LIFE Project Number

LIFE12 ENV/FIN/000409

Second progress report

Covering the project activities from 02/09/2013 to 31/03/2016

Reporting Date

31/03/2016

LIFE+ PROJECT NAME or Acronym

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

Project Data

Project location	Helsinki
Project start date:	02/09/2013
Project end date:	01/09/2017 **Extension date:** <dd/mm/yyyy >
Total Project duration (in months)	48 months (including **Extension of** <XX> **months**)
Total budget	2755288 €
Total eligible budget	2755288€
EU contribution:	1366952 €
(%) of total costs	49.61
(%) of eligible costs	49.61

Beneficiary Data

Name Beneficiary	Ilmatieteen laitos
Contact person	Tuula Aalto
Postal address	Erik Palménin aukio 1, FI-00101, Helsinki, Finland
Visit address	Erik Palménin aukio 1, 00560 Helsinki, Finland
Telephone	+358-295395406
Fax:	+358-9-323 2970
E-mail	tuula.aalto@fmi.fi

MONIMET 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. The 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 is expressed through their effect on country-level and site 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 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.

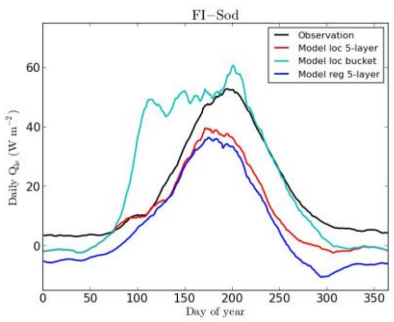


Fig. 1. Latent heat flux at Sodankylä, averaged over years 2001-2008, with the so-called bucket model and 5-layer model.

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 5-layer 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 WUE results for individual sites are generally in accordance with regional results, however the non-stomatal effects that may rarely cause distress on carbon uptake during extremely severe drought are not described in the model and are thus missed (Gao et al., 2016). The calibrated model results connected to soil water status will be used when deriving climate change indicators in Action B5.

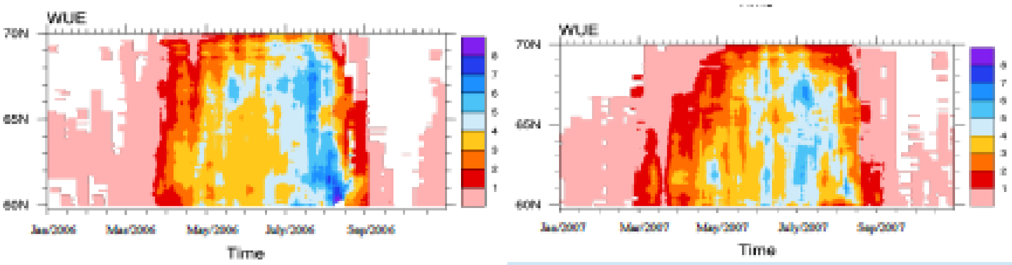


Fig. 2. Latitude-averaged 10-day running WUE for a dry year 2006 (left) and wet year 2007 (right). The latitudes shown, and longitudes included in averaging, roughly cover the area of Finland.

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 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 with ECHAM/JSBACH climate-biosphere model system, 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 JSBACH/YASSO predicts carbon storages which agree better with the nation-wide distributed soil carbon observations by LUKE (Fig. 4, Markkanen et al., in prep.). YASSO will be adopted for the future projections of carbon balances.

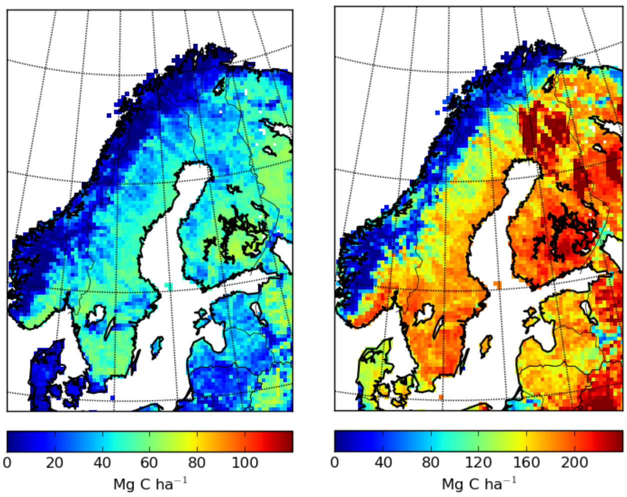


Fig. 3. Soil carbon pools for July 2011 according to JSBACH/YASSO model (left) and JSBACH/CBALANCE (right) after spin-up and 30-yr climate run ending at 2011.

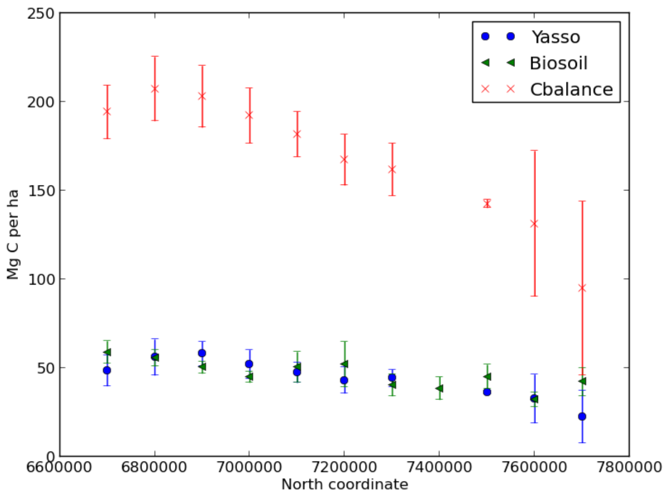


Fig. 4. South - north gradient of soil carbon pools across Finland according to YASSO, CBALANCE and LUKE soil carbon observations (Biosoil data from Aleksi Lehtonen).

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) Adaptive Metropolis algorithm (Mäkelä et al., NPGD 2016). 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. As an initial step, LAI, maximum carboxylation rate and fraction of vegetative soil were adjusted for the site. Different levels of parameter tuning were applied, applying seasonal summary statistics, and point-wise daily and half-hourly optimization. Values for 12 most influential and tuning-affected parameters are given in Table 1, as well as the mean annual GPP fluxes and their changes due to new parametrizations. Same sets of parameters were applied for Sodankylä for comparison and validation. In Fig. 5 are shown the average summertime diurnal cycles of GPP and ET obtained using default (regional) set of parameters, initial tuning to adjust the seasonal GPP and ET sums for the site with 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. 6); 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 has started, the optimization process switching ‘on the run’ between the different conductance formulations and checking which of them produces best results. Observations at boreal forest sites in Finland, Sweden, Russia and

Canada will be included in the analysis. The available new optimized parameters will be tested in a regional context and applied in future projections.

Parameter	default	seasonal	%	daily	%	half-hourly	%
α_q, Farquhar model efficiency for photon capture at 25ºC.	0.28	0.26	7	0.30	3	0.27	1
c_b, Stability parameter near neutrality.	5.0	-	-	8.8	7	5.0	0
f_{c3}, Ratio of C3-plant internal/external CO_2 concentration	0.87	0.88	8	0.72	70	0.76	68
ρ_{int}, Fraction of precipitation intercepted by the canopy.	0.25	0.27	1	0.49	4	0.27	0
W_{dr}, Critical fraction of field capacity above which fast drainage occurs for soil water content.	0.9	0.79	14	0.87	1	0.75	- 1
W_{hum}, Fraction depicting relative humidity based on soil dryness.	0.5	0.54	1	0.25	14	0.37	22
W_{pwp}, Fraction of soil moisture at permanent wilting point.	0.35	0.28	10	0.34	0	0.31	- 1
W_{skin}, Maximum water content of the skin reservoir of bare soil.	2.0E-4	3.1E-4	6	3.0E-4	0	2.2E-4	6
W_{tsp}, Fraction of soil moisture above which transpiration is not affected by soil moisture stress.	0.75	0.64	53	0.60	1	0.75	3
T_{alt}, LoGro phenology: Cutoff temperature used for calculating heatsum to determine the spring event (defined by critical heatsum)	4.0	8.1	0	6.9	1	6.9	2
S_{min}, LoGro phenology: minimum value of critical heat sum	10.0	-	-	23.0	- 0	14.7	- 0
T_{ps}, LoGro phenology: average air temperature with exponential memory loss.	10.0	-	-	21.0	- 0	12.35	- 0

GPP (gC/m2/yr)	default	seasonal	daily	half-hourly	obs
Hyytiälä 2000-2008	857	1057	1048	978	1046
Sodankylä 2000-2008	746	681	657	620	569

Table 1 a) Default and optimized parameter values (if no value is given, the parameter was not part of that tuning and the default value was used instead). The percentage next to a parameter value is the effectiveness of that parameter for that tuning. The reference values for seasonal tuning are the default values and for daily and half-hourly tunings the seasonal values. b) Annual average GPP over the study period in Hyytiälä and Sodankylä according to different parametrizations. Sodankylä was not used in parameter optimization.

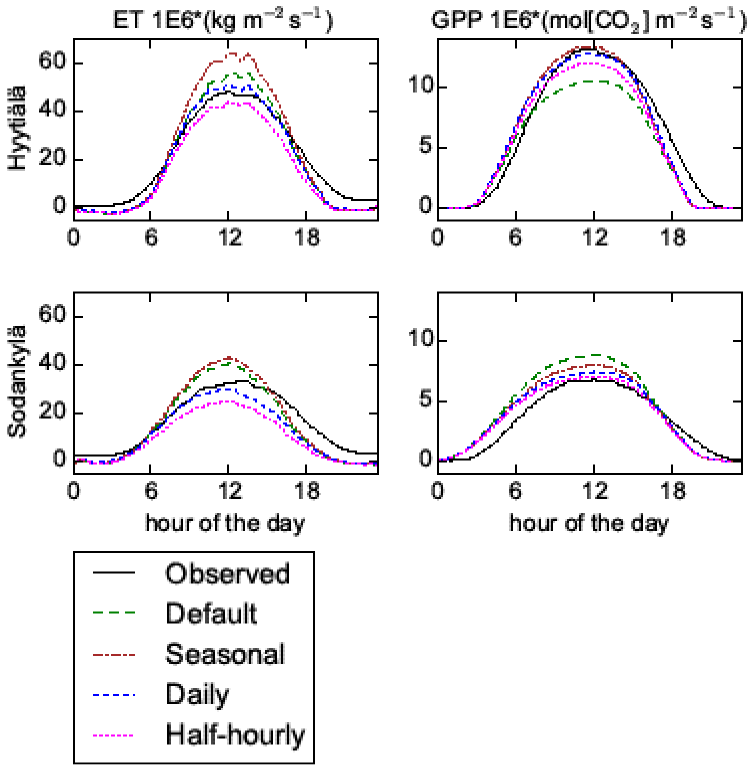


Fig. 5. Hourly average GPP and ET for Hyytiälä and Sodankylä from May to September according to JSBACH model and eddy covariance flux observations and for different levels of model parameter tuning. Years 2005-2008 are included in the figure. For Sodankylä only LAI was tuned, otherwise Hyytiälä parameters were adopted.

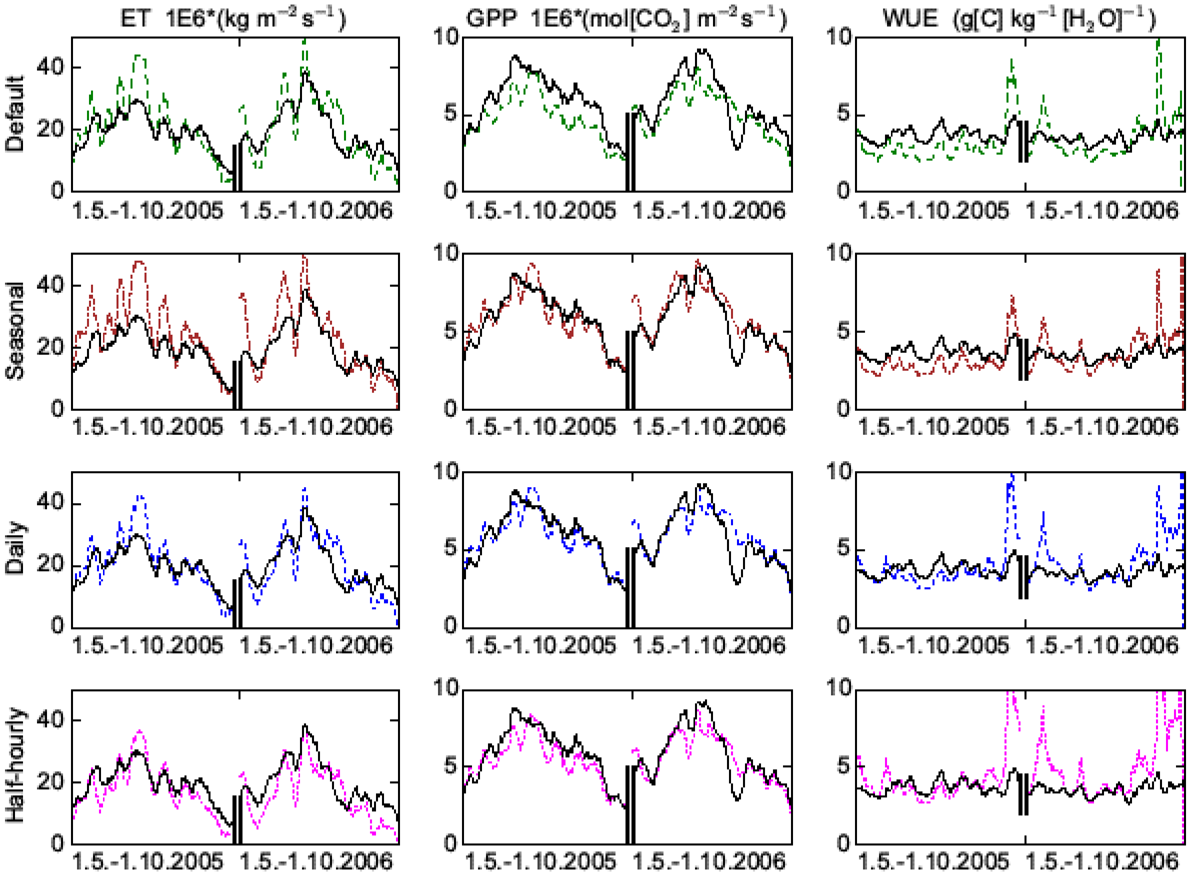


Fig. 6. Seven-day running mean GPP, ET and WUE for Hyytiälä dry (2006) and wet (2005) validation years according to eddy covariance flux observations and tuned JSBACH model.

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 (LANDSAT) LAI for model use was examined. The modelled annual maximum value of LAI at each grid cell was scaled with satellite LAI re-produced at the same resolution and grid. We applied the same scaling to all vegetation types inside the grid cell and kept the temporal development of model effective LAI in its standard form. The distribution and level of GPP in Finland (see Fig. 6 and Table 1), modelled with both standard and new LAI maps, was similar showing high values in southern Finland, and decrease towards north. New LAI map resulted in somewhat steeper gradient of GPP towards north. The steeper LAI gradient is not straightforward to apply for model use without better information in species level combined with land use heterogeneity which weakens the individual grid cell-to-cell correlations when going to high resolution. However, these results will be used in model carbon balance uncertainty estimation in country level.

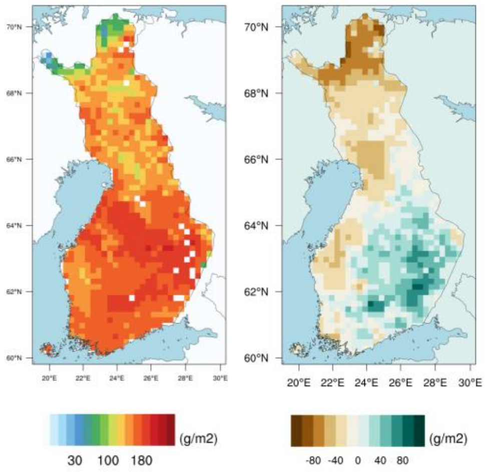


Fig. 6. July 2000 mean GPP according to JSBACH model version with standard LAI (left) and difference to satellite-calibrated LAI (right)

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 and initiation leaf development. The start of growing season using snow melt and the Normalized Difference Water Index from MODIS observations and JSBACH model results has been studied by Böttcher et al. (2016), suggesting too late start of growing season by broadleaved forest and too early start of growing season by needleleaf forest according to the model. This is also indicated by the flux observations. The bias for broadleaved trees can be assessed via the model phenology description, improving the parameters regulating leaf development. Two phenology parameters, alternating temperature and characteristic time for temperature-related memory loss were adjusted in order to reduce the Finland mean bias. However, in order to obtain a better latitudinal gradient for the start of the growing season, a full optimization of the phenology model against the satellite observations is needed.

In coniferous forest the needles are present throughout the year, and photosynthesis starts in spring already before the development of new needles. After the start of vegetation active period, occasional night frosts may induce cold stress on plants. The cold stress effect on plant carbon uptake could be assessed by using e.g. chlorophyll fluorescence measurements, but it is yet unclear through which mechanism (photosynthesis parameters, stomatal conductance) this effect should be mediated. Instead, a simple semi-empirical method has been proposed which takes the cold stress into account and does not require detailed revision of the process descriptions. Previously, the so-called state of acclimation (S) has been used to describe the seasonal development of photosynthetic efficiency at the boreal coniferous 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. S was implemented in JSBACH model, delaying the spring development in photosynthetic carbon uptake (Fig 6). Ecosystem flux measurements at Hyytiälä and Kenttärova also show that the early bias in GPP is reduced (Fig. 7). The difference in the country-level growing season start day between the standard model version and S version is on average less than 10 days during spring (Fig. 6). This corresponds to the Finland mean bias in growing season start day (about 3 days) between model and observations as presented by Böttcher et al. (2016). Using S would thus be appropriate in country level. It will be adopted in future predictions.

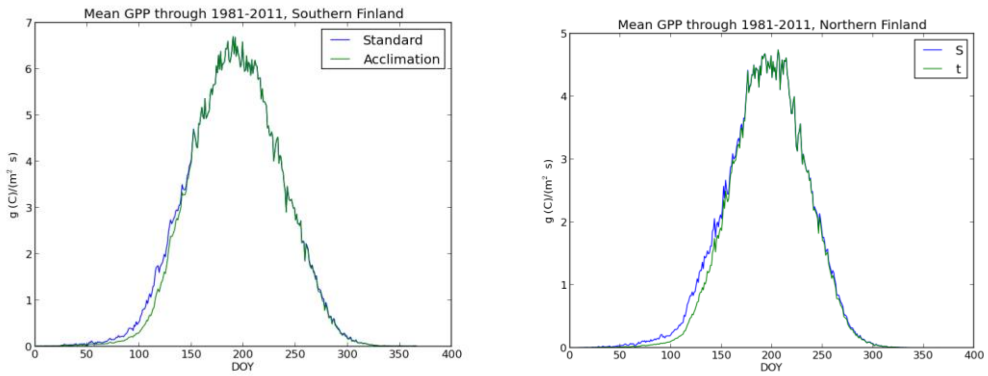


Fig. 6. Daily GPP averaged over 1981 - 2011 at Southern and Northern Finland according to JSBACH standard photosynthesis formulations and those modified with state of acclimation.

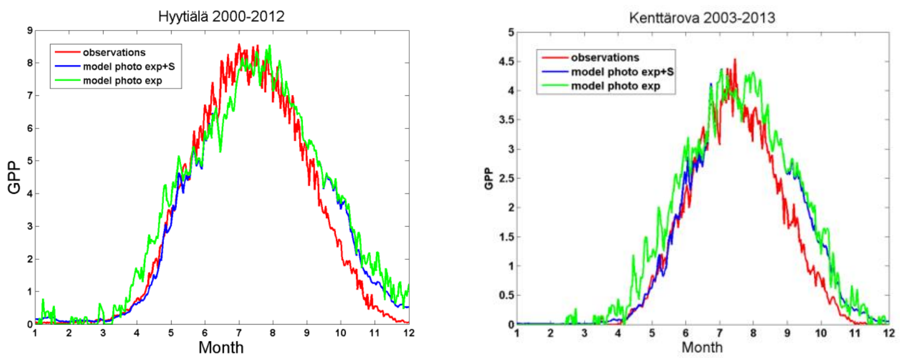
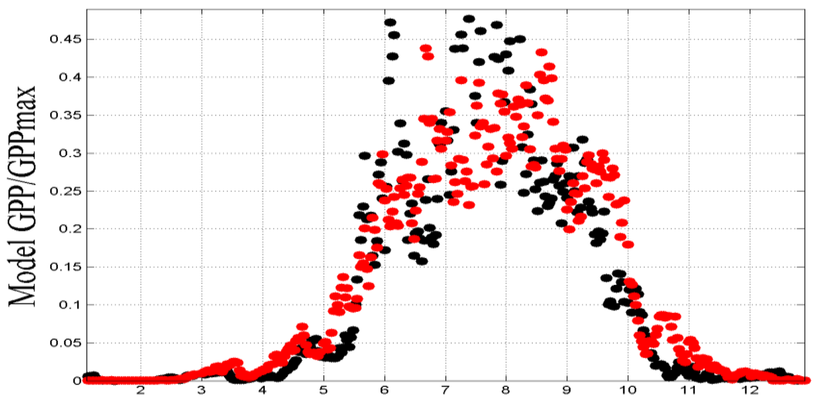


Fig. 7. Daily GPP averaged over several years at Hyytiälä and Kenttärova sites according to observations and JSBACH standard photosynthesis formulations (big-leaf-approach, i.e. describing forest as one layer) and those modified with state of acclimation.

Time series of webcam images show potential in calibrating the JSBACH model phenology. The model version modified with state of acclimation shows similar time development than webcam time series in Sodankylä (Linkosalmi et al., 2016), with e.g. faster decrease of plant activity in autumn 2014 than in 2015. There is also a low plant activity period in June 2014 both in webcam and model results. In model this is most probably due to a cold spell reducing GPP, but the drivers behind the webcam results are probably more complex and remain to be explained. The model phenology parameter calibration remains to be done in the future, when there are enough webcam observation years available.



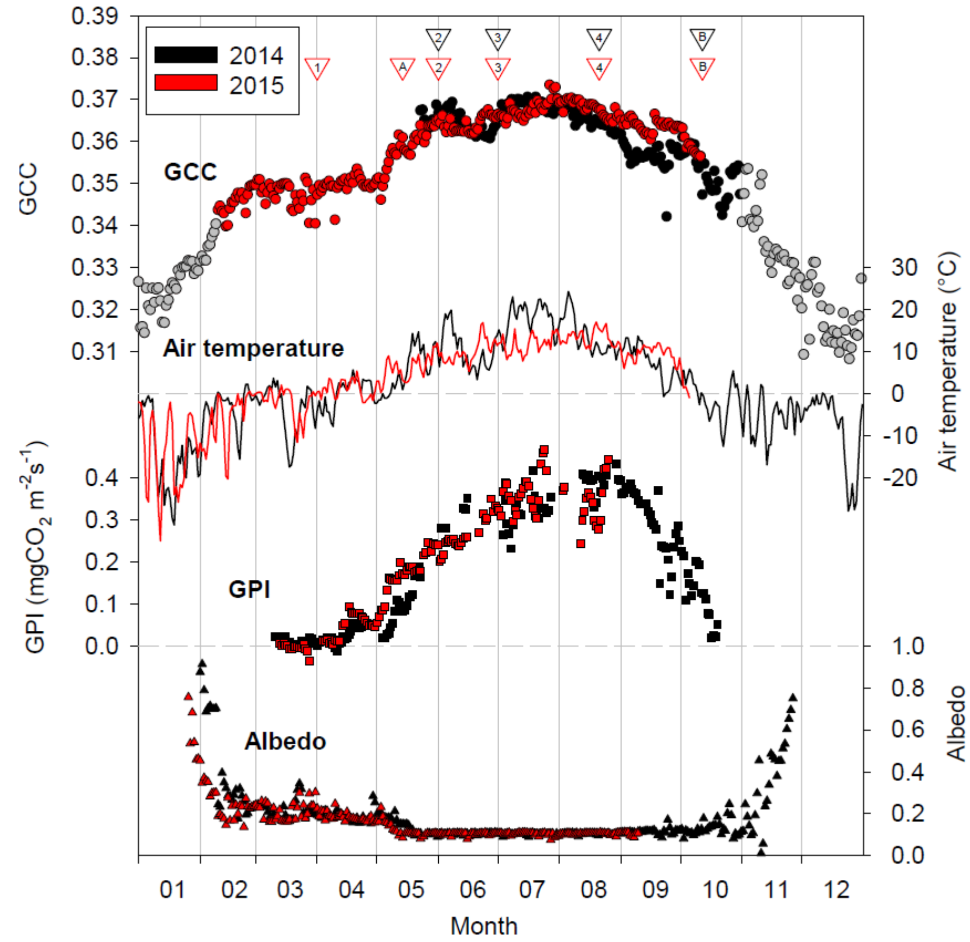


Figure 8a: JSBACH model results, 8b: Adopted from Linkosalmi et al, 2016 (their fig. 11). Mean daytime (11.00–15.00) GCC (crown camera) together with the daily mean air temperature 5 (at 18m), gross photosynthesis index (GPI) and albedo in 2014-2015 at the forest site. The triangles indicate the start dates of visually observed phenological phases (1 = Bud burst, 2 = Bud growth, 3 = Shoot growth, 4 = Old needle browning) and snow status (A = Snow melt, B = Snow appearance). The grey circles indicate the wintertime data that are influenced by an insufficient light level.

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	EO LAI	S acclimation	1-layer-soil
North	399.4 (30.8)	267.3 (14.3)	388.1 (31.2)	410.0 (32.8)
Middle	577.6 (43.1)	527.3 (30.5)	560.0 (44.8)	580.8 (43.5)
South	750.4 (48.3)	802.8 (42.3)	727.6 (49.8)	743.9 (46.1)

Table 1. Annual average GPP sum (TgC) according to different set-ups of JSBACH model. EO LAI refers to scaling with map of maximum LAI for year 2000.

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 describes 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 climate and soil carbon models, or site observations and empirical formulations, including amount of carbon substrates available for methane formation. As a first step, model simulations have been made for Siikaneva wetland nearby Hyytiälä measurement station using site observations as input data (Raivonen et al., in prep.). Methane emission model parameters have been calibrated against

Siikaneva wetland eddy flux measurements, extending over seven years (Susiluoto et al., in prep.). The results are shown in Table 2, where 19 model parameters were optimized using MC methods. The most influential parameters are well constrained and the method shows promising results (Fig. 7). The modelled fluxes are able to reproduce the seasonal cycles and year-to-year variation. The deviation between modelled and observed fluxes is less than 5% on the average, but according to the ensemble of posterior fluxes the flux uncertainty is more than 10%. Annual methane emission estimates are improved, both for Siikaneva where the optimization was made, and for Lompolojänkkä, a wetland flux site in northern Finland. We will include more boreal wetland sites in the parameter optimization to explore the site-to-site variability for regional applications. The JSBACH PeatBalance soil module has also been implemented and used in estimating carbon accumulation in peat soil. It has carbon pools for acrotelm and catotelm, as well as for litter and exudates, which are used in methane production. It has been tested for Siikaneva wetland, and is showing realistic results. If feasible, the PeatBalance module will be used together with the methane emission module in regional simulations. In addition, the regional distribution of wetland water table depths is needed. These can be estimated e.g. with TOPMODEL rainfall-runoff model together with realistic sub-grid topographical information. TOPMODEL is part of JSBACH model system. The set-up of the system for the Finland domain is underway. Depending on the applicability of the results, either a full JSBACH wetland model system or part of it supported by experimental data and regressions will be used for methane emission calculations in the regional context.

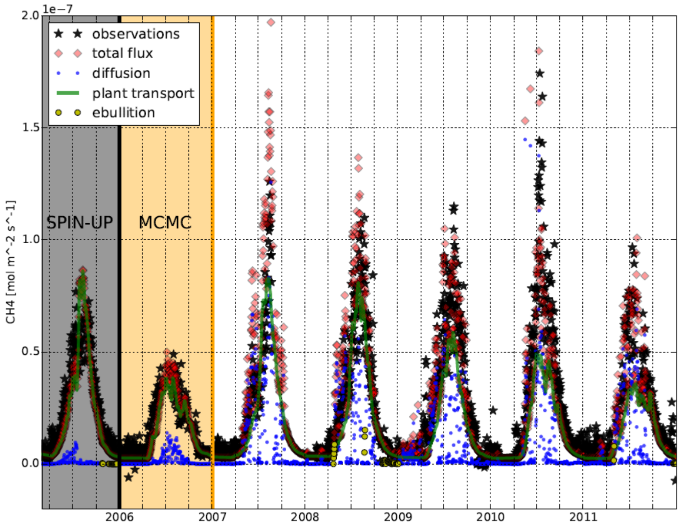


Fig. 7. Measured and modelled methane fluxes at Siikaneva wetland. Grey-shaded period is used for model spin-up and yellow for parameter optimization. The rest of the years are used for evaluation. Methane flux induced by ebullition, plant transport and diffusion are shown separately.

parameter	default	optimised
p, peat porosity	0.8	0.8
$f_{D,a}$, factor for reducing air diffusivity for air-filled peat	0.1	0.902
$f_{D,w}$, factor for reducing water diffusivity for water-filled peat	0.1	0.389
λ_{root}, shape parameter for root distribution in peat layers	0.2517	0.386

τ_{root}, root tortuosity	1.5	1.06
a_{root}, scaling parameter for root ending area	0.085	0.398
τ_{exu}, turnover time for exudate pool	1.2096e+06	5.447e+05
V_{R0}, potential aerobic respiration rate	4.0e-05	3.205e-05
ΔE_R, activation energy for respiration	50000	50000
K_R, Michaelis-Menten constant for respiration	0.22	0.22
V_{O0}, potential oxidation rate	6.0e-04	2.804e-04
ΔE_O, activation energy for oxidation	100000	50000
K_{O2}, Michaelis-Menten constant for O2 in oxidation reaction	0.33	0.33
K_R, Michaelis-Menten constant for CH4 in oxidation reaction	0.44	0.44
f_{exu}, fraction of NPP converted to root exudates	0.5	0.356
f_{exu}, fraction of root exudates converted to methane	0.5	0.25
e_{hl}, ebullition parameter	1800	1800
Q10, temperature coefficient for anaerobic peat decomposition into methane.	6.5	6.334
τ_{cato}, scaling factor for anaerobic peat decomposition into methane	27778	28237

CH4 emission (gCH4/m2/yr)	default	optimised	obs
Siikaneva 2005-2011	11.9	12.6	12.4
Lompolojänkkä 2006-2010	44.0	34.8	27.3

Table 1a). Prior and posterior optimized parameter values for methane emission model applied for Siikaneva wetland. b) Annual average methane emissions over the study period in Siikaneva and Lompolojänkkä according to the new methane emission module with different parametrizations. Lompolojänkkä was not used in optimization.

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.

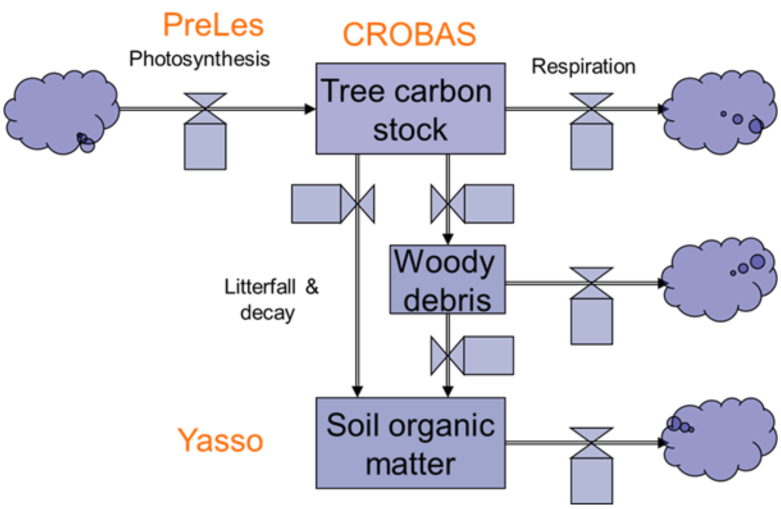


Figure 9. Carbon fluxes as descibed by the modular PREBAS approach to forest production and carbon balance.

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)

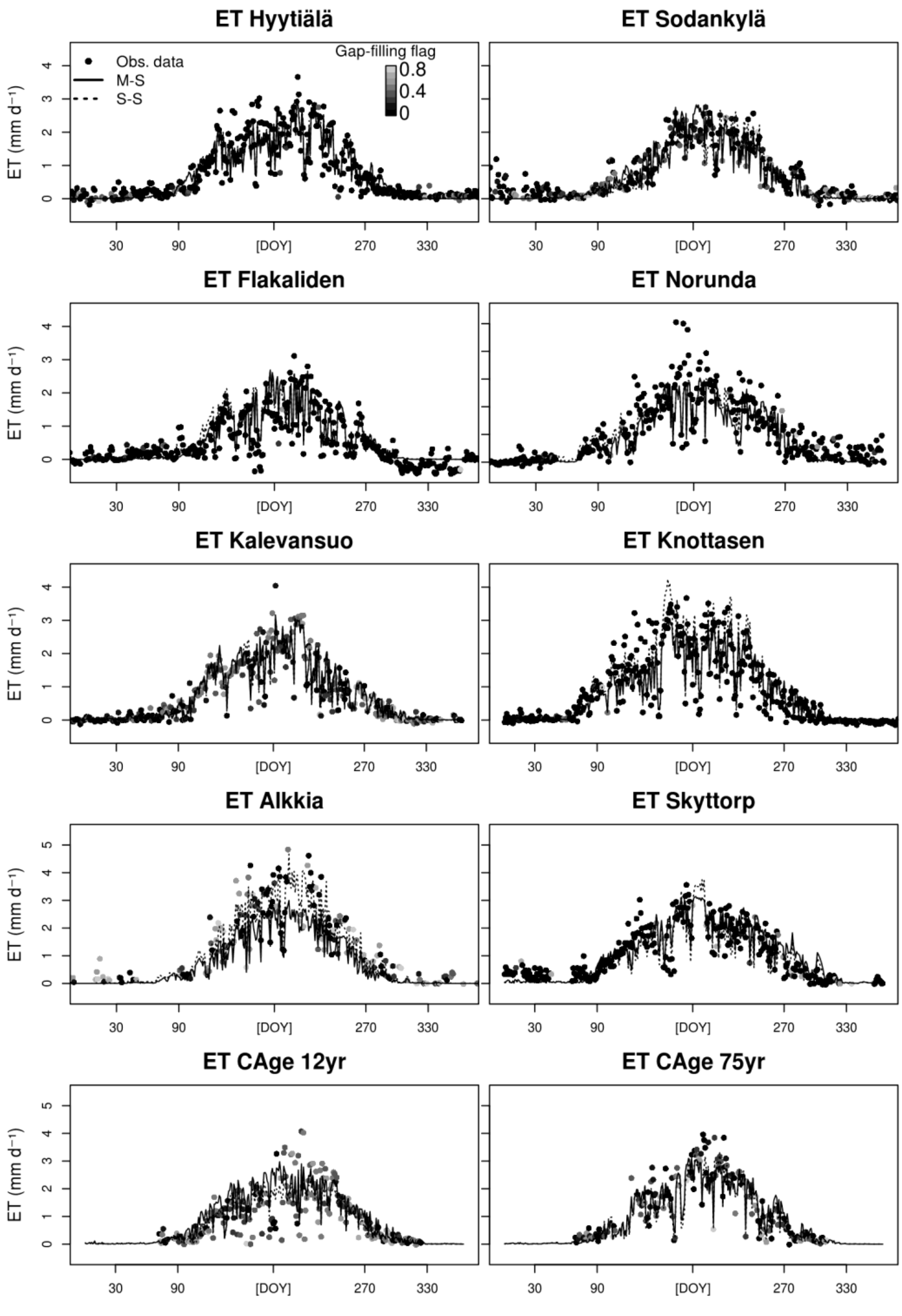


Figure 10. Daily evapotranspiration at each experimental site for a year randomly selected from the dataset. Sites are ordered according to the number of data points available for model calibration. Dots represent the observations and are coloured in grey scale according to the fraction of gap-filled 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.

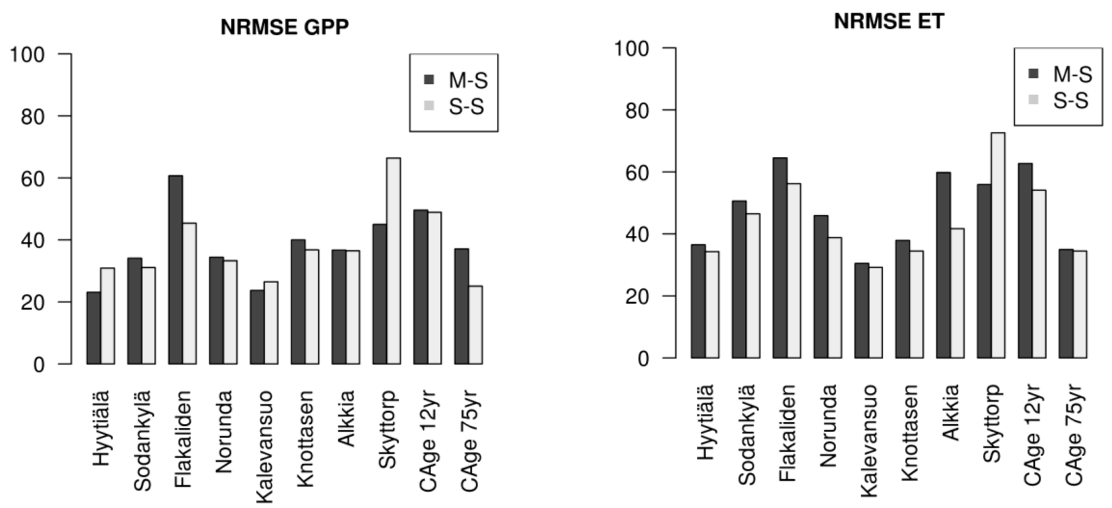


Figure 11a. Normalized root mean squared errors, for GPP. MSEs were normalized using the standard deviations of the observations. Sites are ordered from left to right according to the number of data points available for model calibration and evaluation. M-S and S-S refer to the multi-site and the site-specific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

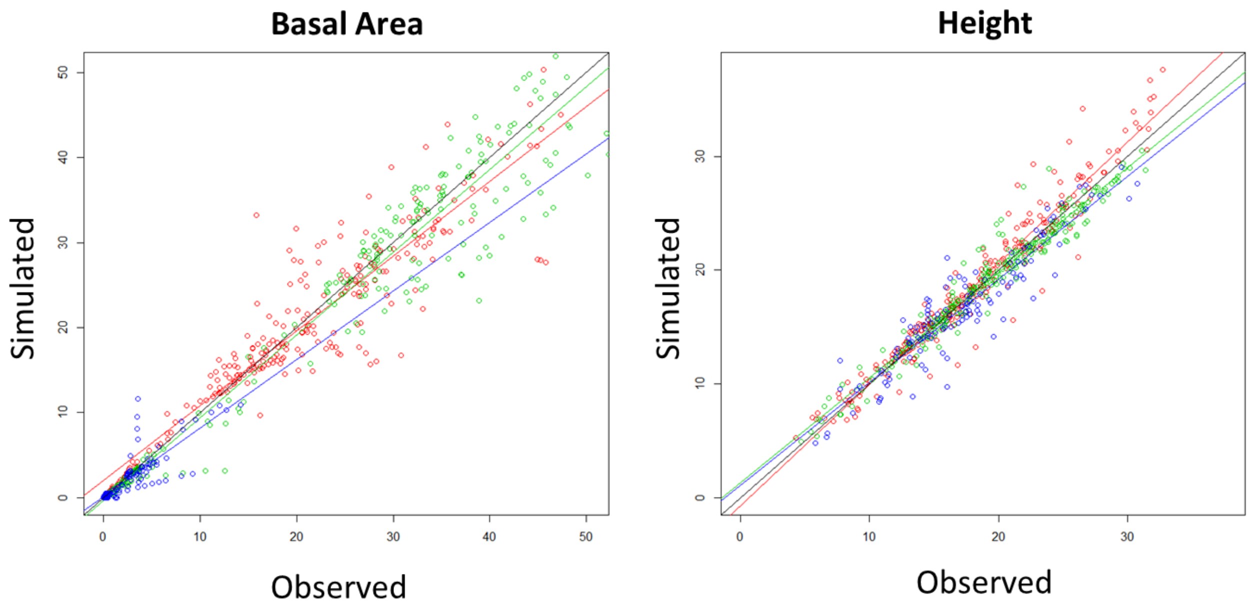


Figure 12. Selected results from CROBAS calibration. All PSP data are pooled and compared with calibrated simulations, where all sites are calibrated with the same parameter set. Red: Scots pine, green: Norway spruce, blue: silver birch.

References

Böttcher, K.; Markkanen, T.; Thum, T.; Aalto, T.; Aurela, M.; Reick, C.H.; Kolari, P.; Arslan, A.N.; Pulliainen, J. Evaluating Biosphere Model Estimates of the Start of the Vegetation Active Season in Boreal Forests by Satellite Observations. *Remote Sens.* **2016**, *8*, 580

Gao Y., Markkanen T., Thum T., Aurela M., Lohila A., Mammarella I., Hagemann S., Aalto T. Assessing various drought indicators in representing drought in boreal forests in Finland. Hydrol. Earth Syst. Sci. 20, 175–191, 2016.

Y. Gao, T. Markkanen, M. Aurela, I. Mammarella, T. Thum, A. Tsuruta, H. Yang, and T. Aalto. Response of water use efficiency to summer drought in boreal Scots pine forests in Finland. Biogeosciences Discuss., doi:10.5194/bg-2016-198, 2016

Hari, P., Kulmala, M., 2005. Station for measuring ecosystem-atmosphere relations. Boreal Env. Res 10, 315–322.

Kolari P., Pumpanen J., Rannik Ü., Ilvesniemi H., Hari P. & Berninger F. 2004. Carbon balance of different aged Scots pine forests in southern Finland. Global Change Biol. 10: 1106–1119.

Kolari P., Lappalainen H.K., Hänninen H. & Hari P. 2007. Relationship between temperature and the seasonal course of photosynthesis in Scots pine at northern timberline and in southern boreal zone. Tellus 59B: 542–552.

Kolari, P., Kulmala, L., Pumpanen, J., Launiainen, S., Ilvesniemi, H., Hari, P., Nikinmaa, E., 2009. CO2 exchange and component CO2 fluxes of a boreal Scots pine forest. Boreal Environ. Res. 14, 761–783.

M. Linkosalmi, M. Aurela, J.-P. Tuovinen, M. Peltoniemi, C. M. Tanis, A. N. Arslan, P. Kolari, T. Aalto, J. Rainne, and T. Laurila. Digital photography for assessing vegetation phenology in two contrasting northern ecosystems. Geosci. Instrum. Method. Data Syst. (in print), 2016. Discussion paper: doi:10.5194/gi-2015-34

Liski, J., Palosuo, T., Peltoniemi, M., Sievänen, R., 2005. Carbon and decomposition model Yasso for forest soils. Ecol. Modell. 189, 168–182.

Lohila, A, Minkkinen, K., Aurela, M., Tuovinen, J-P., Penttilä, T., and Laurila, T. 2011. Greenhouse gas flux measurements in a forestry-drained peatland indicate a large carbon sink. Biogeosciences 8: 3203–3218. http://dx.doi.org/ 10.5194/bg-8-3203-2011

Lundin, L.-C., Halldin, S., Lindroth, A., Cienciala, E., Grelle, A., Hjelm, P., Kellner, E., Lundberg, A., Mölder, M., Morén, A.-S., others, 1999. Continuous long-term measurements of soil-plant-atmosphere variables at a forest site. Agric. For. Meteorol. 98, 53–73.

Mäkelä, A. 1997. A carbon balance model of growth and self-pruning in trees based on structural relationships. *Forest Science* 43(1):7-24

Mäkelä, A., Pulkkinen, M., Kolari, P., Lagergren, F., Berbigier, P., Lindroth, A., Loustau, D., Nikinmaa, E., Vesala, T., Hari, P., 2008. Developing an empirical model of stand GPP with the LUE approach: analysis of eddy covariance data at five contrasting conifer sites in Europe. Glob. Change Biol. 14, 92–108. doi:10.1111/j.1365-2486.2007.01463.x

Mäkelä J., Susiluoto J., Markkanen T., Aurela M., Mammarella I., Hagemann S., Aalto T. Constraining ecosystem model with Adaptive Metropolis algorithm using boreal forest site eddy covariance measurements. Nonlin. Processes Geophys. Discuss., doi:10.5194/npg-2016-21, 2016

Muukkonen P., Nevalainen S., Lindgren M. & Peltoniemi M. 2015: Spatial occurrence of drought-associated damages in Finnish boreal forests: results from forest condition monitoring and GIS analysis. *Boreal Env. Res.* 20: 172–180.

Peltoniemi M., Pulkkinen M., Aurela M., Pumpanen J., Kolari P. & Mäkelä A. 2015: A semi-empirical model of boreal-forest gross primary production, evapotranspiration, and soil water — calibration and sensitivity analysis. Boreal Env. Res. 20: 151–171.

Pihlatie, M.K., Kiese, R., Brüggemann, N., Butterbach-Bahl, K., Kieloaho, A.-J., Laurila, T., Lohila, A., Mammarella, I., Minkkinen, K., Penttilä, T., others, 2010. Greenhouse gas fluxes in a drained peatland forest during spring frost-thaw event. Biogeosciences 7, 1715–1727.

Thum, T., Aalto, T., Laurila, T., Aurela, M., Lindroth, A., Vesala, T., 2008. Assessing seasonality of biochemical CO 2 exchange model parameters from micrometeorological flux observations at boreal coniferous forest. Biogeosciences 5, 1625–1639. et al., 2008)

Thum, T., Räisänen, P., Sevanto, S., Tuomi, M., Reick, C., Vesala, T., Raddatz, T., Aalto, T., Järvinen, H., Altimir, N., Pilegaard, K., Zoltan, N., Rambal, S. and Liski, J. Soil carbon model alternatives for ECHAM5/JSBACH climate model: evaluation and impacts on global carbon cycle estimates. Journal of Geophysical Research, 116, G02028, doi:10.1029/2010JG001612, 2011

Tuomi, M., Thum, T., Järvinen, H., Fronzek, S., Berg, B., Harmon, M., Trofymow, J.A., Sevanto, S., Liski, J., 2009. Leaf litter decomposition – Estimates of global variability based on Yasso07 model. Ecol. Modell. 220, 3362–3371

Törmä M., Markkanen T., Hatunen S., Härmä P., Mattila O.-P. & Arslan A.N. 2015: Assessment of land-cover data for land-surface modelling in regional climate studies. Boreal Env. Res. 20: 243–260.

Valentine H.T. and Mäkelä A 2005. Bridging process-based and empirical approaches to modeling tree growth. *Tree Physiology* 25:769–779