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Action 8 – Demonstration and validation by FMI

LIFE+ PROJECT NAME or Acronym

SNOWCARBO

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List of abbreviations

FMI	Finnish Meteorological Institute
MPI-M	Max Planck Institute on Meteorology, Hamburg
JSBACH	Jena Scheme for Biosphere-Atmosphere (model describing biosphere-atmosphere interaction)
REMO	Regional climate model
EC	Eddy covariance method to determine matter (e.g. CO_2) and energy exchange
NEE	Net exchange of CO_2 in between the atmosphere and a ecosystem
GPP	Gross primary production, i.e. CO_2 uptake in photosynthesis
NPP	Net primary production, i.e. effective CO_2 uptake by plants when both photosynthesis and autotrophic respiration has been taken into account

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
ECMWF	European Centre for Medium-Range Weather Forecasts
CTE	Carbon Tracker Europe
GAW	The Global Atmosphere Watch programme of WMO is a partnership involving 80 countries, which provides reliable scientific data and information on the chemical composition of the atmosphere

1 Introduction

This action focuses on demonstration of carbon balance assessment methodology by applying information from actions A9, A3 and A4 as reference data. The modeling tasks consist of the climate model REMO runs in the forecast mode (see the "1st report on methodology" of A6 for a more thorough description of the running modes) in which the model is initialized daily from re-analysis data of ECMWF (see reports of A4) and consequent offline JSBACH land surface model run (see the "1st and 2nd progress report on methodology" of A6 for the description of the structure of the modeling framework). Target years span from 2001 to 2009 and the domain covers Northern Europe, i.e. Nordic countries (except for Iceland) and Baltic countries. The demonstration of the modeling framework consists of sensitivity analysis among the different modeling schemes and comparison to observation data of different climate related variables. The selection of the most suitable modeling framework for producing the present day CO2 balance will include comparison to the in situ data of A4 and phenology data from A3. In this document the performed evaluations of some central variables are shown with outline of the methods.

2 Objective

While the principle product of the modeling framework is the regional CO2 balance estimate, a few other predicted variables can be assessed against the wide observation data set available for the project. Assessment of the variables that can be considered as by-products from the CO2 balance point of view, is important in order to find out the strengths and weaknesses of the overall modeling framework.
The predicted variables that were evaluated included central climatic variables such as temperature and precipitation as well as other variables relevant for water balance. In general, the variables related to the surface energy balance reveal fundamental features of model performance and thus they play an important role in assessment of the model performance. In addition to comparison with the observation data, the differences in the predictions of both models – REMO and JSBACH - were explored. In order to evaluate the influence of improved land cover data sets, both REMO and JSBACH predictions with different surface data were compared. All in all, the model evaluation consists of model intra-comparison, model inter-comparison and comparison to the observations. This division in to the three comparison categories is given in order to organize the process of testing the models. The definition of the classes is given in the "1st progress report on methodology" as well as in the chapter below.

3 Approaches

Various model simulations calculated for a certain period of time may deviate from eachother 1) due to differences in the running set up, 2) due to differences in the boundary and initial conditions and 3) due to differences in the process descriptions in the applied models. The first case occurs for instance in between the REMO forecast and climate runs, the second case holds when the land cover data or the driving meteorological fields are varied, and the third case holds for differences in between REMO and JSBACH which both predict independently a set of variables related to surface processes, such as latent heat flux or snow depth.
The reference data suitable for the evaluation depends on the causes of deviations and the goals of the evaluation. Thus in the "1st report on methodology" we defined three different evaluation approaches to be applied in the assessment of the performance of the modeling 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.

3.1 Spatial scale of the evaluations

The first two comparison methods can be performed simultaneously for the whole model domain whereas the target area of the last method depends on the nature of the reference data. In areal comparison the primary method is visual assessment of the areas of largest differences. Areal averages of various resolution will be exploited in determining the spatial scales of the deviations.
The above mentioned measures can be used also in the comparison to the observations whenever the observation can be transformed into the spatial grid respective to that of the model results. However, when site wise data such as EC flux data from A4 is used the grid cell enclosing the flux site is picked from the regional model runs. Additionally, flux measurements are compared with site-level simulations (see Chapter 3.3).

3.2 Temporal scale of the evaluations

Time averages of different scales - i.e. daily, weekly, monthly and yearly - were applied in processing and reporting the results. The time resolution of the model evaluations was decided separetely for each type of data depending on the nature of the variable and applied reference data. The data storage requirements played an important role in decision making. However, because CO2 exchange rate has several distinct cycles, such as the daily cycle due to PAR irradiance and the yearly cycle due to temperature and radiation, the averaging windows for the model evaluation were adjusted so as to capture the time scales each reference is sensitive to.

3.3 Application of JSBACH at site-level

In order to perform site specific system evaluation, JSBACH model was run with site specific meteorological data for Sodankylä CAL-VAL site and Hyytiälä site of the University of Helsinki. Dominant species of both sites is Scots pine. A half hourly meteorological data was used for site level evaluations. As site-level runs provided information on the model performance under the particular weather situations that occurred at the location of the flux tower, the results are better comparable to the flux data. Furthermore, the site specific characteristics of vegetation and soil properties were easier adopted in the modeling and thus the features due to process description can be easier distinguished from the features due to parameterization.

4 Reference data

In the following the various types of reference data are explained separately with discussion on their characteristic features to be considered in model evaluation.

4.1 Regional data

Regionally the performance of the vegetation model was evaluated against phenological data, such as NDVI from satellites A3 or in situ data set for phenology A5 (see reports of A7).
The required time averaging window was set to agree the time resolution of the reference data. During spring and autumn the time averaging window should be set as narrow as possible in order to capture rapid changes in the state of the vegetation.

4.2 In situ data

4.2.1 Flux site data

In *in situ* comparisons we used CO2 net ecosystem exchange (NEE) data of CARBOEUROFLUX sites that belong to FLUXNET network (see reports of A4).
In the land surface model JSBACH the CO2 fluxes related to processes releasing (respiration processes) and assimilating (photosynthesis) carbon are explicitly solved and output in separate variables. These variables include: 1) GPP (gross primary production) that accounts for assimilation in photosynthesis and a small CO2 production term called photorespiration; 2) NPP (net primary production) that is sum of GPP and autotrophic respiration that accounts for CO2 release by plants in maintenance and growth processes; and 3) soil respiration that consists of CO2 releasing processes due to decomposition of organic material. Sum of heterotrophic respiration and autotrophic respiration is the Total Ecosystem Respiration (TER).
A sum of NPP and soil respiration is net ecosystem production (NEP) that in turn is a negative of NEE, providing thus a direct link from model predictions to measurements. Some of the applications used in this project (e.g. determination of groving season start, A7) base on GPP that cannot be directly measured, however, various methods exist for determining GPP and TER from existing NEE observations (see Reichstein et al 2005 and reports of A4).
In addition to the NEE values there is data available on the of surface energy balance – water vapor flux (i.e. latent heat flux), sensible heat flux and various radiation terms – that were used in model evaluation.

4.2.2 CO2 background concentration data

CO2 background concentration that is continuously measured at Pallas-Sodankylä GAW site (see data documents of A4) is used in atmospheric inversion model CarbonTracker Europe (CTE, www.carbontracker.eu/, Peters et al., 2010) that is developed in Wageningen University, the Netherlands and is currently further developed also in FMI. CTE produces a top down estimate of regional CO2 balances that are calculated 1 degree spatial resolution and half hourly time resolution. However, CTE results are considered reliable for larger areas (so called eco-regions) and time scale of typically one month. This word of caution has to be born in mind when looking at the comparison against our NEE estimates.

4.3 National GHG inventory data

In addition to CTE estimates, in national level the CO2 balance predictions have been compared with the national GHG inventory data by Statistics Finland (http://www.stat.fi/til/khki/index_en.html). For this comparison, yearly Snowcarbo land ecosystem balances are summed over the Finnish territory and compared to the estimates of CO2 emissions of Finland from land used land use change and forestry (LULUCF, see the last column of table: http://www.stat.fi/til/khki/2010/khki_2010_2012-04-26_tau_003_en.html, Official Statistics of Finland (OSF): Greenhouse gases [e-publication]). One has to bear in mind, that the SnowCarbo modeling framework does not model land use change implicitly. Also the treatment of crop lands is different as the OSF does not include crop yield into LULUCF. Another important difference is the method to estimate the faith of soil organic matter: The OSF statistics are based on climatic mean air temperature and precipitation over the time period from 1971 to 2000, which reduce year to year variation.

5 Run settings

REMO model have been run for the pre-existing climate data series, i.e. for years 2000-2009, in forecast mode which means daily ignition of the model from initial data with a spin-up period of 6 hours (see reports of A6 for more thorough explanation of the running modes). The REMO climate (see reports of A6) runs at horizontal resolution of 0.167° were carried out for years 2001-2006 with ECMWF-analysis data as initial and boundary data. The reader is referred to the “Preliminary Demonstration Report” of this action for more details.

REMO model was run with two different land use data – the original USGS data set, GlobCover and National Corine+GlobCover (NCLCGlobC) land cover classifications from WP11 in climate mode. The differences in energy balance partitioning due to different surface parameter maps in climate runs was discussed in the preliminary demonstration report. Unfortunately a decisive selection of the most suitable land cover data is handicapped due to the local nature of the energy balance data from the flux sites and lack of regional data. The REMO runs for producing JSBACH boundary data were carried out with NCLCGlobC that is based on most detailed and up to date land cover data.

The JSBACH production runs were carried out with surface libraries base on USGS data and NCLCGlobC. For this aim the forcing data was extracted from hourly REMO weather data series.

The model spin-up procedures for climatic variables in both REMO and JSBACH, as well as the procedure for stabilizing JSBACH ecosystem carbon pools, have been described in “Preliminary demonstration report” of this action. Year 2000 has been preserved for spin-up purposes in JSBACH runs and its results have not been used in evaluation or included in final results.

6 Evaluation of model results

The reader is referred to the “Preliminary Demonstration Report” of this action for the comparison of results on the REMO climate mode runs with ECMWF-analysis data. From here on the REMO results presented have been produced with NCLCGlobC land cover based surface data. JSBACH results have been produced for both USGS and NCLCGlobC based surface libraries. For site level simulations the plant functional type (PFT) distribution representative for the site have been applied.

6.1 Flux site level results with local meteorology

The micrometeorological observations of Sodankylä CAL-VAL site in daily time resolution have been compared to site level simulations that are forced with half hourly locally measured meteorology (see chapter 3.3). In Sodankylä flux site the dominant species is Scots-pine that falls into PFT class Coniferous Evergreen Trees. The JSBACH was run at Sodankylä for years 2001-2008. The spinup was performed with Cbalone and after that the model was run. In the following the model are compared to measurements and two calibrations to model parameterization are suggested. Furthermore the performance of the stabilization of carbon pools during the spin-up procedure is demonstrated.

Gas exchange compared to measurements

The modelled TER levels showed overestimation from measured for the winter time (Fig. 1). The heterotrophic respiration was not limited at low temperatures in the original model version. When respiration was forced to stop when soil temperatures dropped below -3 °C, the modelling of the winter time respiration level improved (Fig. 1).

During summer the respiration levels were underestimated by the model (Fig. 1). At Sodankylä there are large soil respiration values during summer and the process that causes them is not described in the model. Therefore the model failed to replicate this behaviour.

To simulate measured respiration values, we artificially increased the Q10 value, that is influencing the magnitude of the respiration. We multiplied Q10 by value 2.2 during time period DOY 176-238 (June 25 – August 26) to match the simulated respiration with the observed one (Fig. 1). Despite these modifications there occurs still some mismatch between the observation and simulation. In the first part of the year TER is underestimated by the model, but in October and November the respiration is overestimated.

For calculation of GPP and NEE the modified model (wintertime inhibition + Q10 multiplication) was used. The modelled daily GPP was at the same level as the measured GPP, but the model had some tendency to earlier spring time uptake compared to the measurements (Fig. 2). The simulation also overestimated the June and July uptake.

The modelled NEE is the sum of these two component fluxes, negative GPP and positive TER. Too early commencement of GPP is therefore also seen in the NEE and the summertime uptake is overestimated (Fig. 3).

The time series of monthly TER, GPP and NEE are shown in Figs. 4-6, respectively. The simulated monthly TER seems to be underestimated during wintertime in many years, but the summertime peaks overall are in good agreement with the measurements (Fig. 4). The simulated monthly GPP is mostly overestimating the observations during summertime, but in two first years the summertime GPP remains underestimated (Fig. 5). As expected, the interannual variation of GPP in the measurements is not captured by the simulations. The simulated monthly NEE time series shows some respiration peaks during wintertime that are not present in the observations (Fig. 6).

The daily time series of TER, GPP and NEE are shown in Figs. 7-9, respectively. The simulated daily TER has differences in the maximum summertime values between years (Fig. 7). The bias in the phase of the simulated GPP is seen also in the daily values (Fig. 8). The daily values of NEE show the abrupt change in the level of wintertime respiration, as the soil respiration was set to zero at one threshold temperature value (Fig. 9).

The modeled and observed annual balances for TER, GPP and NEE are shown in Table 1 and in Figs. 10-12. The modeled and observed TER values are overall quite close to each other (Table 1 and Fig. 10). The annual GPP values are overestimated by the model in all other year except 2001 (Fig. 11). The model estimates the forest to be a carbon sink or close to carbon neutral, but the observations indicate that the forest is a carbon source (Table 1 and Fig. 12).

The discrepancies between the model and simulations are likely caused by the overestimated carbon uptake by the forest that is shifted towards too early spring. It is not as straightforward as it was for the respiration part to try to tune the model to match the GPP observations better.

LAI

The modelled LAI reaches its lowest value of the year, 1.5 m2 m-2, on DOY 156 (June 6) when the LAI starts to increase, reaching the maximum value 1.9 on DOY 214 (August 2) (Fig. 13). The LAI in the JSBACH model describes the total LAI (Sönke Zaehle, pers. comm.), but it is closer to the measured projected LAI that is 1.2 m^2 m^{-2}. However, with the low total LAI value the model gives similar GPP values to measurements. The annual cycle of LAI is quite similar between different years, with small variation in the annual minimum and maximum values (Fig. 14).

Latent heat flux Qle

The comparison between daily measured and simulated latent heat fluxes revealed more variability than measurements (Fig. 15). The simulated Qle was overestimated, but not always on same years as the GPP was overestimated. This suggests that the overestimation is not always caused by stomatal conductance but maybe by the evaporation from surfaces.

Soil carbon

As expected, the modelled soil carbon content is largely overestimated at Sodankylä after spinup (Fig. 16). The total soil carbon after spinup in simulation is 27 kg C m-2, whereas the estimated soil carbon content from estimates is about 3.6 kg C m-2 (pers comm Mika Aurela, A4).

Table 1. Annual balances of TER, GPP and NEE at Sodankylä.

Year	TER:obs	TER:sim (units g C m-2)
2001	686	578
2002	nan	574
2003	584	556
2004	647	604
2005	645	650
2006	647	549
2007	596	635
2008	471	607

Year	GPP:obs	GPP:sim (units g C m-2)
2001	658	571
2002	nan	679
2003	537	643
2004	555	614
2005	563	652
2006	612	690
2007	556	625
2008	471	569

Year	NEE:obs	NEE:sim (units g C m-2)
2001	35.6	7.9
2002	nan	-104.4
2003	34.5	-87.8
2004	70.5	-9.8
2005	75.6	-2.4
2006	41.7	-141.8
2007	65.3	10.4
2008	7.8	38.9

Fig. 1. The averaged annual cycle of TER at Sodankylä. The observation is in black, the original model in blue and the modified model in blue. Note that months run from 0 to 11.

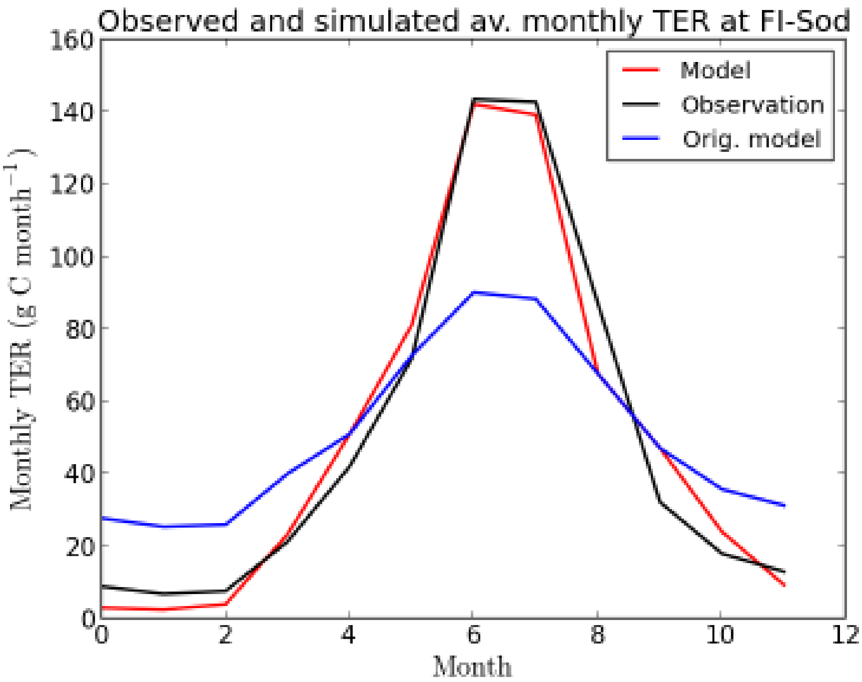
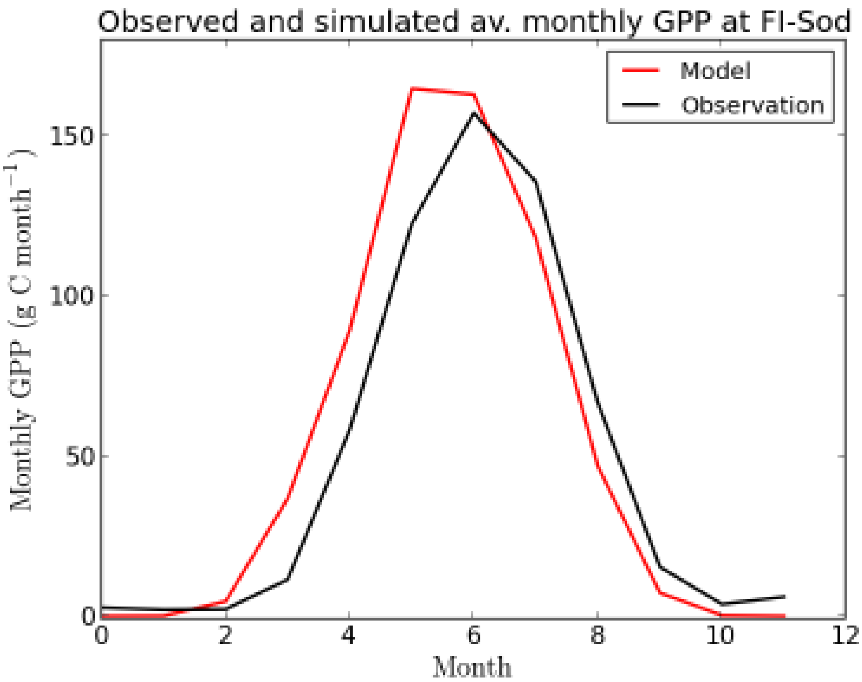


Fig. 2. The averaged annual cycle of GPP at Sodankylä, observation and simulation. Only positive daily



values were used in the calculation. The modification of TER does not influence the modelled GPP. Note that months run from 0 to 11.

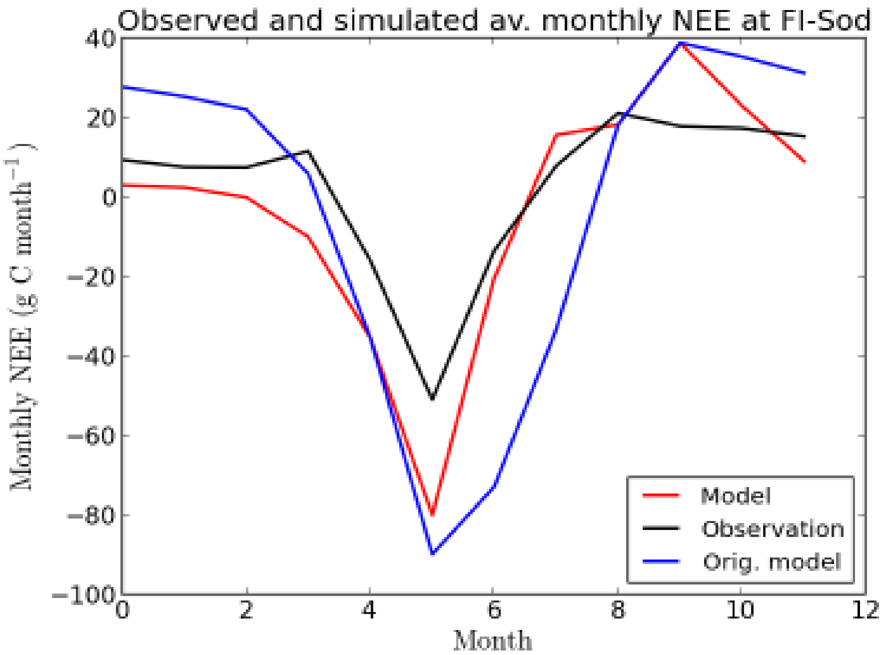


Fig. 3. The averaged annual cycle of NEE at Sodankylä. The observation is in black, the original model in blue and the modified model in blue. Note that months run from 0 to 11.

Fig. 4. The monthly TER at Sodankylä in 2001-2008.

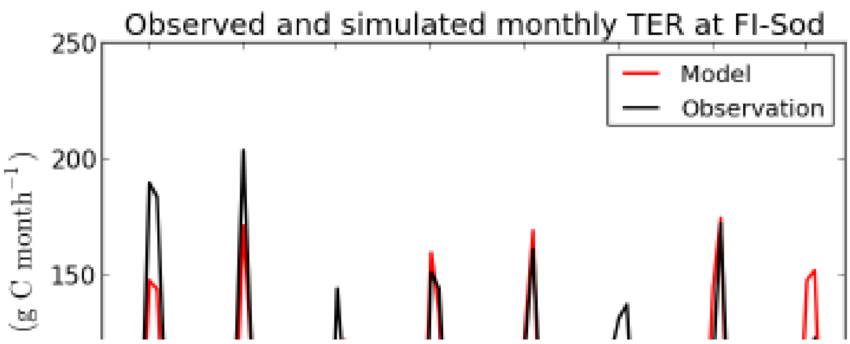


Fig. 5. The monthly GPP at Sodankylä in 2001-2008.

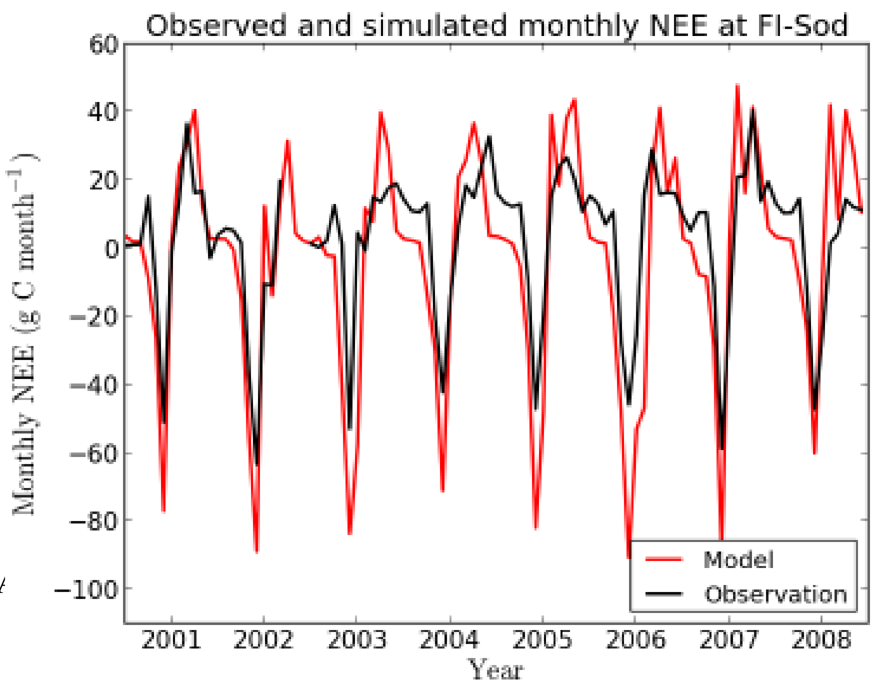


Fig. 6. The

monthly NEE at Sodankylä in 2001-2008.

Fig. 7. The daily TER at Sodankylä in 2001-2008. The observation is in black, the original model in blue and the modified model in red.

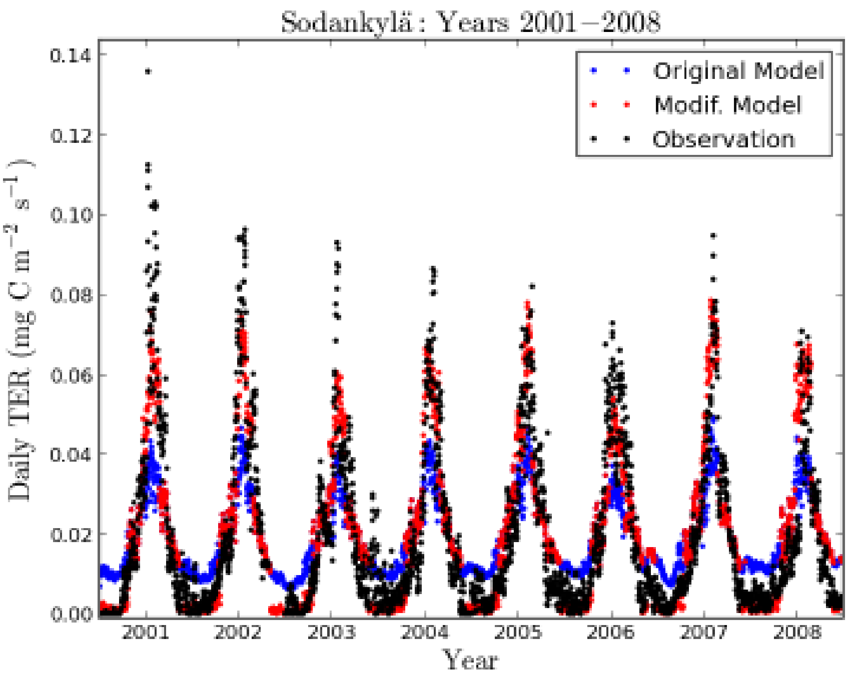


Fig. 8. The daily GPP at Sodankylä in 2001-2008.

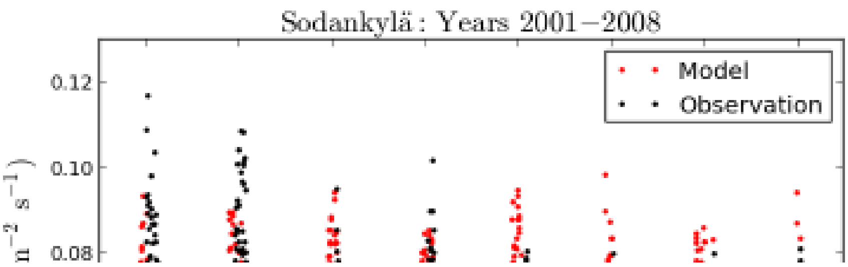
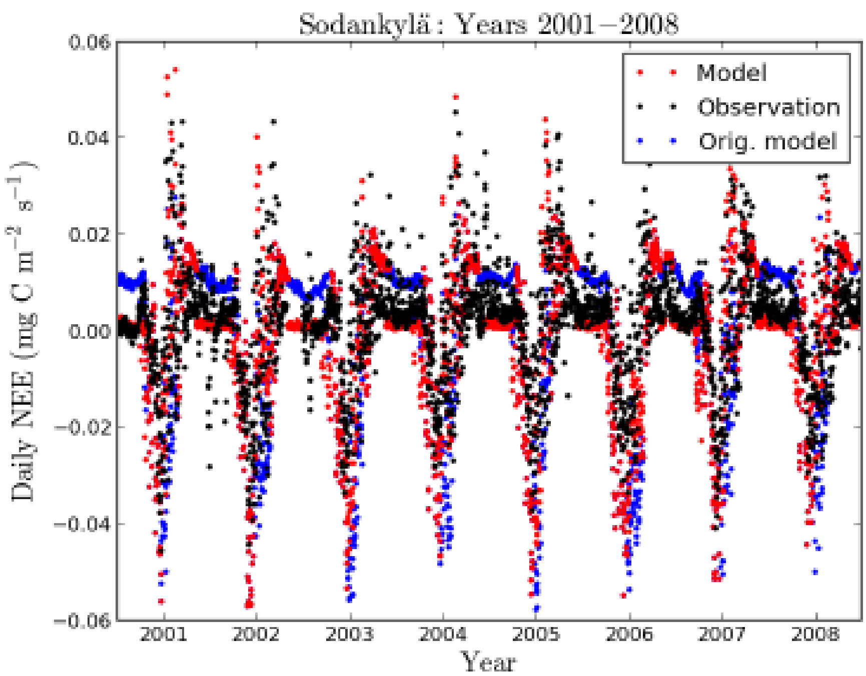


Fig. 9. The daily NEE at Sodankylä in 2001-2008. The observation is in black, the original model in blue and the modified model in



red.

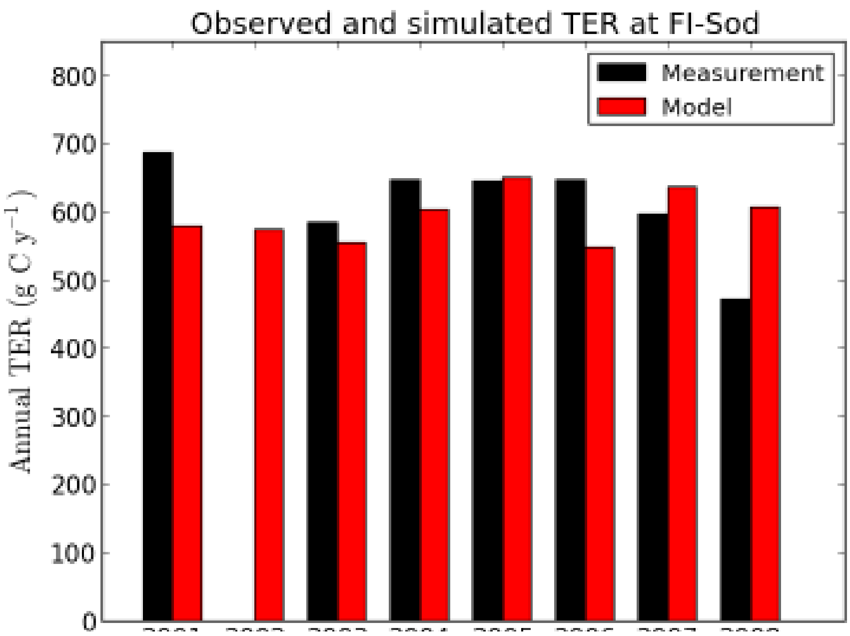


Fig. 10. Annual TER values at Sodankylä.

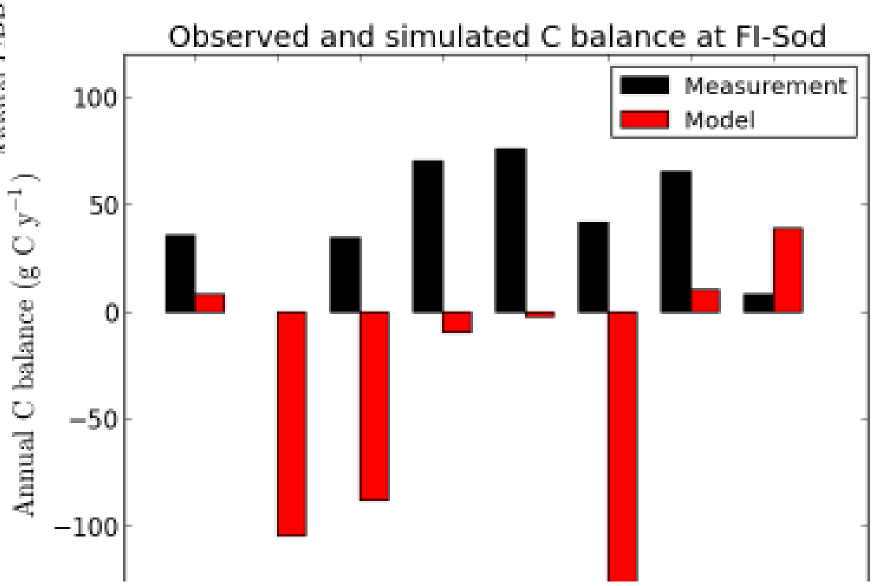


Fig. 11. Annual GPP values at Sodankylä.

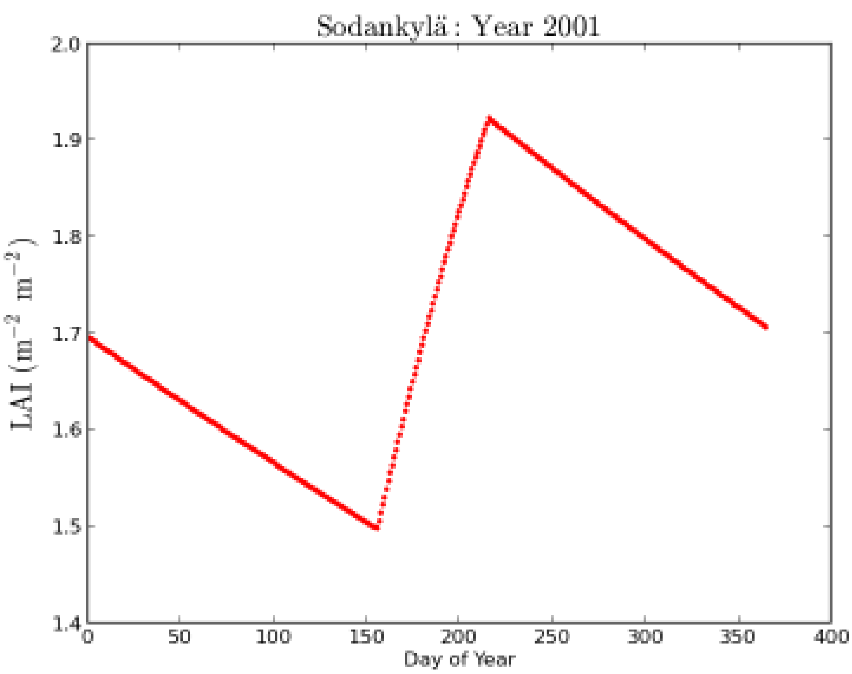
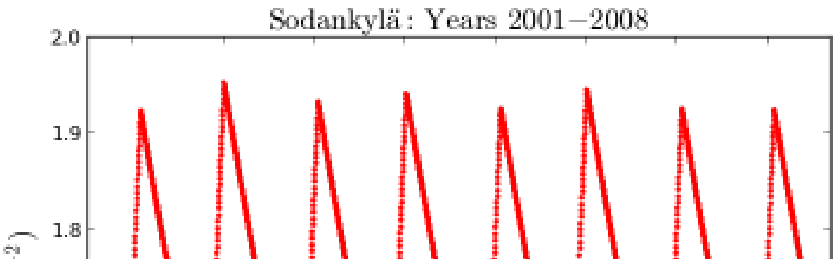


Fig. 12. Annual NEE values at Sodankylä.

Fig. 13. Daily LAI values at Sodankylä in 2001.

Fig. 14. LAI at Sodankylä in 2001-2008.



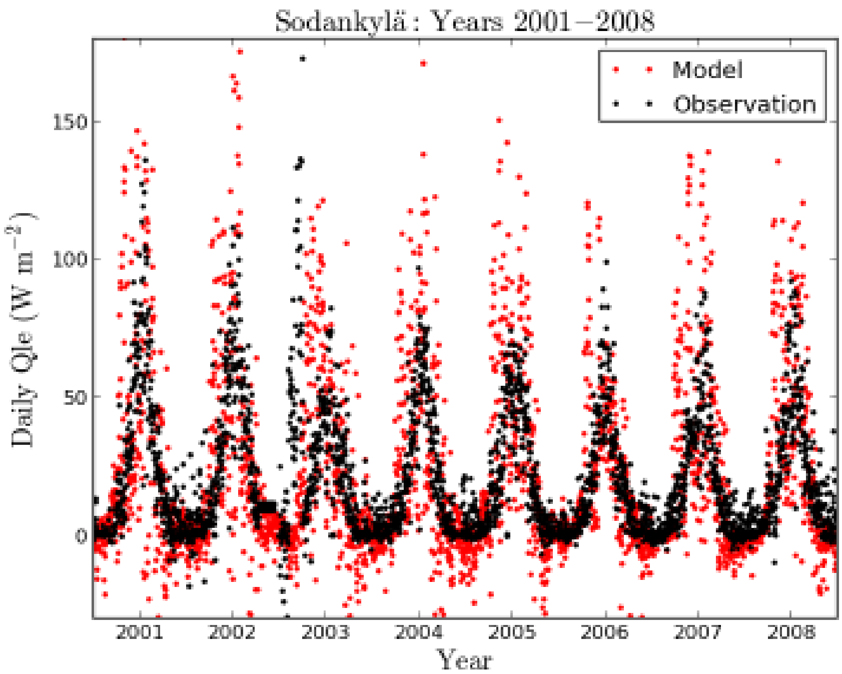


Fig. 15. Latent heat flux at Sodankylä in 2001-2008.

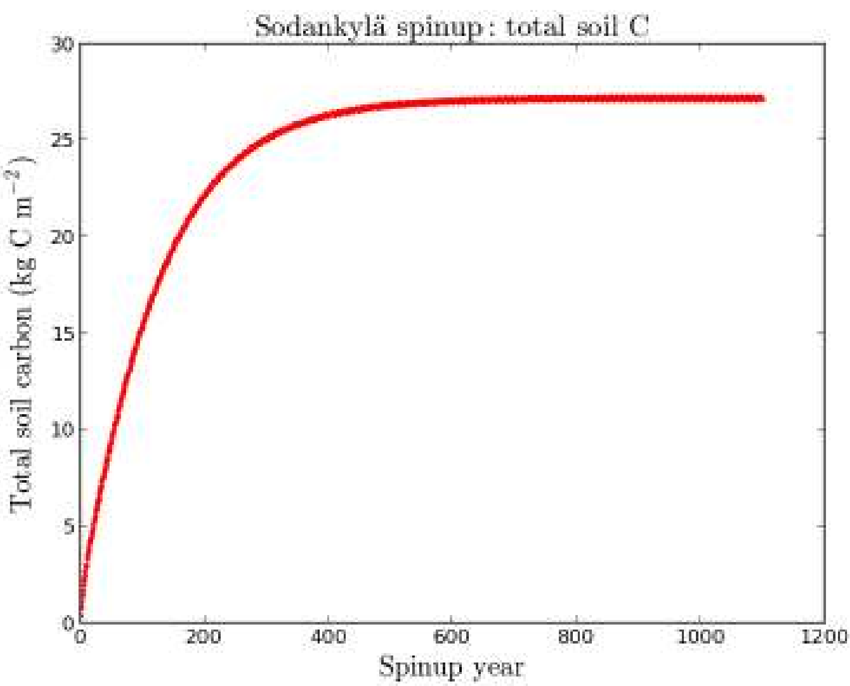


Fig. 16. Total soil carbon at Sodankylä during spinup.

Growing season start date

From GPP time series (Fig. 5 and 8) it can be deduced that the model predicts a slightly earlier onset of CO2 uptake than the measurements. The growing season start date (GSSD) was determined from the site level model results in the method that was used in determining the GSSD from the flux measurements in A4 and A7 (see reports of A4 and A7 and references therein). Comparison between GSSDs determined from modeled and measured GPPs (Table 2) show that the modeled growing season started typically a week ahead actually measured growing season. The maximum difference was 24 and 18 days in Northern Sodankylä and Southern Hyytiälä, respectively. In Hyytiälä there is even one year with measured GSSD ahead its modeled counterpart.

Table 2: Day of year of the GSSDs in a) Sodankylä and b) Hyytiälä according to measurements and the model.

a Sodankylä	model	measured
2001	110	118
2002	109	114
2003	124	127
2004	96	120
2005	113	126
2006	100	116
2007	102	113
2008	108	122
2009	111	120
2010	116	127

b Hyytiälä	model	measured
2001	87	95
2002	85	102
2003	101	107
2004	87	105
2005	89	93
2006	102	104
2007	83	75
2008	106	90
2009	*	97
2010	*	90

6.2 Flux site level comparison of regional results

In the following the performance the offline coupled REMO-JSBACH modeling framework have been evaluated against flux site data and flux site data driven JSBACH. For this comparison, the results of the 0.167° grid cells that enclose flux sites in Sodankylä and Hyytiälä, were extracted for comparison from the regional JSBACH results. The comparison was performed for all meteorological forcing variables as well as for predicted surface fluxes.

Meteorological variables

The comparison between monthly means of the measured and REMO modeled forcing variables revealed that 1) air humidity matches nearly perfectly, 2) shortwave radiation and consequently photosynthetically active radiation (PAR) agree well in timing but the modeled values are up to 15% underestimated, 3) longwave radiation reaches exactly the same montly maximum value in July in both cases, however, from November to January the REMO model values are smaller than local values. The winter minimun in February agrees quite well. Both the timing and the level of measured and modeled monthly mean air temperature matches well (Fig. 17). However, the modeled values lag behind measurements in spring time, which has implications for temperature driven processes such as partitioning of precipitation into snow and water.
The abovementioned implication of spring time temperature deviation is, indeed, visible in snow precipitation predicted with measured and modeled meteorological forcing (Fig. 18). Additionally, already in fall there is excess snow accumulation that cannot be explained with temperature difference, but has to be due to larger predicted total precipitation by REMO. These deviations lead into snow accumulation that is both larger in amount and lasts longer. Together with postponed melting because of lower spring time air temperatures, the snowcover is thicker and lasts longer (Fig. 19).
All the snow precipitation and snow cover related values shown above are modeled with JSBACH that is forced either with measured or with REMO predicted climatic variables. Thus the partitioning into snow and water precipitation is resolved in JSBACH model. Because JSBACH predicts very similar values of water precipitation with both forcings (not shown), it can be concluded that REMO predicted winter precipitation exceeds the measured values. When the snow depths (Fig 19) of January given in water equivalent are multiplied by five - a ratio of water and snow densities in January (http://wwwi2.ymparisto.fi/i2/95/lumikuormanarviointi.html, Table 3), one gets a snow depth of 0.30 m and 0.70 m, with measured and modeled forcings respectively. As according to statistics the snow depth at Sodankylä during the past ten year has varied from 0.30 m to 0.60 m having typically a value 0.40 m (http://ilmatieteenlaitos.fi/lumitilastot), we can conclude that the snow depth produced with REMO precipitation is indeed an overestimation while the prediction based on measured precipitation is in fact a slight underestimation.

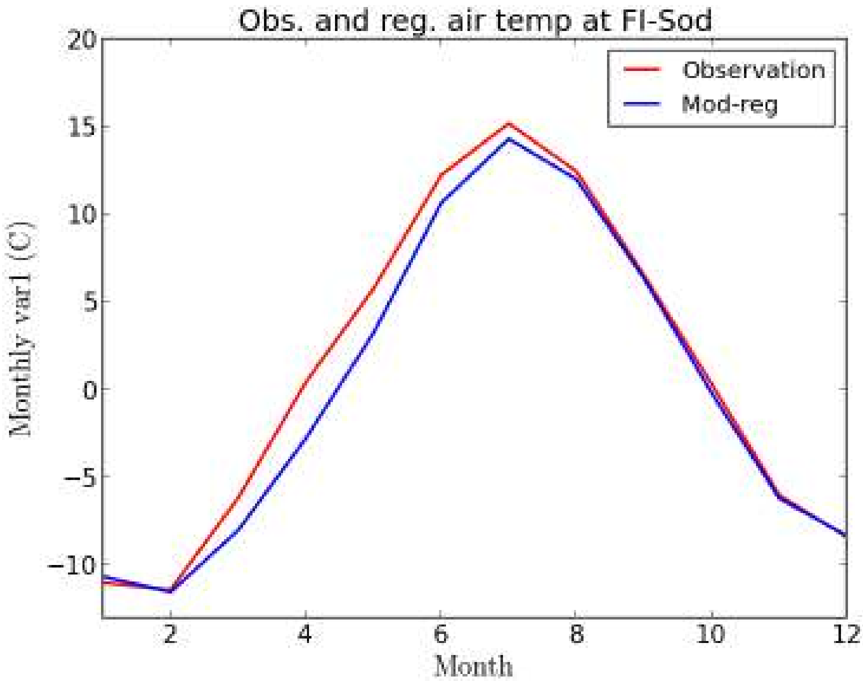


Figure 17. Measured and modeled mean monthly air temperature at Sodankylä in 2001-2009. The modeled value is produced by REMO model in forecast mode with daily ignition.

Predicted variables

In consequent to the larger snow accumulation in the beginning of the winter the soil temperature minimum (not shown) is not as cold in regional as in local runs because of the insulation by snow-cover. In spring the soil temperature rises slower in regional runs because of both the aforementioned insulation and lower air temperature. For instance, the time lag in the zero crossing is on the average approximately half a month in the soil layer nearest to the surface.

Latent and sensible heat fluxes (Figs. 20 and 21) are the turbulent transport terms of energy balance that account for transport of energy between the surface and the atmosphere. The range of yearly variation of turbulent fluxes agrees well among the model results and their measured counterparts. The timing of yearly maximums agree well with measurements in the runs with local forcings and the overestimation of modeled values is within the accuracy of measurements. There are, however, differences in the shape of the everage yearly cycles that relate to the cycles of other component of the energy balance – i.e. net radiation and soil heat flux. The cycles of turbulent fluxes extracted from regional runs show a shift towards smaller values. Especially the large negative winter values are quite suspicious. There is also shift in timing of the cycles – the latent heat flux (Fig. 20) reaches its maximum too early when compared to the obervations and the runs forced with local data. The cycle of the sensible heat flux of the regional runs is rather somewhat delayed in Sodankylä (Fig. 21).

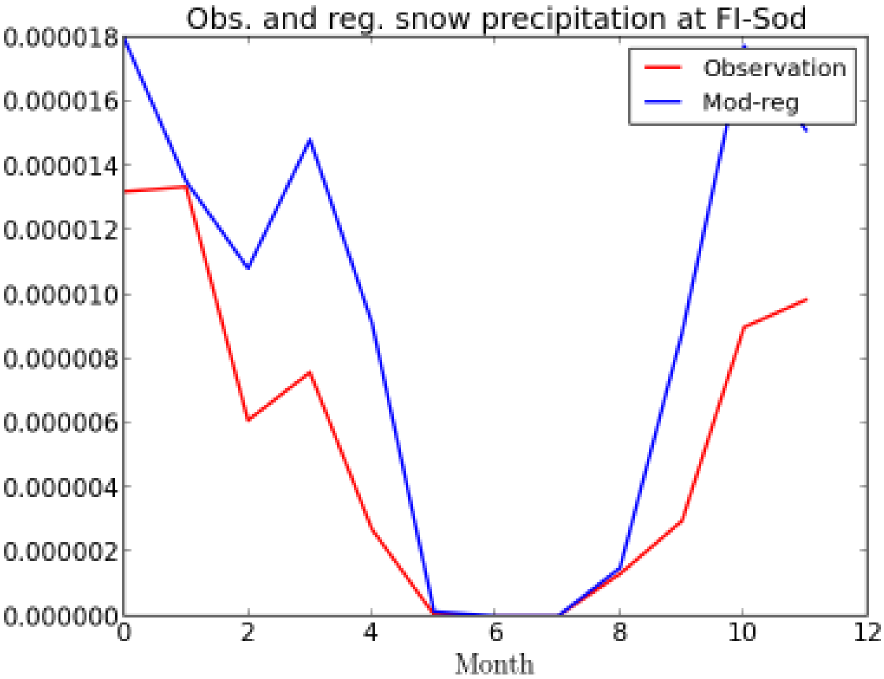


Figure 18. Mean monthly modeled snow precipitation at Sodankylä in 2001-2009. The value in blue has been predicted with JSBACH forced with REMO meteorology and the red value has been predicted with JSBACH forced with local measurement.

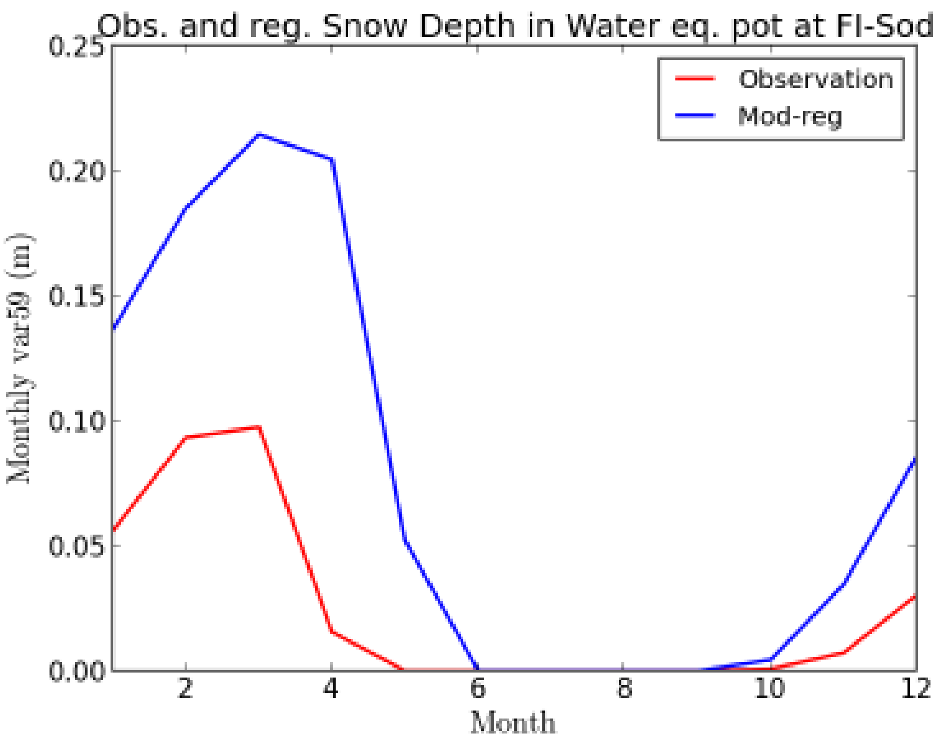


Figure 19. Mean monthly modeled snow depth in water equivalent at Sodankylä in 2001-2009. The value in blue has been predicted with JSBACH forced with REMO meteorology and the red value has been predicted with JSBACH forced with local measurement.

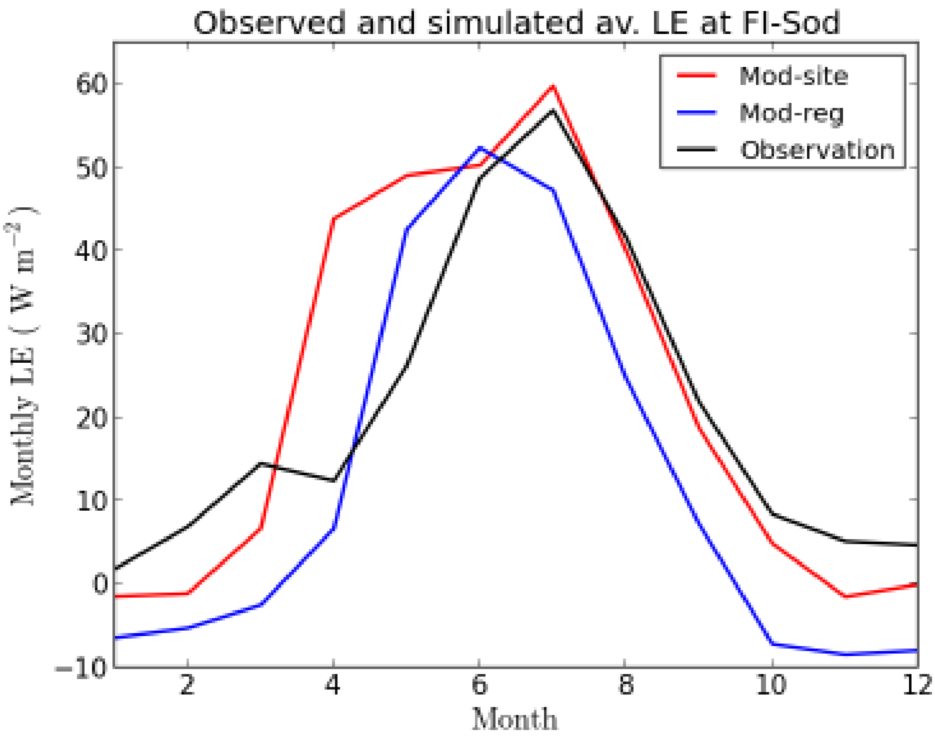


Figure 20. Mean monthly modelled and measured latent heat fluxes at Sodankylä in 2001-2009. The JSBACH results forced with REMO meteorology is in blue, the JSBACH result forced with local measurement is in red and the black line is direct observation by EC.

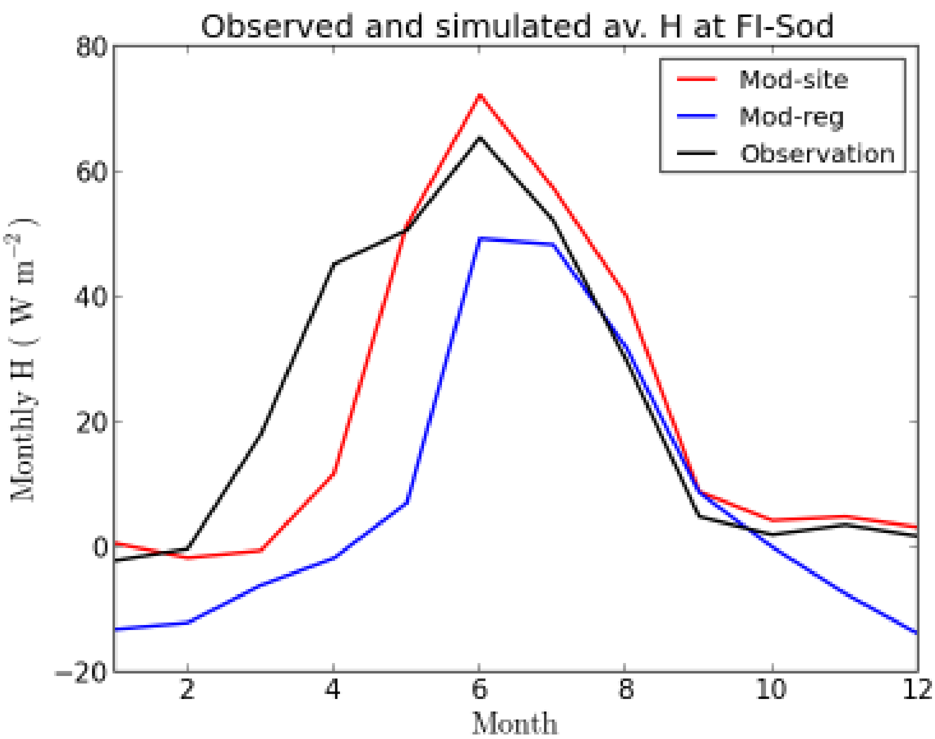


Figure 21. Mean monthly modelled and measured sensible heat fluxes at Sodankylä in 2001-2009. The JSBACH results forced with REMO meteorology is in blue, the JSBACH result forced with local measurement is in red and the black line is direct observation by EC.

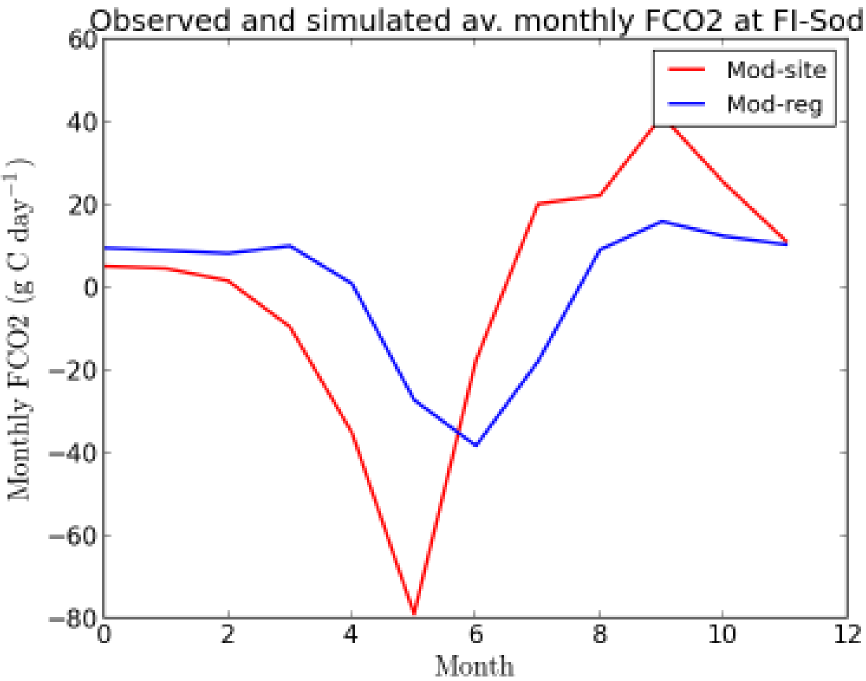


Figure 22. Mean monthly modeled and measured NEEs at Sodankylä in 2001-2009. The JSBACH results forced with REMO meteorology in blue and the JSBACH result forced with local measurement in red. Note that months run from 0 to 11.

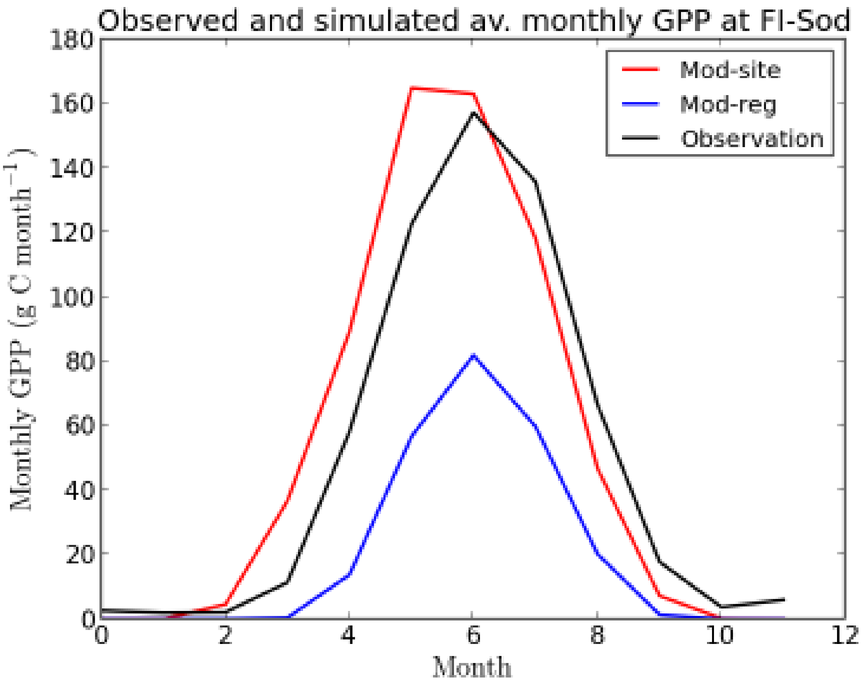


Figure 23. Mean monthly modeled and measured GPPs at Sodankylä in 2001-2009. The JSBACH results forced with REMO meteorology is in blue, the JSBACH result forced with local measurement is in red and the black line is direct observation by EC. Note that months run from 0 to 11.

CO_2 balance

The timing of peak value of montly averaged NEE predicted by the regional run lacks its locally forced counterpart for a month (Fig. 22). The absolute of the peak summer value of

regional results is approximately half of the locally forced value, whereas the wintertime respiration is double in regional runs. The maximum and the minimum and consequently the range of yearly variations are closer to the measurements (see Fig. 3) in regional than in locally forced JSBACH runs. However, there is one month lag in timing of the peak values between the regionally modeled and measured NEEs.
As the yearly photosynthesis peaks in July in both the measured and regionally modeled cases (Fig. 23) the reason for the time lack in NEE lies in yearly cycle of TER.

Comparisons among ORCHIDEE and JSBACH

The site-level simulations by two versions of ORCHIDEE model and JSBACH were compared to the measurements of CO2 fluxes by the eddy covariance method at Hyytiälä, Southern Finland. The models were run into steady state, i.e., the spinup was performed by cycling the observed meteorology at the site. In the model run the observed climatic variables were used as well.

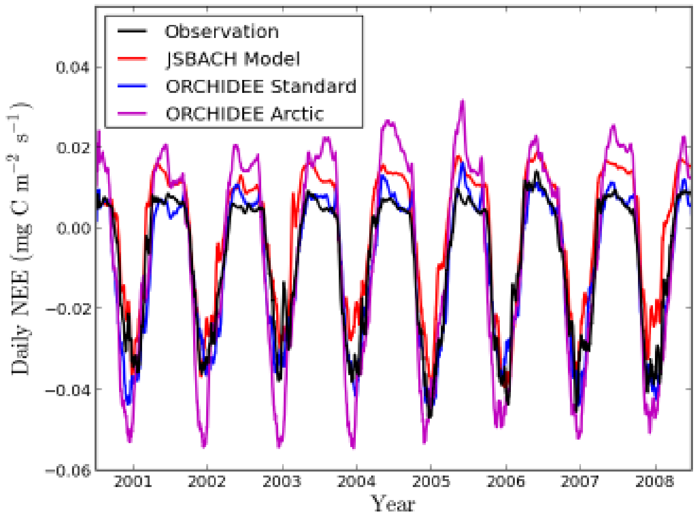


Fig. 4. The daily NEE values (smoothed by 30-day average) at Hyytiälä in 2001-2009: observations (in black), JSBACH model (in red), ORCHIDEE model (in blue), ORCHIDEE Arctic model (in magenta).

The JSBACH model was not tuned to the site, but run only by its default values for coniferous evergreen forests. This lead to overestimation of the wintertime respiration (Fig. 24). During summertime the CO2 uptake was respectively underestimated. The commencement of uptake in spring was too slow in many years compared to the observations and the end of the uptake was often estimated to be too early. All of these contributed to the fact that the cumulative NEE was highly underestimated by the JSBACH model at Hyytiälä (Fig. 2).
The parameters of the standard ORCHIDEE model were first optimized by using the observed NEE and latent heat fluxes for year 2001. This Bayesian optimization was based on gradient linear method. The overall performance of the optimized standard ORCHIDEE model was quite good (Fig. 24), but it did result in overestimation of the cumulated NEE (Fig. 25).
The Arctic ORCHIDEE model version had some modifications on top of the standard ORCHIDEE that enhance its performance in arctic conditions. The annual amplitude between

the summertime and wintertime NEE levels was too pronounced by the model (Fig. 24). In addition, the springtime commencement of photosynthesis appeared to bee too sudden and ceasing of photosynthesis was in some years a bit delayed (Fig. 24). However, the Arctic ORCHIDEE provided the closest estimate of the cumulated NEE compared to the observations (Fig. 25).

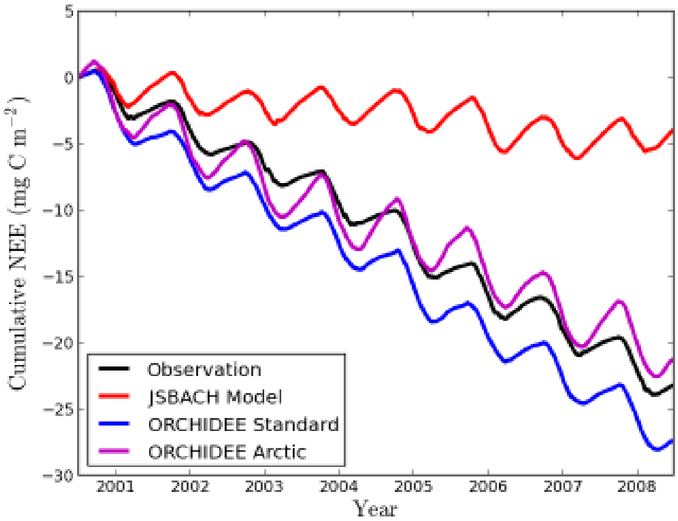


Fig. 25. The cumulative NEE values at Hyytiälä in 2001-2009: observations (in black), JSBACH model (in red), ORCHIDEE model (in blue), ORCHIDEE Arctic model (in magenta).

6.3 Regional results

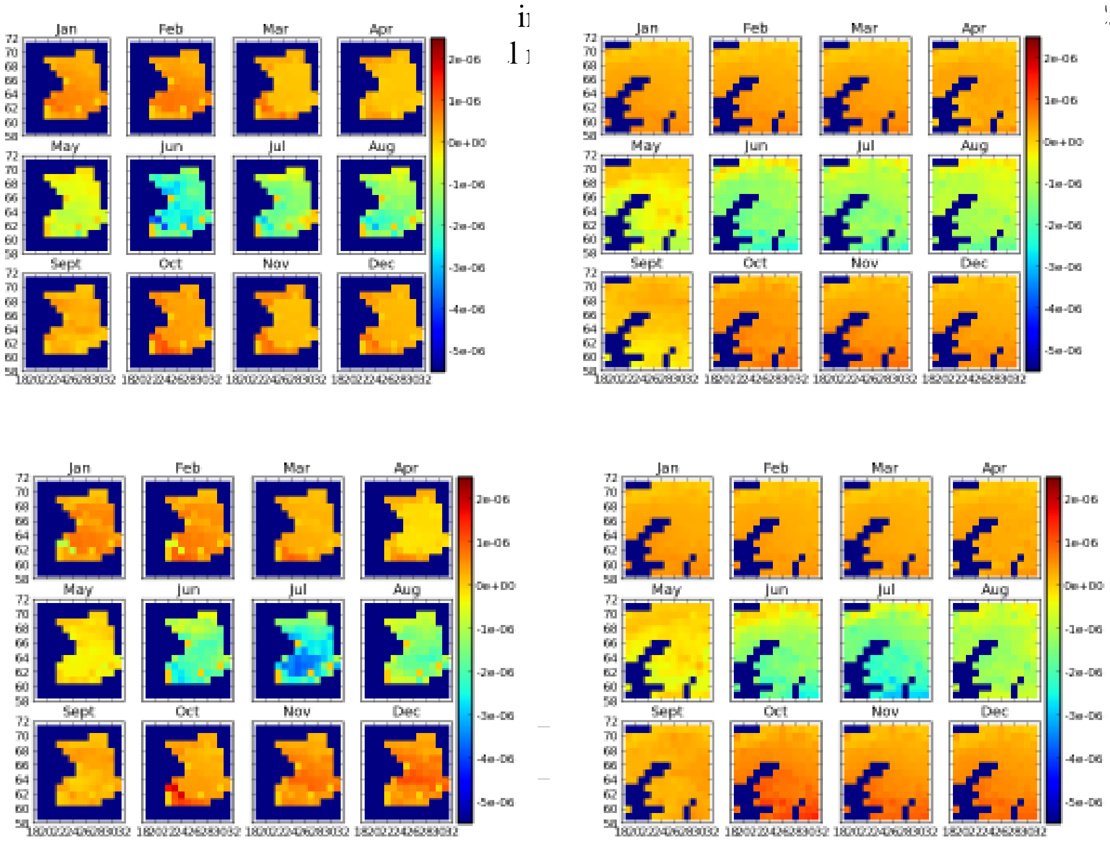


Fig. 27 Monthly CO2 balance of Finland in 2006 predicted by CTE (left) and SnowCarbo modeling framework (right). The horizontal resolution is 1° and the unit is $\mu mol/m^2s$.

Regional comparison with CTE data is restricted to Finland. Visual inspection (Fig. 26 and Fig. 27) shows that at monthly time resolution the general patterns of the variations both in time and regionally are very similar. In year 2002 (Fig. 26) the strongest sink occurs in May according to both models while in 2006 (Fig. 27) according both models the peak of CO2 uptake is in August.

Annual CO2 balance predictions for whole Finnish territory by both models (Table 3) show a considerable difference in the basic level of the balances: whereas CTE consistently estimates the Finnish lands being a sink of CO2 from year to year, SnowCarbo modeling framework estimates also net source for some years. This is because in JSBACH the land cover is fixed to present situation and the model is driven to equilibrium with present day climate and atmospheric CO2 concentration. Thus the amount of carbon stored in soil organic compounds, that sets the basic level of CO2 balance, does not represent the real situation, which is regulated by the interplay between past climate and the disturbances that have affected the history of the land cover. Furthermore, no extensive enough dataset exists to prescribe soil carbon storages for regional modeling purposes.

There are fundamental differences between the two model methodologies. JSBACH is more truly a process based description of ecosystem functioning driven solely by the weather, whereas in CTE the vegetation phenology is adopted from NDVI observations. Even more importantly, CTE is an atmospheric inversion model, which makes use of observed CO2 concentrations and an atmospheric transport model in order to improve the forward modeled first guess estimate of biospheric CO2 sources and sinks. As a matter of fact, the CO2 balance modeled in this project can in the future be used as a first guess estimate for an inversion model such as CTE.

Regardless of the major difference in the methodologies, yearly values show certain important agreements that are worth of pointing out. First, during the seven years for which the CTE estimates are available, the timing of extremes is relatively well predicted; the year of largest sink according to JSBACH is the year of second largest sink in CTE and the year of largest source in JSBACH is the year of the smallest sink in CTE. Second, the range of variability is on the same order of magnitude, being accordin to JSBACH approximately 2/3 of the range estimated by CTE.

Table 3. Yearly land vegetation CO2 balance of Finland in 2001-2009 according to National GHG inventory of Statictics Finland (StatF), Carbon Tracker Europe (CTE) and SnowCarbo modeling framework (REMO-JABACH). The units are million tons of CO2 per year.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	Range
StatF	-23,22	-23,74	-24,16	-24,86	-28,76	-32,32	-24,12	-26,76	-36,27	13
CTE	-51.18	-115.88	-28.16	-19.04	-130.04	-99.84	-59.81			111
REMO-JSBACH	15.7	-41.6	-11.3	27.0	8.1	-37.6	17.3	30.5	-6.8	72

The comparison between SnowCarbo modeling framework and National GHG inventories (Table 3) does not show equally good resemblance among the two methods as the comparison to CTE results. The reasons for the discrepancies were listed in the description of the data in the Chapter 4.3. Most importantly, one has to bear in mind that the methodology National GHG inventory tends to underestimate year to year variations due to actual weather conditions.

Finally, the impact of climatic drivers to year to year variations in SnowCarbo CO2 balance estimates are studied. In this investigation the focus has been limited to Finnish territory and the time scale of the extracted statistics has been set to a month. The year to year variations are accounted for growing season differences (Fig. 28). The contribution of dormancy season variability to the yearly balances is marginal.

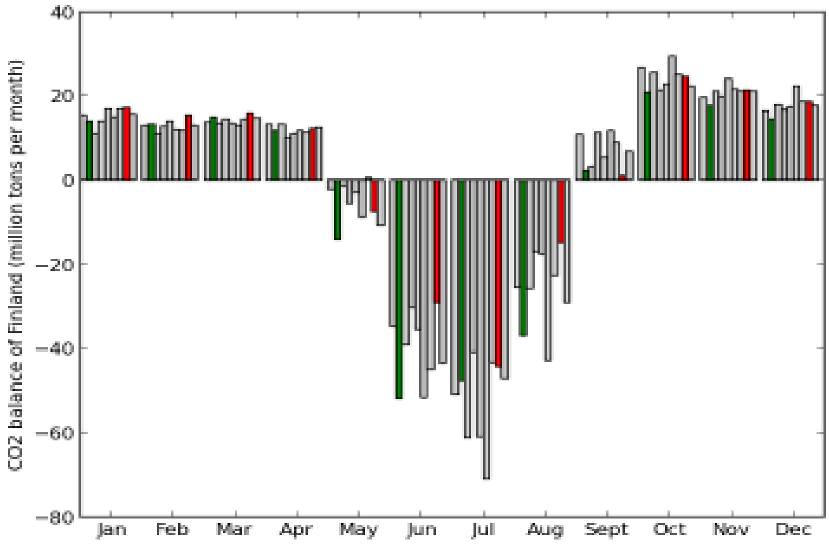


Fig. 28. Monthly CO2 balance of Finland from 2001 to 2009 (gray bars). The year of the largest sink (2002) and the largest source (2008) are indicated in green and red, respectively. The investigation of the impact of monthly climate variables on year to year variations revealed a clear control of air temperature during the growing season (Fig. 29). Neither

precipitation (Fig. 30) nor any other climatic driver showed equally strong correlation with NEE at monthly level as air temperature.

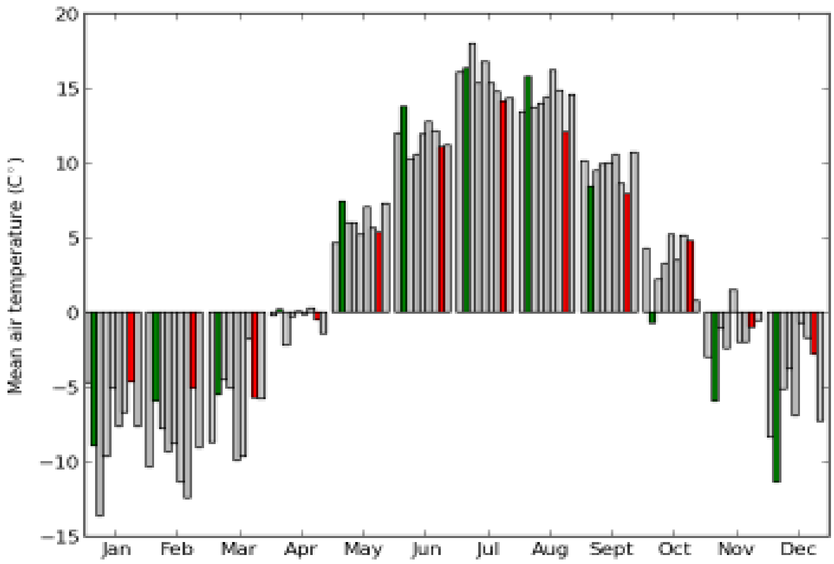


Fig. 30. Monthly mean air temperature of Finland from 2001 to 2009 (gray bars). The year of the largest CO2 sink (2002) and the largest source (2008) are indicated in green and red, respectively.

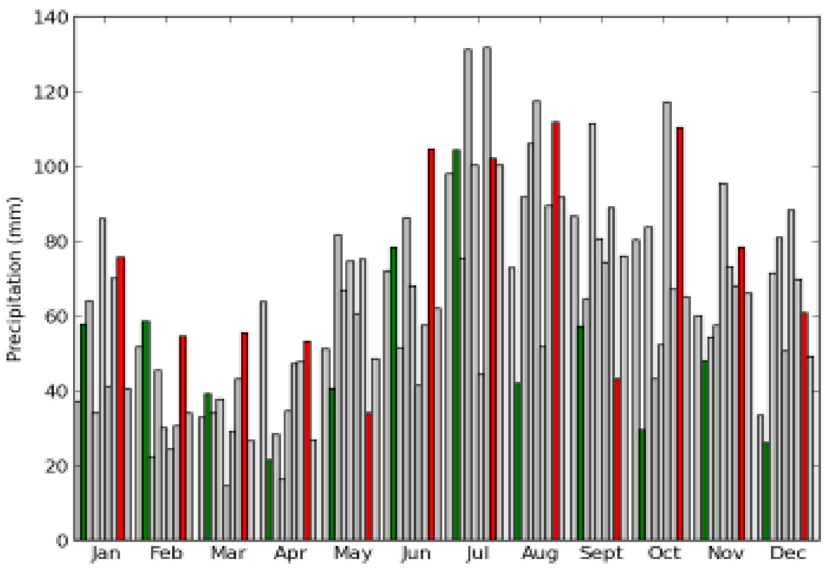


Fig. 31. Monthly mean air temperature of Finland from 2001 to 2009 (gray bars). The year of the largest CO2 sink (2002) and the largest source (2008) are indicated in green and red, respectively.

7 Concluding remarks

The evaluation of the modeling 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 predited by the modeling 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 CO2 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, that 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 modeling system. Neverthless, the levels of GPP as well as NEE are within the range predicted by other modeling systems. The main concern of Nordic countries being too often a net CO2 source, can be to some degree corrected by changing the spin-up procedure for ecosystem carbon storages so that the rise in atmospheric CO2 concentrations is better accounted for.

8 References

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