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First Progress Report

Reporting Date

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LIFE+ PROJECT NAME or Acronym

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

Project Data

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Project end date:	01/09/2017 **Extension date:** <dd/mm/yyyy >
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Action B4: Model calibration

1. Summary

JSBACH land ecosystem model, PRELES photosynthesis and evapotranspiration model and CROBAS tree growth model have been involved in model calibration. PRELES model parameters have been calibrated for 10 boreal sites. A preliminary calibration of the CROBAS model has been performed on the sample plot data. JSBACH model has been developed by adding new soil carbon, methane and water related modules and parametrisations and optimizing hydrological, evapotranspiration and photosynthesis – related parameters. Data collected by project partners has been used in this work, including evaluation and validation of the new developments. The impact of these developments will be expressed through their effect on country-level GHG balances.

2. JSBACH Model

2.1 Soil water

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

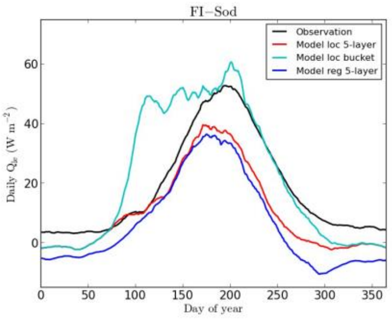


Fig. 1. Latent heat flux at Sodankylä, averaged over years 2001-2008, with the so-called bucket model and 5-layer model.

Further, regional evaporation and transpiration rates have been studied and they have been connected to CO2 uptake, enabling investigation of regional water use efficiency (WUE) values. Regulation of CO2 uptake by loss of water through stomata and available soil water and their practical implementation in models is still an open issue. The present version of the model is able to reproduce the dynamics of observed soil moisture at individual Finnish flux sites during wet and dry periods (Gao et al., 2015), such as the drought in July-August 2006, which affected forest health in southern Finland (Muukkonen et al., 2015). Also, regional WUE values show that the model is able to capture the change in WUE during drought year 2006 (Fig. 2). The calibrated model results connected to soil water status will be used when deriving climate change indicators in Action B5.

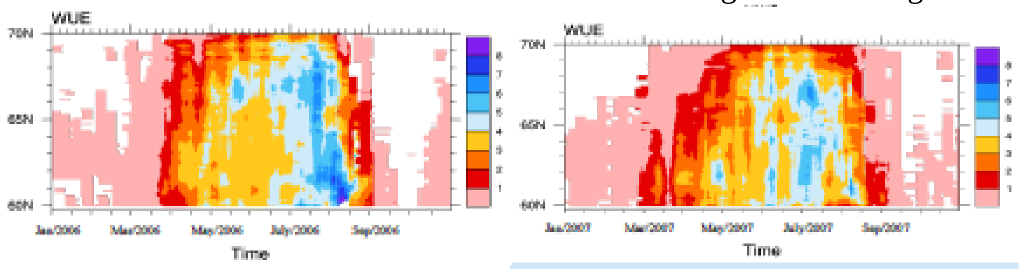


Fig. 2. Latitude-averaged 10-day running WUE for a dry year 2006 (left) and wet year 2007 (right). The latitudes shown, and longitudes included in averaging, roughly cover the area of Finland.

2.2 Soil carbon

JSBACH includes two options for soil carbon modules, new YASSO (Liski et al., 2005, Tuomi et al., 2009) with six carbon pools: four fast decomposing pools separated according to solubility of decomposing material, one pool for slowly decomposing coarse woody litter and one very slow pool for humus, and old CBALANCE with two pools for fast and slow decomposition rates. CBALANCE was used for example in previous SNOWCARBO Life+ project. New YASSO version has now been taken into use and the results have been compared to old CBALANCE module at local and regional level and against empirical evidence on soil carbon content. Also Finland-validated distribution of soil property values for peatlands and mineral soils (field capacities, porosities etc., see Törmä et al., 2015) have been implemented in the model. Regional results are shown in Fig. 3. According to earlier global scale studies, YASSO releases more carbon into atmosphere and has smaller carbon storages in soil, which globally is better in line with observations (Thum et al., 2011). Also for Finland Yasso predicts carbon storages which agree better with the nation-wide distributed soil carbon observations (LUKE/Aleksi Mäkelä, personal communication). Yasso will be adopted for the future projections of carbon balances.

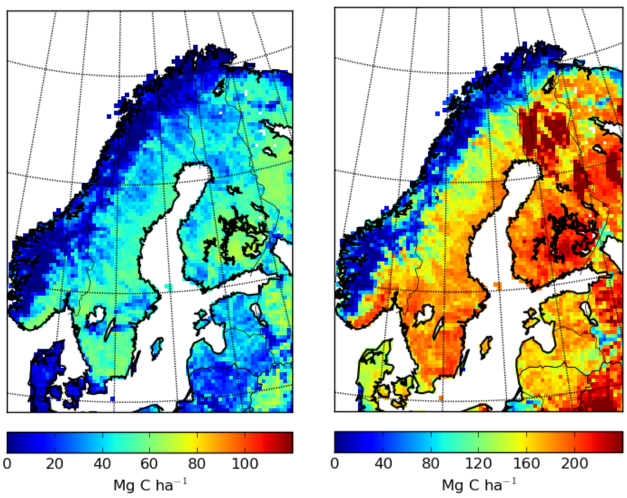


Fig. 3. Soil carbon pools for July 2011 according to YASSO model (left) and CBALANCE (right) after spin-up and 30-yr climate run ending at 2011.

2.3 Parameter optimisation

It is important to obtain information of which model parameters can be constrained by observations, what are their most probable values in local and regional scales, and which parameters are in key position regarding the carbon and water balance uncertainty estimations. We have optimized a set of JSBACH hydrological, evapotranspiration and photosynthesis parameters using statistical Monte

Carlo (MC) Metropolis algorithm. A computing scheme for MC simulation runs was implemented, and then a parameter set was optimized against Hyytiälä evapotranspiration (ET) and GPP observations using data from years 2000-2004 and validated using data from years 2005-2008. Same set of parameters was applied for Sodankylä for comparison and validation. Different levels of parameter tuning were applied, applying seasonal summary statistics, and point-wise daily and half-hourly optimisation. In fig. 4 are shown the GPP obtained using default (regional) set of parameters, initial tuning to adjust the seasonal GPP and ET sums for the site with e.g. realistic LAI, and daily and half-hourly tuning of a larger (N=15) set of parameters. Daily tuning reduces the model-data mismatch in comparison to default and initial cases, and also appears to produce better results than half-hourly tuning. The same is true for both Hyytiälä and Sodankylä, though for Sodankylä daily tuning was not performed, rather parameters were adopted from Hyytiälä. The validation period shows good agreement of the model with the data (Fig. 5); At Hyytiälä the observed depression of GPP and ET during dry summer 2006 is reproduced by the model, but drawdown is not as deep as in observations. However, the tuned parameters correspond to the 4-year optimization period where such a severe drought did not occur. Enhancing the response to drought would probably require a re-consideration of the JSBACH conductance formulations. This work will be started soon but it is uncertain whether utilizable results will be obtained during the project. The currently available new optimized parameters will be tested in a regional context and applied in future projections.

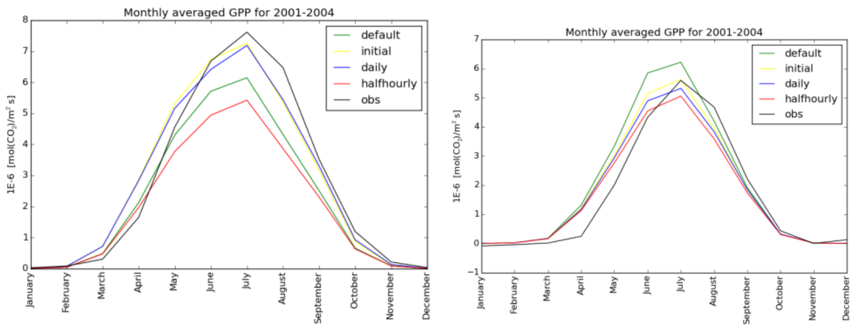
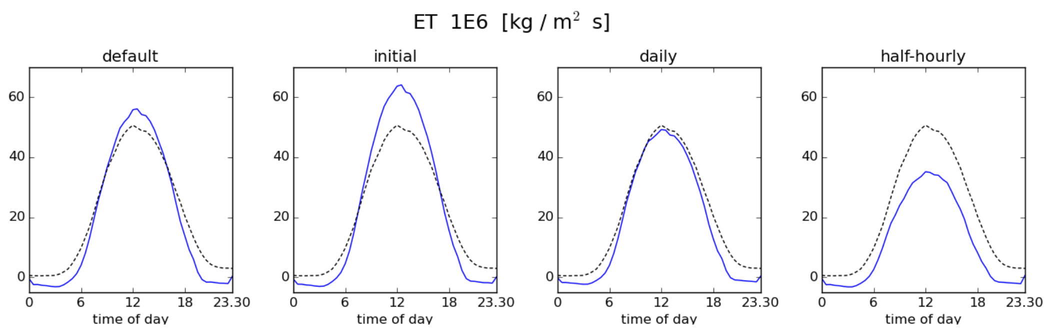


Fig. 4a. Monthly average GPP for Hyytiälä (left) and Sodankylä (right) according to JSBACH model and eddy covariance flux observations and for different levels of model parameter tuning. For Sodankylä only LAI was tuned, otherwise Hyytiälä parameters were adopted.



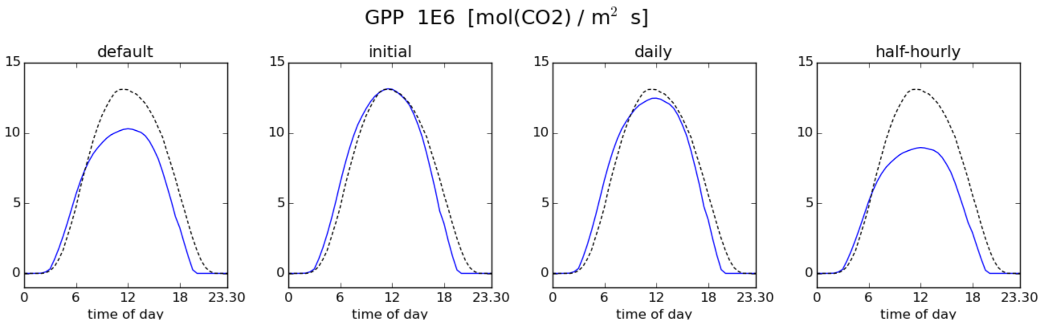


Fig. 4b. Hourly average GPP (upper) and ET (lower) for Hyytiälä according to JSBACH model and eddy covariance flux observations and for different levels of model parameter tuning. Years 2000-2008 are included in the figure.

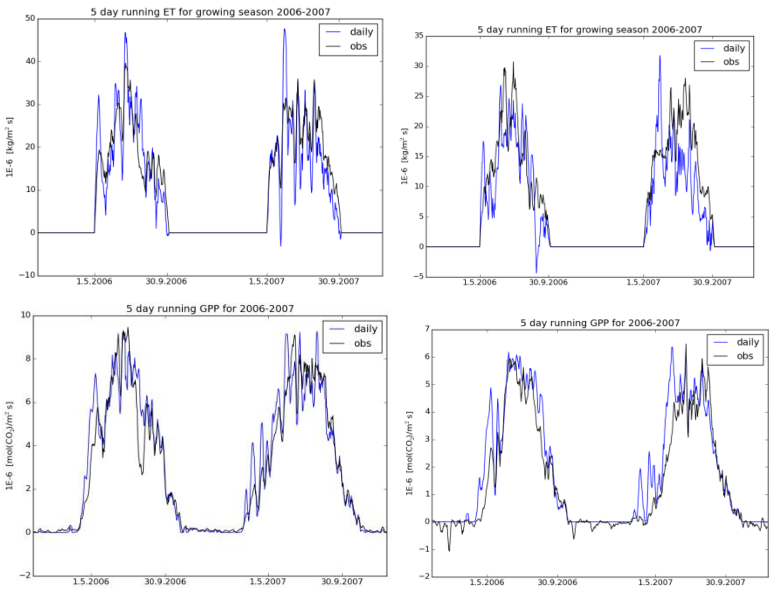


Fig. 5. Five-day running mean GPP and ET for Hyytiälä (left) and Sodankylä (right) dry (2006) and wet (2007) validation years according to eddy covariance flux observations and tuned JSBACH model. For Sodankylä only LAI was tuned, otherwise Hyytiälä parameters were adopted.

2.4 Alternative LAI distributions

Leaf Area Index (LAI) is one of the most important variables determining the level of CO2 assimilation by the forest. JSBACH can produce estimates of the annual cycle of leaf area index (LAI). Alternatively, the maximum LAI value or full LAI annual cycle can be assimilated from an independent data source. The option to assimilate remotely sensed (MODIS) LAI for model use was examined. The modelled annual maximum value of LAI at each grid cell was scaled with MODIS LAI re-produced at the same resolution and grid. This resulted in significant changes in modelled GPP distribution and level (see Table 1). These results will be used in model LAI distribution evaluation and carbon balance uncertainty estimation.

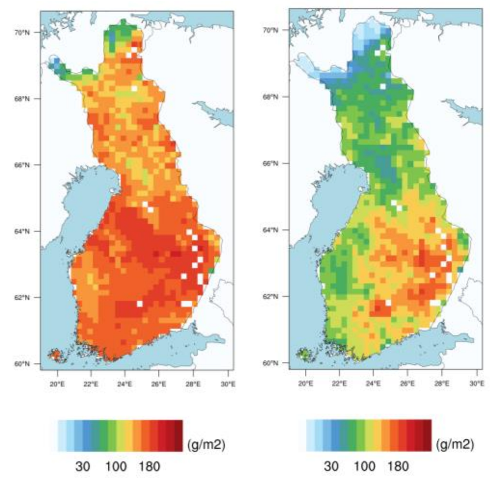


Fig. 6. July 2000 mean GPP according to JSBACH model version with standard LAI (left) and MODIS-calibrated LAI (right)

2.5 Seasonality of carbon exchange

In northern latitudes the strong seasonal climate variations determine the cycle of carbon exchange. The change from freezing winter temperatures and snow to above-zero temperatures and soil melt determines the onset of photosynthesis. The start of growing season using snow melt from MODIS observations and JSBACH model results has been studied by Böttcher et al. (manuscript), suggesting too early start of growing season by needleleaf forest according to the model. This is also indicated by the flux observations. The early start could be assessed by e.g. using chlorophyll fluorescence measurements to improve the temperature dependence of model photosynthesis parameter Vcmax during cold stress. For this, in situ fluorescence observations already exist for Sodankylä. Time series of webcam images will also be examined and their potential in calibrating the model phenology parameters will be studied. Previously, the so-called state of acclimation (S) has been used to describe the seasonal development of photosynthetic efficiency at the boreal sites (Kolari et al., 2007, Peltoniemi et al., 2015). S forms a relationship between the ambient temperature history and photosynthetic capacity thus describing the state of acclimation of the photosynthetic apparatus to changing temperatures. The use of S seem to be most advantageous in low temperatures ($S < 10$ C), where the photosynthesis response to temperature is close to linear and previous cold nights may affect plant functioning. At higher temperatures an instantaneous exponential photosynthesis response produces better correspondence with (half-hourly) flux observations. Implementation of S in JSBACH model may improve spring (and autumn) development in photosynthetic carbon uptake, but this needs to be studied further together with the webcam and fluorescence options listed above.

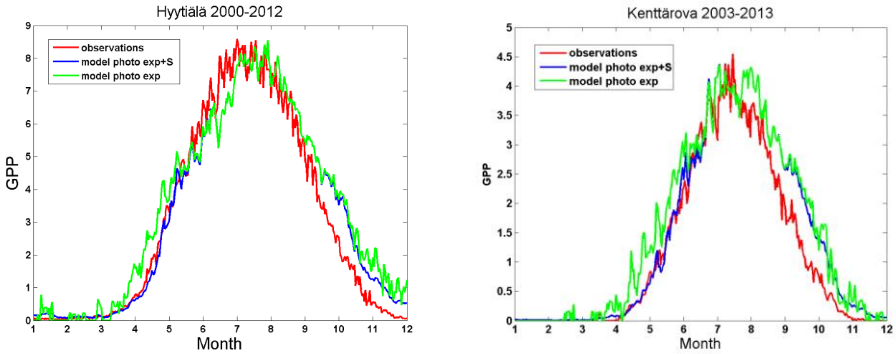


Fig. 6. Daily GPP averaged over several years at Hyytiälä and Kenttärova sites according to observations and JSBACH standard photosynthesis formulations (for one forest layer) and those modified with state of acclimation.

2.6 Implications to Finland regional carbon balance

The model modifications introduced above change the estimate of the regional annual carbon dioxide balances. They are of different magnitude but e.g. small change in average annual GPP may contain significant conceptual improvements, e.g. presentation of drought, which may in some years have long-reaching implications on the forest functioning. A preliminary estimate of the sensitivity of average annual GPP and soil carbon storages in different parts of the Finland is shown in the two tables below. More entries are to be added into these tables as more simulation results become available.

GPP (std) 2000-2006	Standard model LAI	EO LAI 2000	EO LAI 2006	1-layer-soil
North	399.4 (30.8)	179.4 (9.6)	163.7 (8.6)	410.0 (32.8)
Middle	577.6 (43.1)	353.9 (20.5)	377.3 (21.9)	580.8 (43.5)
South	750.4 (48.3)	538.8 (28.4)	535.7 (28.2)	743.9 (46.1)

Table 1. Annual average GPP sum (TgC) according to different set-ups of JSBACH model.

Soil C pools (Mg(C)/ha)	Cbalance	Yasso
North	181	33
Middle	202	44
South	199	52

Table 2. Soil pools in JSBACH model according to CBALANCE and YASSO soil module after spin-up and 30-yr climate run ending at 2011.

2.7 Methane emission module

The newly developed JSBACH methane emission module includes description of methane production, oxidation and transport processes in several soil layers with a distribution of plant roots. Transport processes include diffusion in water filled soil, air filled soil, through roots and sedges, ebullition as well as transport of oxygen for methane oxidation. The methane emission module obtains input from soil carbon module including amount of carbon substrates available for methane formation. The new JSBACH PeatBalance soil module has been implemented and used in estimating carbon accumulation in peat soil. It has carbon pools separately for acrotelm and catotelm. Litter and exudate pools have also been implemented during current year. Model simulations have been made for Siikaneva wetland (Fig. 7) nearby Hyytiälä measurement station. Methane emission model parameters are being calibrated against Siikaneva wetland eddy flux measurements. Preliminary results are shown in Fig 8, where 15 model parameters were optimized using MC methods. The most influential parameters are well constrained and the method shows promising results. The performance of the model will be evaluated in the regional context and it will be applied for future projections.

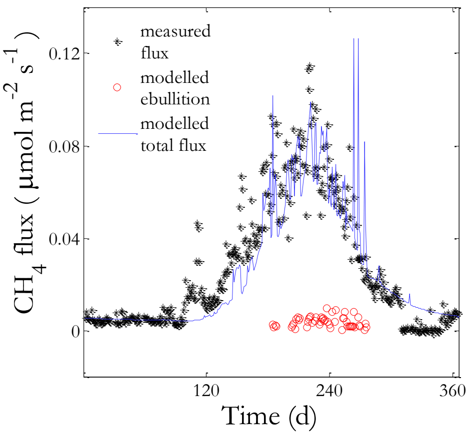


Fig. 7. Measured (black stars) and modelled (blue line) CH4 flux at Siikaneva wetland. Methane flux induced by ebullition in the water-filled peat layers is shown separately.

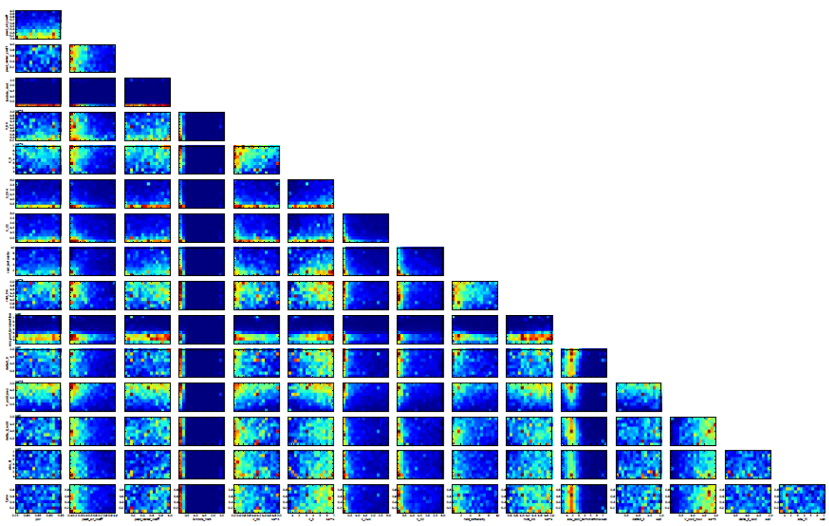


Fig. 8. Pairwise distributions of methane emission model parameters. Parameter values found in the red regions are more probable than those in the blue regions.

3. PRELES and CROBAS models

The models developed by UHEL (Fig. 9) include modules for monitoring daily GPP on the basis of weather data and minimal stand structure information (PRELES, Mäkelä et al. 2008, Peltoniemi et al. 2015a, 2015b, Minunno et al. 2015), a stand growth module based on carbon balance (CROBAS, Mäkelä 1997, Valentine and Mäkelä 2005) which helps translate the GPP into NPP and stemwood growth when combined with observations on stand structure (Härkönen et al. 2010), and a soil carbon model (Yasso, Liski et al. 2005, Tuomi et al. 2009) which, in combination with the other modules, will complete the estimation of net ecosystem exchange (NEE).

The approach is modular:
1) PRELES can be used independently to predict GPP and ET if leaf area index or fraction of absorbed photosynthetically active radiation, f_{APAR}, is known, in addition to daily weather data.
2) For the next step, NPP and current litter fall can be approximated if sufficient information on relevant stand structures is available, such as from EO data. This is done using stand structural relationships and respiration and litter fall functions included in the growth model CROBAS. Minimal structural inputs include f_{APAR} and mean stand height, but more information on e.g. stand basal area and mean diameter at breast height.
3) To estimate NEE, the soil carbon model YASSO will be used with litter inputs from CROBAS. YASSO provides litter decomposition rates using temperature and precipitation inputs, and has previously been parameterised for the boreal region. This application will not require additional EO data, but soil maps and ecosystem data will be needed for initialising the soil carbon pools.

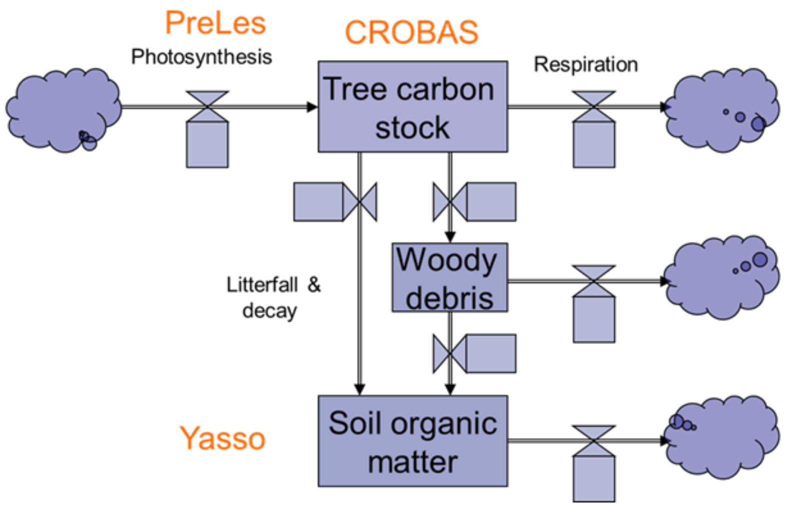


Figure 9. Carbon fluxes as descibed by the modular PREBAS approach to forest production and carbon balance.

In MONIMET we have calibrated PRELES for boreal forests in Finland (Minunno et al. 2015) and are working on the calibration of CROBAS to be applicable across Finland. Here, we report the main results of these exercises. The Yasso model has already been calibrated elsewhere.

3.1 PRELES

We have calibrated PRELES model parameters related to photosynthesis and transpiration against eddy-site flux measurements from 10 sites in Finland and Sweden (Table 3), as had already been done previously using Hyytiälä and Sodankylä GPP and evapotranspiration results. Bayesian calibration was carried out for site specific parameters (S-S) as well as for all sites combined (M-S for Multi-Site). M-S has the advantage that the data involved in the calibration cover a wider variability in terms of climate and forest structure since they come from different sites, including measurement and other errors which may or may not partially cancel out when all data are used in parameter inference. In contrast, S-S could provide good correspondence to local data, but may not be spatially generalizable, firstly because the processes may not be generic, and secondly because the risk of bias increases with less measurements.

Table 3. Sites used in calibration.

	Lat (deg)	Long (deg)	Elev (m)	Site type	Dominant species	all-sided LAI including understory (m^2m^{-2})	Age (yrs)	Annual P (mm)	Annual T (°C)	Years of flux measurements	Reference
Hyytiälä	61.51	24.17	180	haplic podzol, mean depth 0.6 m	Scots pine	7.9	40-49	709	2.9	2000 – 2010	Hari & Kulmala (2005); Kolari et al. (2009)
Sodankylä	67.22	26.38	179	haplic podzol, mean depth 1.5 m	Scots pine	3.8	50-160	527	-0.4	2001 – 2009	Thum et al. (2008)
Flakaliden	64.07	19.27	300	Sandy podzolic till	Norway spruce	9.5	43	600	2.3	1997, 1998, 2001, 2002, 2007 – 2009	Berggren et al. (2008)
Norunda	60.1	17.5	45	Sandy podzolic till	Norway spruce , Scots pine	12.7	ca. 100	527	5.5	1996 – 1999, 2003	Lundin et al. (1999); Lindroth et al. (2008)
Kalevansuo	60.39	24.22	123	Originally ombotrophic dwarf-shrub pine bog, drained in 1969. Fertilized with P and K.	Scots pine	5.7	<40	606	4.3	2004 – 2009	Pihlatie et al. (2010); Lohila et al. (2011); Ojanen et al. (2012)
Knottåsen	61	16.13	320	Sandy podzolic till	Norway spruce	7.0	39	613	3.4	2007, 2009	Berggren et al. (2008)
Alkkia	62.11	22.47	153	Former Sphagnum bog drained for agriculture in 1936-38, amended with mineral soil. Regular agricultural fertilization. Afforested in 1971 with Scots pine	Scots pine, very dense understory reflecting high nutrient content of the soil	9.0	32	681	4.1	2002 – 2004	Lohila et al. (2007)
Skyttorp	60.07	17.5	40	Sandy podzolic till	Scots pine	8.0	NA	830	7.1	2005	-
CAge 12yr	61.51	24.17	170	haplic podzol	Scots pine	7.0	12	709	2.9	2002	Kolari et al. (2004)
CAge 75yr	61.51	24.17	170	haplic podzol	Scots pine	7.9	75	709	29	2002	Kolari et al. (2004)

(Projects submitting final reports after 1 January 2014 must use this format.)

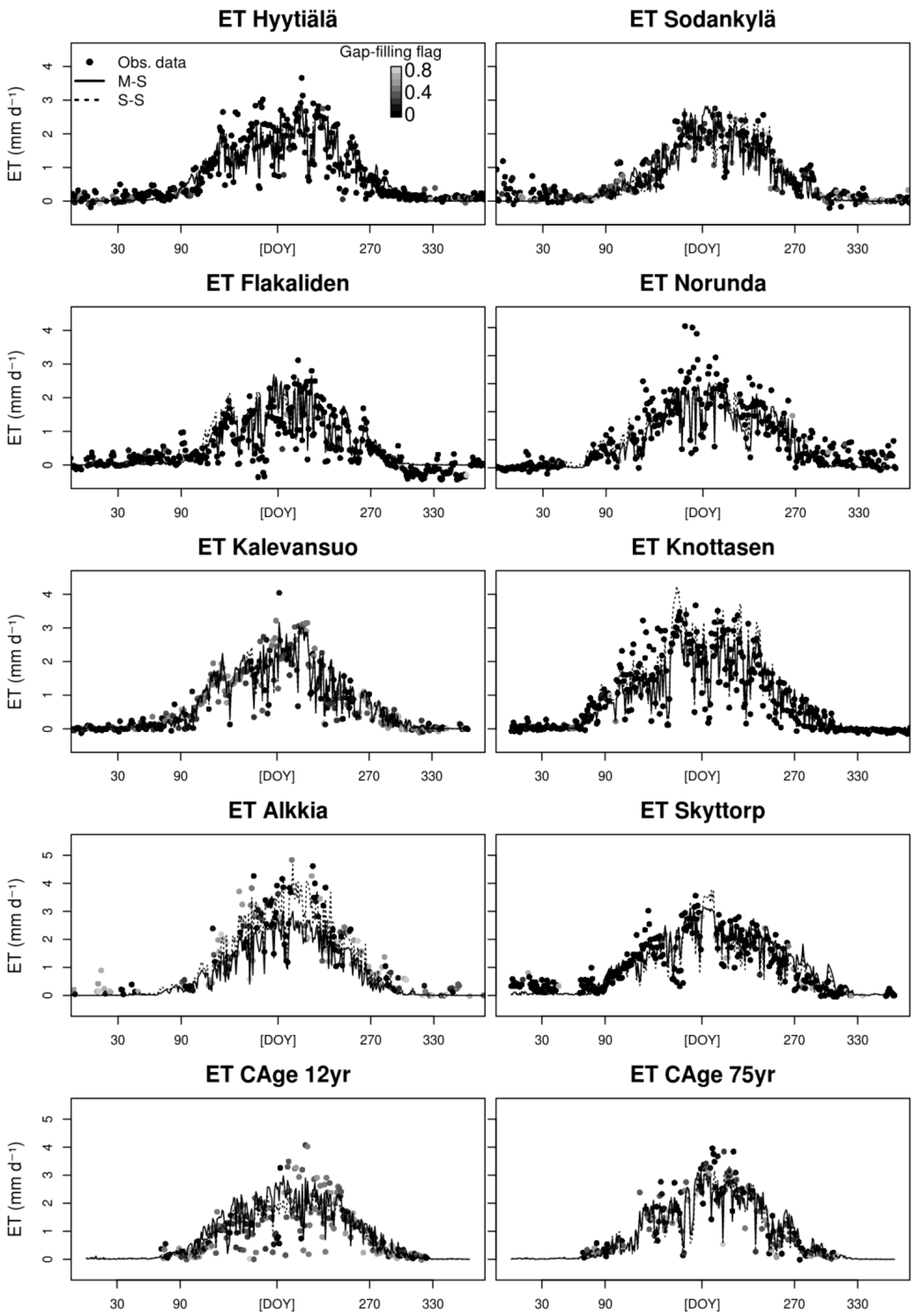


Figure 10. Daily evapotranspiration at each experimental site for a year randomly selected from the dataset. Sites are ordered according to the number of data points available for model calibration. Dots represent the observations and are coloured in grey scale according to the fraction of gap-filled data in a day (i.e., black = all data were observed, white = all data were gap-filled). The lines are PRELES predictions; the dashed line is the output from the site-specific calibrations, while the continuous lines represent the multi-site calibration

We evaluated model performances in terms of R^2 and the slopes of the simulated vs. observed data, calculated for each calibration and each model output (i.e., GPP and ET) at daily time step (Table 4, Figure 10). The predictions were generated using the maximum *a posteriori* (MAP, i.e. the modal parameter vector of the posterior distribution) parameter vectors of M-S and S-S. The variance explained by the model was higher for GPP than for ET, both being in most of the cases higher than 70% (R^2 of Table 4); however the model tended to underestimate carbon and water fluxes (slopes lower than 1) (Table 4). Model fit to the Flakaliden data was generally rather poor. Furthermore, the multi-site calibration significantly underestimated evapotranspiration at Alkkia site (slope = 0.62). In general, after BC, model outputs were characterized by low uncertainty.‘

Table 4. . R^2 and slopes calculated for the multi-site and site-specific calibration

	GPP				ET			
	multi-site		site-specific		multi-site		site-specific	
	R^2	slope	R^2	slope	R^2	slope	R^2	slope
Hyytiälä	0.96	0.98	0.96	0.98	0.89	0.90	0.89	0.92
Sodankylä	0.89	0.82	0.91	0.89	0.75	0.79	0.80	0.80
Flakaliden	0.79	1.09	0.81	0.80	0.68	0.87	0.71	0.77
Norunda	0.89	0.97	0.90	0.92	0.82	0.84	0.85	0.85
Kalevansuo	0.93	0.95	0.95	0.97	0.87	0.85	0.91	0.88
Knottåsen	0.91	0.78	0.91	0.93	0.89	0.74	0.89	0.86
Alkkia	0.89	0.80	0.89	0.88	0.83	0.62	0.84	0.89
Skyttorp	0.80	0.87	0.81	0.85	0.72	0.86	0.72	0.81
CAge 12yr	0.73	0.77	0.84	0.87	0.71	0.80	0.75	0.72
CAge 75yr	0.93	1.10	0.95	0.97	0.88	0.83	0.92	0.89

Further analysis of the results showed that parameters are largely transferable between sites. Firstly, the parameters that mattered for the output obtained values relatively independent of the estimation method and site, and secondly, the overall estimation accuracy was similar with both methods and sometimes even greater with M-S than S-S (Fig. 11).

Our data set contained a variety of boreal sites including two peatland sites (Alkkia and Kalevansuo) where water relations were expected to lead to differences in results. This was not evident in the results, however, we will next extend this analysis specifically to peatland sites, including methane flux as well, to assess the generality of the model for peatlands also.

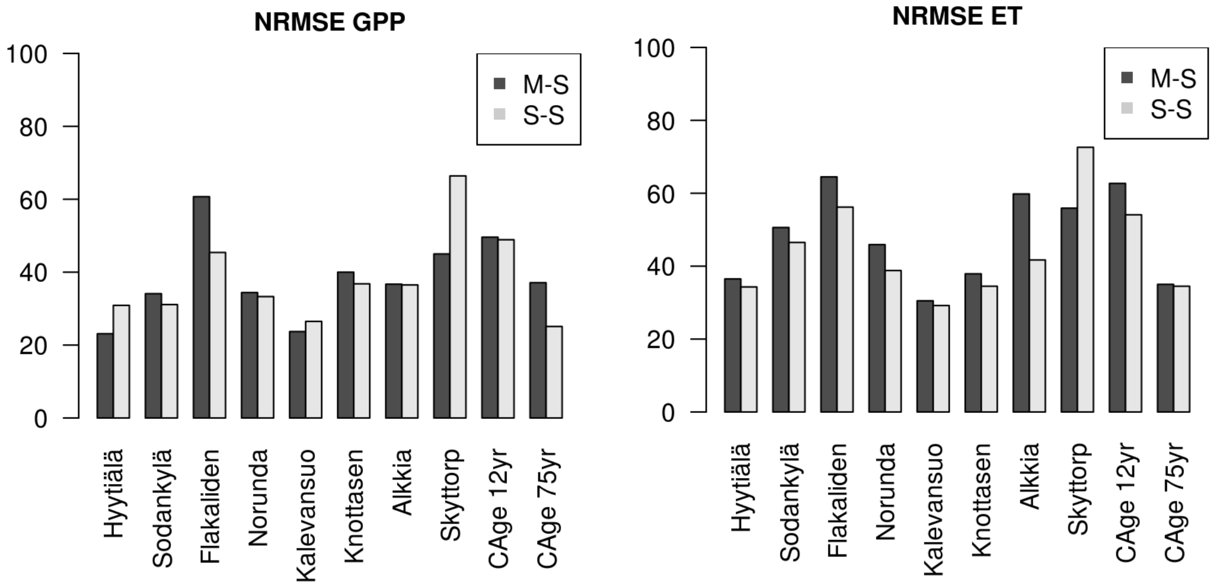


Figure 11a. Normalized root mean squared errors, for GPP. MSEs were normalized using the standard deviations of the observations. Sites are ordered from left to right according to the number of data points available for model calibration and evaluation. M-S and S-S refer to the multi-site and the site-specific calibration, respectively.

Figure 11b. Normalized root mean squared errors, for ET. MSEs were normalized using the standard deviations of the observations. Sites are ordered from left to right according to the number of data points available for model calibration and evaluation. M-S and S-S refer to the multi-site and the site-specific calibration, respectively.

3.2 CROBAS

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

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

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

Secondly, we use data from 46 Permanent Sample Plots (PSP) from Finland. The PSP dataset consists of stand variables (i.e., DBH, H, V and BA) collected at 46 sites. The data were collected along forest rotation development, covering a time interval of 50-80 years.

Thirdly, permanent plots of the National Forest Inventory (NFI) provide data on consists of H and BA measurements collected at 151 plots spread across Finland in 1995 and 2005.

We have carried out a preliminary calibration of the model on the PSP data. Model performance in this calibration is satisfactory, considering that the data set covers different site fertilities, monocultures and mixed stands over forest rotation (Figure 12). The calibration has also been tested against the intensive measurements in Hyytiälä. We are still working on improving the mortality routines and the interactions between species.

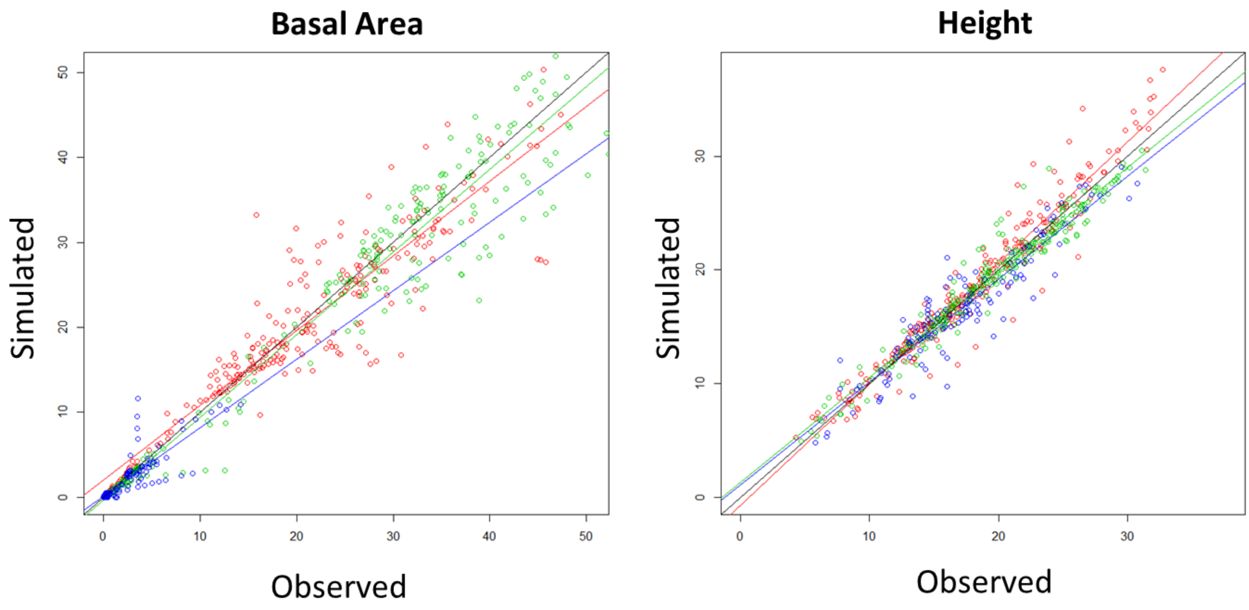


Figure 12. Selected results from CROBAS calibration. All PSP data are pooled and compared with calibrated simulations, where all sites are calibrated with the same parameter set. Red: Scots pine, green: Norway spruce, blue: silver birch.

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