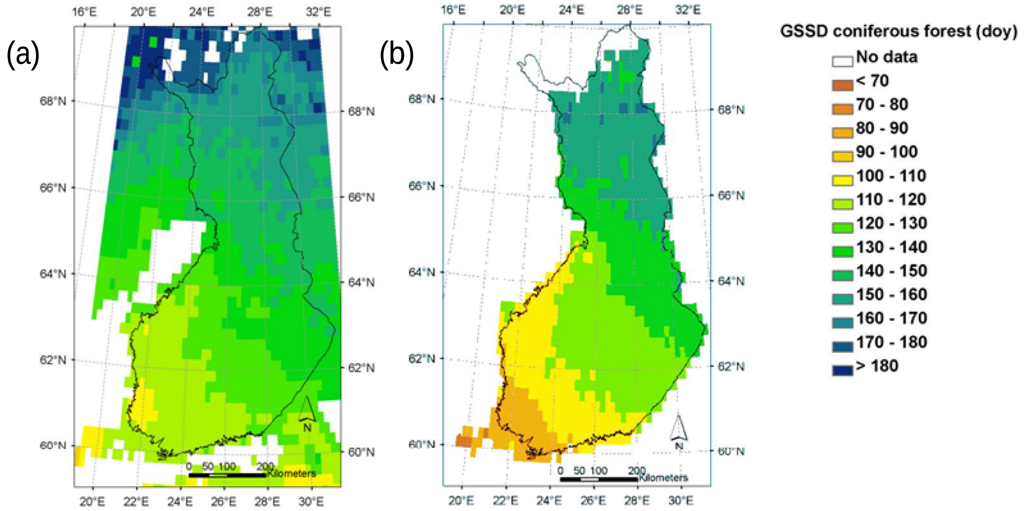

Figure 6. Average GSSD in coniferous forest by JSBACH model (a) and derived from satellite data (b) for years 2003–2008.

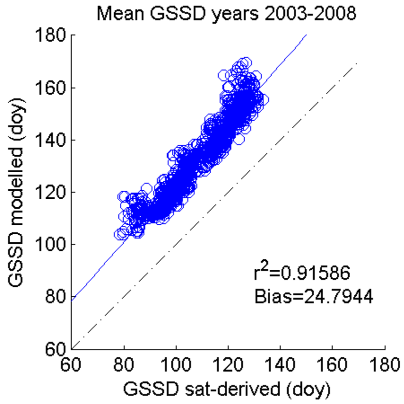

Figure 7. Scatterplot of average (period 2003-2008) satellite-derived and modelled GSSD.

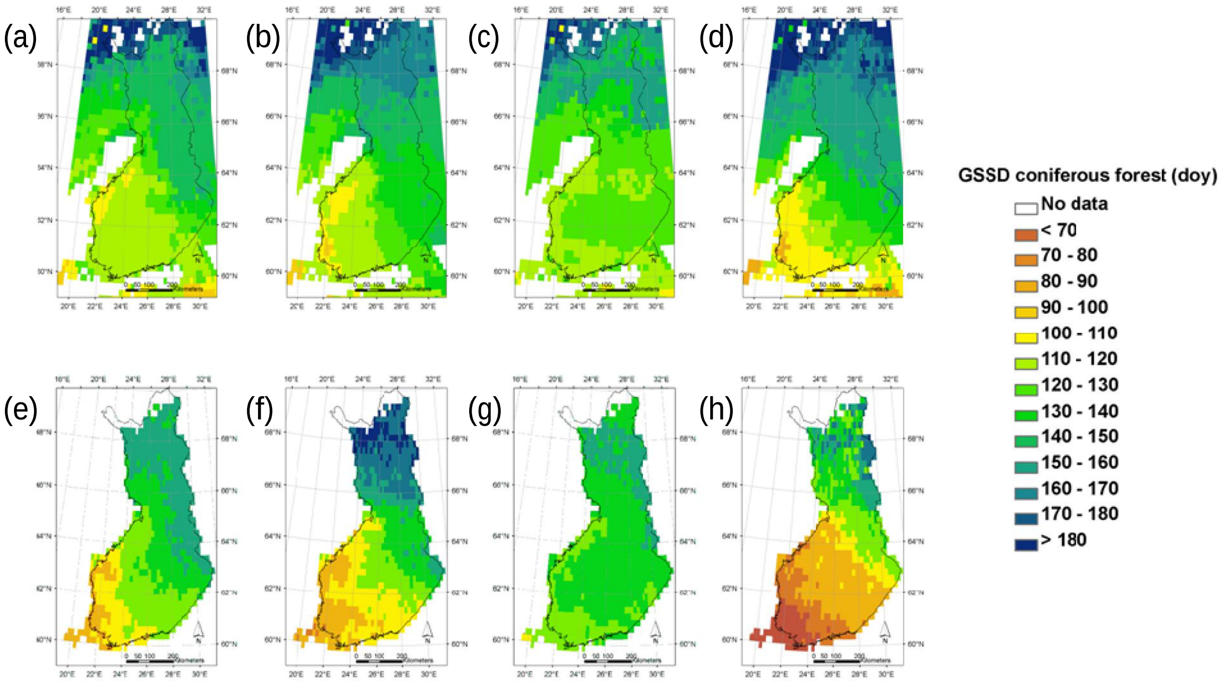

Figure 8. Maps of GSSD in Finland from JSBACH model (top) and derived from satellite time-series (down).

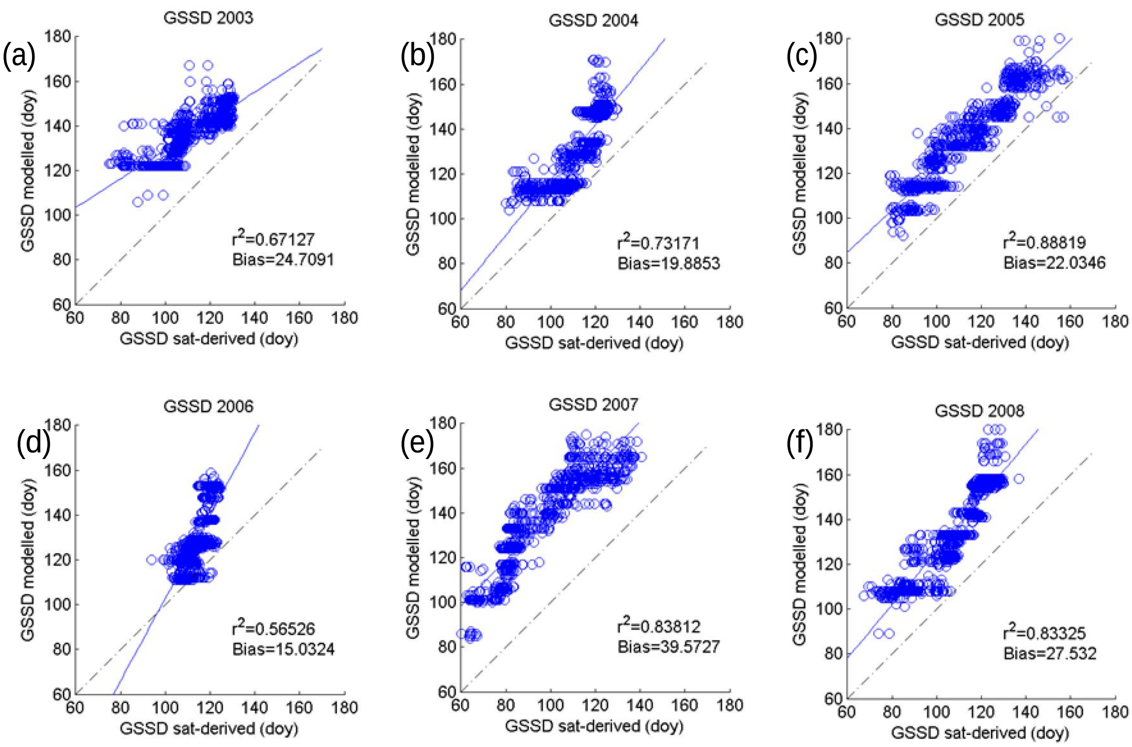

Figure 9. Scatterplots of satellite-derived and modelled GSSD with JSBACH for Finland (years 2003–2008).

Maps of the GSSD in Finland and scatterplots of simulated versus satellite-observed GSSD for single years are given in Figure 8 and Figure 9. The scatterplots indicated considerable differences in correspondence of modelled and satellite-derived GSSD. The coefficient of correlation ranged from 0.56 in year 2006 (Figure 9d) to 0.88 in year 2005 (Figure 9c).

GSSD was delayed compared to the satellite-observed value in each year, with highest bias in year 2007. The year 2007 was characterized by an early (one month earlier) thermal spring and the mean march temperatures were higher than normal (Finnish Meteorological Institute 2012). In correspondence with weather observations, the satellite-observed GSSD in Southern and Central Finland was advanced by 10-20 days (compared to the mean of 2003-2008). In some regions of the south-western coast and in central Finland the advancement was more than 20 days (Figure 10b). The model-derived anomaly depicted only an earlier beginning of growing season (10-20 days) for the Southern parts of Finland and a delay in some areas in central and northern Finland.

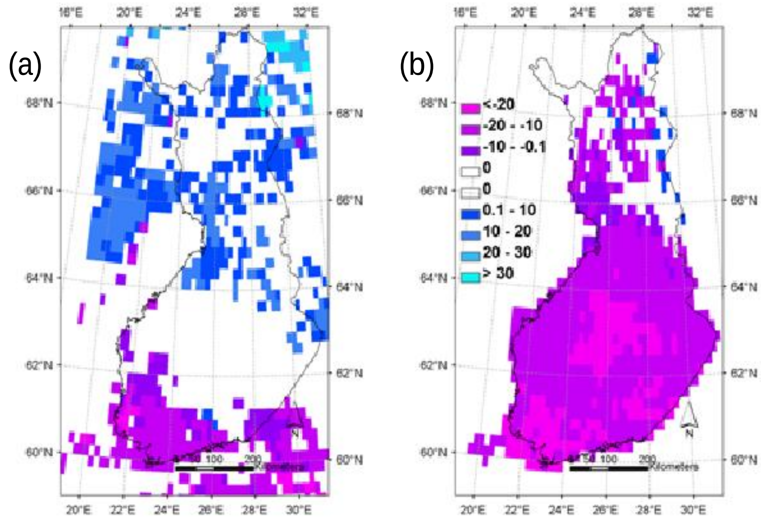

Figure 10. Anomaly of GSSD (days) in year 2007 from JSBACH model (a) and derived from satellite data (b). The yearly anomaly is determined by calculating the deviation from mean GSSD (years 2003-2008). Only deviations from the mean greater than one standard deviation are shown.

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