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User guide for PRELES, a simple model for the assessment of gross primary production and water balance of forests

Mikko Peltoniemi, Tuomo Kalliokoski, Antti-Jussi Lindroos, Egbert Beuker, Annikki Mäkelä

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Abstract
Simple models of ecosystem processes are useful tools for various kind of ecosystem impact studies. We built a simple model of ecosystem gross primary production, evapotranspiration and soil water content, which requires minimal input data, and which is efficient to run. In this report, we briefly describe the model equations, document the model program and provide user guide for the current version of the model. We also use the model to run a few example simulations that describe how the model responds to the environment, and test the model predictions of soil water in reference conditions with ICP level II data on soil water. The model is intended to be used in large scale prediction of GPP, ET, and drought in the Climforisk EU Life+ project.

Keywords
carbon, climate change, drought, ecosystem model, photosynthesis, water balance

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1 Introduction

Estimates of ecosystem carbon sinks and water balances are a starting base for many ecosystem impact studies. These two primary variables are influenced by the prevailing weather and as such, they are vulnerable to changes in climate. Increasing temperature and CO2 of air means higher gross primary production (GPP), but increasing summer temperatures will also increase the evaporative demand. Increasing evaporation may not be fully compensated by increasing summer precipitation, partially because variability of summer rains is expected to increase (IPCC 2007, Fischlin ym. 2009, Jylhä ym. 2009). This means that water cannot be neglected from impact assessments as has been frequently assumed (e.g. Bergh ym. 2003). Water effects on GPP may turn out to be important for any prognosis of future forests. A natural framework for this is linking GPP to transpiration, as the carbon and water fluxes are inherently bound to each other due to stomata of leaves.

For purposes of large-scale regional analysis a simplified modelling approach is preferable, because it can be quick and it can be applied at high spatial resolution. Although more complex models would provide a more accurate description of processes governing e.g. water balance, their use is often uncertain due to missing input data at this scale. Many researches have earlier applied simplified models of potential evapotranspiration (PET), defined at daily to monthly time steps, and scaled these down to actual evapotranspiration on the basis of the availability of water in the soil over the same period, which itself is influenced by the evapotranspiration estimate (Running ja Coughlan 1988, Kellomäki 1995, Bugmann ja Cramer 1998, Sun ym. 2008). Commonly used PET models include Thornthwaite (Thorthwaite 1948) and Hamon (Hamon 1963) models based on temperature, and the Turc (Turc 1961) and Priestley and Taylor (Priestley ja Taylor 1972) models based on global radiation. However, these methods have been shown to produce mutually different results that do not necessarily correlate well with actual evapotranspiration (Lu ym. 2005). The temperature-based methods, especially, do not easily transfer from one biome or geographic area to another (Bugmann ja Cramer 1998, Shaw ja Riha 2011).

In this report, we describe a model which has been developed and parameterized for the prediction of GPP and soil water balance in boreal conditions, and provide guidance for the use of the model program that has been developed.

The complexity of the model is at intermediate level between the highly mechanistic and the simple, index-type models based on PET and water availability. The set of simple empirical models predicts daily ecosystem gross primary production (GPP, P), evapotranspiration (ET, E), and soil water content (θ). Following the principles of leaf-level models, ET model depends on our canopy-level GPP model through canopy conductance. Our θ model, in turn, influences both the GPP and ET models, as soil water is an essential factor in both photosynthesis and ET. Finally, the θ model depends on the E model, as E is one of important processes determining θ.

2 Model

2.1 Ecosystem processes represented by the model

The model is a simple semi process-based model representing the inter-linkages between photosynthesis of the canopy (P) and water balance of the ecosystem (Figure **1**). The ecosystem model is called PRELES (PREdict with LESs – or - PREdict Light-use efficiency, Evapotranspiration and Soil water) and it runs using standard weather data. The required inputs are daily mean temperature (T), vapor pressure deficit (D), precipitation (R), and photosynthetic photon flux density (PPFD, ϕ) which can be derived with sufficient accuracy from frequently measured global short-wave radiation (G). The structural information the model requires is the fraction of absorbed PPFD, which can be estimated from LAI (L_A), possibly modified by information about stand structure (Duursma ja Mäkelä 2007).

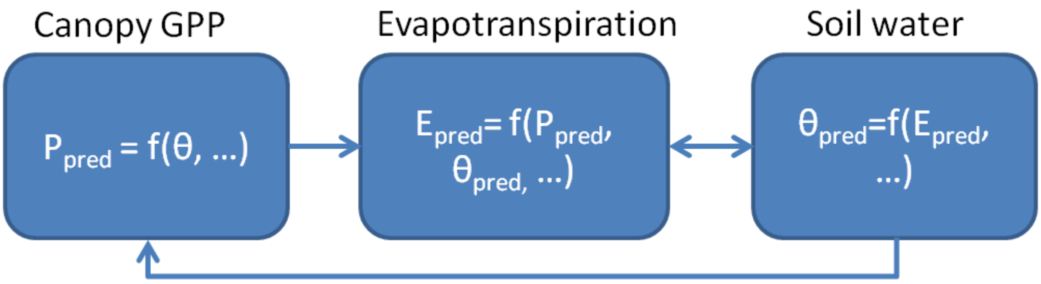

Figure 1 Linkages between GPP, evapotranspiration and soil water represented by the model

In the model, the canopy GPP is represented with an empirical equation developed in an earlier study (Mäkelä ym. 2008). The GPP model has been slightly modified in the current model version.

The GPP model

The GPP model predicts photosynthetic production P_k (P, gC m^{-2} day^{-1}) during the day k:

$$P_k = \beta \phi_k \prod_i f_{i,k}$$

where β is the potential LUE (gC (mol PPFD)$^{-1}$), i.e. the maximum LUE reached in optimal growing conditions, and at low light. This parameter can also be related to canopy nitrogen concentration (Peltoniemi ym. 2012). ϕ is photosynthetic photon flux density (PPFD, mol m^{-2} day^{-1}) during day k. $f_{i,}$ are modifiers that account for the suboptimal conditions i.. All modifiers range from 0 to 1. See Table 1 for explanations of f_i.

In the previous version of the model (Mäkelä ym. 2008) water vapour pressure deficit of atmosphere reduced P through an exponential relationship $f_D = e^{\kappa D}$ (κ is negative) and a separate modifier was introduced to account for soil water. Here we merged the f_D and f_W modifiers following the principle of one constraint of stomatal conductance (Landsberg ja Waring 1997):

$$f_{DW,P} = \min(f_D, f_{W,P}),$$

where $f_{W,P}$ is estimated from relative extractable water, W, defined as

$$W = \frac{\theta - \theta_{WP}}{\theta_{FC} - \theta_{WP}},$$

where θ_{WP} is the soil water content at wilting point, and θ_{FC} is the water content at field capacity. For the soil water modifier we adopted the widely used threshold model proposed by Granier (Granier 1987), where

$$f_{W,P} = \min(1, W/\rho_P),$$

i.e., $f_{W,P}$ increases linearly with increasing W between θ_{WP} and ρ_P, after which it is set to value 1. Using previous day's estimate for soil water is justifiable because changes in soil water are small during a day when soil water is constraining GPP.

CO_2 influences GPP in two ways in the model:

1. Modifier $f_{CO2} = 1 + (C_a - C_{a0})/(C_a - C_{a0} + c_m)$, which represents the mean increase of GPP with increasing CO_2, C_a.. The base level C_{a0}=380 ppm, and c_m is a parameter.
2. Increasing CO_2 influences also the stomatal conductance, which becomes less reactive to VPD. This is the reason for introducing a multiplier for κ in the f_D-modifier, which takes the form
$(C_{a0}/C_a)^{c\kappa}$, where c_κ is a unitless parameter.

A summary of *f*-modifiers is presented in Table 1. Further information can be found elsewhere (Mäkelä ym. 2008)., which is introduced as one of the *f*-modifiers, f_{aPPFD} . Not all absorbed PPFD can be used in photosynthesis. The light modifer (f_L) describes the saturation of photosynthetic production with high PPFD, with $f_L = \frac{1}{\gamma\phi+1}$..

Table 1 Environmental modifiers influencing GPP. For parameters, see text and Box 4.

Modifier	Function	Explanation
f_{aPPFD}	-	The structure of the forest stand is characterized by the fraction of absorbed PPFD. Fraction of absorbed PPFD is estimated usually from LAI, or it is directly measured.
f_L	$\frac{1}{\gamma\phi+1}$	Photosynthetic efficiency of canopy decreases under high irradiance. Multiplied with PPFD, [ϕ]= mol m^{-2}, this gives the canopy GPP and rectangular shaped response function to PPFD (Peltoniemi ym. 2012)
f_S	$f_{S,k} = \min\{\frac{S_k}{S_{\max}}, 1\}$, where $S_k = \max\{X_k - X_0, 0\}$, where $X_k = X_{k-1} + \frac{1}{\tau}(T_k - X_{k-1})$, where $X_1 = T_1$ $S_{\max}$ (˚C) is temperature when canopy GPP is not constrained by temperature. S_k (˚C) is state of acclimation estimated using a first-order dynamic delay model for X_k (˚C), which is the a priori estimate for the state of acclimation. It is influenced by the ambient temperature T_k (˚C) on day *k*, and its value for the previous day (X_{k-1}). τ is a constant related to the speed of response of the current acclimation status to changes in T_k. X_0 (◦C) is a threshold for X_k defining the low limit above which S_k starts to increase	This modifier captures the seasonal cycle, as well as the variation in daily temperature, but so that the responses of ambient temperature are delayed (Mäkelä ym. 2004, Mäkelä ym. 2008).

	f_S. S_{max} (∘C) is the value where the acclimation modifier reaches its optimum temperature state-related effects are modelled using a modifier for temperature acclimation (f_S).	
$f_{DW,P}$	$\min(f_D, f_{W,P})$	Effect of stomata to GPP is assumed to be the
f_D	$e^{\kappa\left(\frac{C_{a,0}}{C_a}\right)^{c_\kappa} D}$	Effect of vapour pressure deficit [D] = kPa on GPP, which accounts for the effect of atmospheric CO_2 [C_a]=ppm. $C_{a,0}$ is the reference CO_2, 380 ppm. High D decreases canopy conductance, which decreases photosynthesis.
$f_{W,P}$	$\min(1/\rho_P)$	See text for explanations.
f_{CO2}	$1 + (C_a - C_{a0})/(C_a - C_{a0} + c_m)$	Mean response of canopy GPP to CO_2. See text for explanations.

The evapotranspiration model

Evapotranspiration is composed of transpiration of vegetation and free evaporation from non-photosynthetic surfaces. The transpiration part is represented in the model by an equation assuming that the canopy is well connected to the atmosphere, such that transpiration can be predicted with canopy conductance multiplied with vapour pressure deficit, ie. transpiration = $g_s D$ (Jarvis 1976, Whitehead 1998, Brümmer ym. 2012). Canopy conductance g_s is predicted with an equation loosely following an empirical leaf-level stomatal conductance function that uses GPP of the whole canopy as input, instead of leaf photosynthesis (Medlyn ym. 2011). Radiation drives evaporation on non-green surfaces. Because PPFD is strongly correlated with global radiation, we use PPFD (ϕ) here as we did in the GPP model. The proportion of radiation incident on non-green surfaces can be approximated with $(1 - f_{aPPFD})$. This formulation of evapotranspiration requires minimal input data, but allows for a link between P and E and a fairly straightforward and flexible fit to data.

$$E = \alpha \frac{P}{D^{\lambda}} f_{W,P}^{\nu} D f_{CO2,T} + \chi(1 - f_{aPPFD})\phi f_{W,E}$$

Where $f_{CO2,T} = 1 - 1.95\,(C_a - C_{a0})/(C_a - C_{a0} + 2000)$ removes the mean effect of elevated on GPP (generated by f_{CO2} in the model) due to increased concentration of CO_2, which does not directly influence transpiration. The quantities α and χ are fitted parameters, which partially determine the fraction of the two water fluxes. The parameters ν and λ are needed because VPD and soil water do not equally influence GPP and transpiration. The modifier $f_{W,E}$ is estimated similarly to that for the GPP submodel, but with its own threshold parameter ρ_{E}. If there is any water in the canopy, $f_{WE}=1$.

The soil water model

Soil water is predicted with a simple bucket model, with three parameters: field capacity θ_{FC}, wilting point θ_{WP}, and the daily drainage fraction τ_D for water above field capacity. No drainage occurs below field capacity. The model also includes water storages for snow and free water in the canopy, which are also simple bucket models. Each day, the soil water content of these storages is updated with the following rules:

i) Interception fills the canopy water storage, while excess water in the storage drains down to the soil (the maximum amount of canopy water is a parameter of the model, *CWmax*)

ii) Snow water storage θ_{snow} accumulates when mean daily temperature $T < 0$ °C and melts if temperature of day k, $T_k > 0$° C: $M_k = \begin{cases} mT_k & T_k > 0 \\ 0 & T_k \leq 0 \end{cases}$ (Kuusisto 1984), where m is a parameter in the model. Snowmelt is transferred to soil water.

iii) Evapotranspiration decreases water storages in the sequence: 1. canopy water, 2. snow, and 3. soil. Evapotranspiration is influenced by soil water.

iv) Drainage from the soil occurs above field capacity only. Drained water on day k is estimated as $F_k = (\theta_k - \theta_{FC})/\tau$.

A more detailed description of the model appears elsewhere (Peltoniemi et al. 201X, manuscript).

2.2. Model parameterization

The model has been parameterized using Hyytiälä eddy-covariance derived data on GPP and evapotranspiration, and measurements of other variable used to run the model. Soil water data from Hyytiälä has been used in the parameterization as well. The model has also been calibrated with data from Sodankylä eddy-covariance site, and the Hyytiälä parameterization has been tested at the Sodankylä site (Peltoniemi et al. 2012, manuscript).

Based on these tests, the Hyytiälä parameterized model predicted Sodankylä fluxes of GPP and evapotranspiration surprisingly well, R^2 for GPP was 0.82 and for evapotranspiration it was 0.61. These are fairly close to the values we obtained when the model was parameterized with Sodankylä's own data (R^2=0.88 for GPP and R^2=0.76 for evapotranspiration).

3 Model implementation

PRELES has been implemented in C programming language, and the model code is available for any use in the Project web-pages (www.metla.fi/life/climforisk/). Readily compiled executables have been provided for Windows 32 bit platforms and Linux 64 platforms. For other platforms we propose that the user installs Qt development platform (http://qt.nokia.com/) and compiles the source code. In the compilation, the gcc compiler provided by the Qt development environment was used.

3.1 Program structure

The model code is organised in the following files:

- main.c:
  - Read input files
  - Call the workhorse preles()
  - Write output files
- preles.c: The main workhorse for calculation of ecosystem processes.
  - Estimate GPP
  - Estimate evapotranspiration
  - Update water balance
- gpp.c
  - Functions to estimate GPP and f-modifiers
- water.c
  - Functions to estimate evapotranspiration and ecosystem water balance
- initruns.c

  - Utility functions to initialize variables with irrational or missing values
  - Functions for handling model parameters
- prelesglobals.h
  - Include header files globally
  - Global declaration of structures that contain submodel parameters.

3.2 Model use

Model use and inputs

The PRELES program is run on command line in both Windows and Linux systems. It can be executed in several modes, depending on the purpose of use. It can be run i) for an arbitrarily long period for one site by using a weather input data file, or ii) run for arbitrary number of sites for one day (useMeasurement=10), iii) for just one day for one site by providing weather inputs and the initial states of storages as arguments on command line or iv) for arbitrary number of sites for arbitrary nu,ber of days (N):

i) ./PRELES preles.par preles.input
ii) ./PRELES preles.par preles.input
iii) ./PRELES preles.par 30 11 1 0 380 0.79 180 0 0 20
iv) ./PRELES preles.par fapar.csv initvars.csv weather.csv N

The run mode of the model is determined by the number of arguments given to the model and the parameter file (preles.par) of the model (see section Model parameters).

In options i) and ii), the program requires an input file (preles.input), which lists model inputs in semicolon separated (?) format. Box 1describes the contents of the input file for options i) and ii). In the input file, mean or cumulative daily values appear on separate rows. The colums of the input file of Box 1are presented in Box 2.

Box 1 First four rows of a weather input (+fAPAR) file.

```
0.50571;-11.0127083333;1;0;380.01;0.7936249222;180;1.1;1.2;100
0.172224;-7.5989583333;-999;0.1;380.01;0.7936249222;180;0;0;0
0.328482;-4.2079166667;-999;2;380.01;0.7936249222;180;0;0;0
0.29592;-1.0316666667;-999;1.1806;380.01;0.7936249222;180;0;0;0
```

Box 2 Colums of the input data file.

PPFD (Photosynthetic photon flux density, mol/m2/day)
Tair (Mean temperature, C)
VPD (Mean vapour pressure deficit of the day, kPa)
Precip (Precipitation above canopy, mm)
CO2 (CO2 of air, ppm)
fAPAR (Fraction of absorbed photososynthetic radiation, between 0-1. Estimated from LAI of the stand)
SW (Soil water, mm. First row value used for model initialization)

Canopywater (Canopy water, mm. First value used for model initialization)
SOG (Snow on ground, mm of water. First value used for model initialization)
S (Temperature acclimation state, C. First value used for model initialization)

Missing data in the input files is represented with -999. If data is missing, the program will use previous days values as input.

In option i) only the first row values of input data are used to initialise SW, Canopywater, SOG and S, whereas in option ii) simulation is repeatedly initialised for each row of the file, because the model is run for independent sites and not for consequtive days.

The program generates an output file that is automatically named as <parameter file>_predictions. The file is is in semicolon separated format and it lists the output column names shown in Box 3.

Box 3 Output columns of the model

Day: The running number of the day, i.e. row number
GPP: Gross primary production, gC/m2/day
ET: Evapotranspiration, mm
SW: Soil water, mm
SOG: Snow on ground in mm of water
CW: Water in the canopy, mm.
Snowmelt: Snowmelt estimate, mm of water
Throughfall: Water raining to soil, mm
Drainage: Drainage, mm of water
S: Acclimation state, C
fS: Acclimation/temperature modifier (0-1)
fD: VPD-modifier (0-1)
fW: Soil water modifier (0-1)

In run mode iii) all input data is given as model arguments, which are in the same order as the input data in the files of the modes i-ii). Mode iii) is executed automatically if weather data is given as program arguments.

Option iv) requires separate input files for fAPAR-values, initial storage values and weather table, and an argument that tells for how many days the model is run, which must correspond for the number of days there is weather data in weather table. This mode is meant for high performance calculation where cumulative output variables for several days are produced for a great number of sites by using weather data point and observations indicated in the fapar.csv-file. Box 4 shows the logic of the calculation and the contents of input and cumulative output.

Box 4 Logic of mode iv) of running Preles and contents of input files. Values in boxes are for example only. Weather.csv is a lookup table, which lists daily weather observations for FMI grid points for N days.

fapar.csv

```
2100;0.7
25;0.5
39;0.8
…
```

- Unique lines indicate unique sites. Order of sites/lines is irrelevant for Preles,
- Columns: weather grid point id; fAPAR

statevars.csv

```
2100;180;0;0;0
25;100;10;0;-9.1
39;190;0;0;2
…
```

- Columns: SW; CW; SOG; S
- Sites should be in the same order as in fapar.csv

weather.csv

```
1;1;20;-10;1;10;380
1;2;20;10;1;10;380
1;3;20;20;1;1;380
2;1;20;-10;1;10;380
2;2;20;-10;1;10;380
2;3;2;20;10;1;10;380
3;1;20;20;1;1;380
3;2;20;-10;1;10;380
3;3;20;-10;1;10;380
4;1;20;10;1;10;380
4;2;20;20;1;1;380
4;3;20;-10;1;10;380
```

- Columns: Weather grid point number; running number of day in period; PPFD; Temperature; VPD; Rainfall; CO2

- Grid points should be in increasing order
- Days in each grid point should be in increasing order for the period of **N** days

1. Loop sites in fapar.csv
   - Record closest weather grid point
2. Get initial storages from statevar.csv from the same row
3. Get weather data for N days for closest weather grid point from weather.csv
4. Write period's predictions to a file preles.par_predictions and the new state of the model to statevars.csv_after

preles.par_predictions

```
2100;6.54;0.5;187.2;180
25;3.54;0.4;182.2;180
39;3.54;0.4;184.2;180
…
```

- Columns: Mean GPP; Mean ET; Mean SW; Minimum SW

Input of model parameters

The PRELES program used a parameter file (named preles.par in the above example), which has the same format in each run mode. The parameter file lists the parameters of the model, and tells how the model is run. The box below shows the meaning of each parameter.

Box 5 Parameter file (left cell), explanations, and symbols of parameters.

RUN_PARAMETERS_FOR_MODEL	
0 useMeasurement	# 0 (mode i), 10 (mode ii), 30 (mode iv)
0 LOGFLAG	# Loglevels 0-2 cause increasing quantity of logging
SITE_SPECIFIC_PARAMETERS	# Depth of the soil, mm
413 soildepth	# θ_{FC}, Field capacity, above drainage occurs
0.450 ThetaFC	# θ_{WP} Wilting point
0.118 ThetaPWP	# τ_D, Fraction 1/tauDrainage of water above ThetaFC drains in a day
3 tauDrainage	# β_P, Light use-efficiency (gC/mol)
GPP_MODEL_PARAMETERS	# τ , fS-model (season/temperature) parameter
0.748464 betaGPP	# S_0, fS parameter
12.74915 tauGPP	# S_{max}, fS parameter
-3.566967 S0GPP	# κ, fD parameter (effect of VPD on GPP)

18.4513 SmaxGPP	# γ, fL parameter (sat. effect of PPFD)
-0.136732 kappaGPP	# ρ_P, fW parameter (GPP reduces after REW < soilthresGPP)
0.033942 gammaGPP	# c_m parameter: Mean effect of CO2 (ppm) on GPP
0.448975 soilthresGPP	# C_κ parameter: Change in CO2 effect on VPD
2000 cmCO2	
0.4 ckappaCO2	# α, Parameter for transpiration, multiplier
EVAPOTRANSPIRATION_PARAMETERS	# λ, VPD correction for transpiration
0.33271 alpha	# χ, Parameter for evaporation
0.857291 lambda	# ρ_E, REW threshold when evaporation decreases
0.041781 chi	# ν, Soil water correction for transpiration
0.474173 soilthresET	
0.278332 nuET	# m, Melting coefficient of snow
SNOW_RAIN_PARAMETERS	# Fraction of intercepted water = I_0 fAPAR / 0.75
1.5 Meltcoef 0	# Maximum storage for canopy (surfacial) water for free evaporation
0.33 I_0	
4.824704 CWmax	

4 Example simulations with the model

4.1 Model predictions and climate change

The primary interest in PRELES is in the prediction of climate change effects on forest GPP and soil water balance. To give an impression about model predictions under climate change, and in comparison to current climate, we made a few model simulations.

As the starting base for simulations, we used the data measured in year 2006 in Hyytiälä eddy-covariance site. The year 2006 was a special year because it includes one of the rare sequence of days in the measurement history of the Hyytiälä site when drought clearly influence ecosystem GPP and evapotranspiration.

We asked whether the Hyytiälä pine stand would have suffered from drought, had there been more CO_2 in the air and had there been higher temperatures, as expected under climate change. For this example, we assumed that precipiration is the same under climate change as it was in 2006. Changes of temperature for each of the four seasons, were obtained from A1B scenario in the year 2100 as represented in Jylhä et al 2009 (Table 10, Appendix 10), and CO_2 concentration was assumed accordingly to be 760 ppm.

The following cases were simulated:

1. Hyytiälä soil and stand, i.e. θ_{FC}=0.45; f_{aPPFD} =0.75
2. Dry soil and Hyytiälä stand, i.e. θ_{FC}=0.225; f_{aPPFD} =0.75
3. Hyytiälä soil and low canopy cover, i.e. θ_{FC}=0.45; f_{aPPFD} =0.25

Simulation case 1

The model predicted less summer evapotranspiration in 2100 than in 2006 (Figure **2**). This was mainly caused by the reduced sensitivity of transpiration to increased VPD under higher ambient CO_2. Winter evapotranspiration was little affected. Soil water content increased in the changed climate during the winter because of changes in the timings of the snowmelt days. Soil water content during the summer remained slightly higher in the changed climate than with 2006 weather. This had consequent effects on the GPP, which was slightly higher in changed climate during the summer soil water minima.

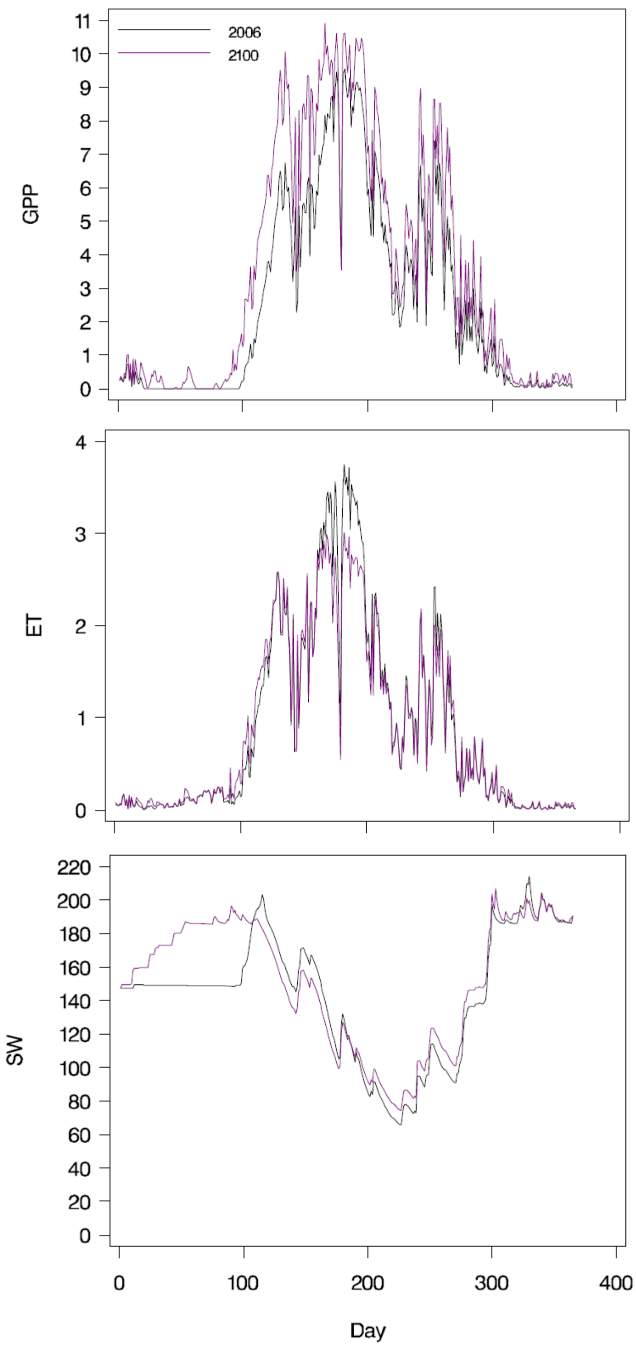

Figure 2 Simulation of gross primary production (GPP, $gC/m^2/day$, top panel), evapotranspiration (ET, mm, top panel), soil water conteent (SW, mm, bottom panel), with 2006 weather (black) and predicted weather in 2100 (purple).

Simulation case 2 and 3
GPP at the dry site (case 2) was variable, due to smaller soil water holding capacity of the soil. The model predicted a stonger drought effect on GPP during early summer in the changed climate than with 2006 weather data (

Figure 3, top panel). This was due to the higher evapotranspiration in the beginning of the season, which reduced the soil water content in the changed climate more than with 2006 data (

Figure 3, bottom panel). The most severe drought during the summer was still less pronounced in the changed climate than it was with 2006 data.

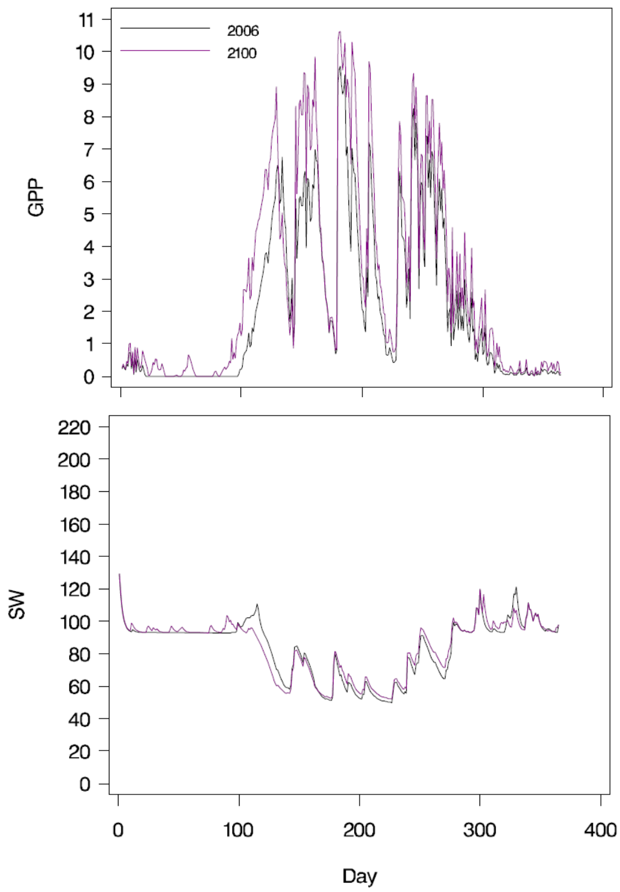

Figure 3 GPP and SW at the hypothetical dry site (simulation case 2).

The level of GPP at the low canopy cover site was generally low due to small amount of light harvested (

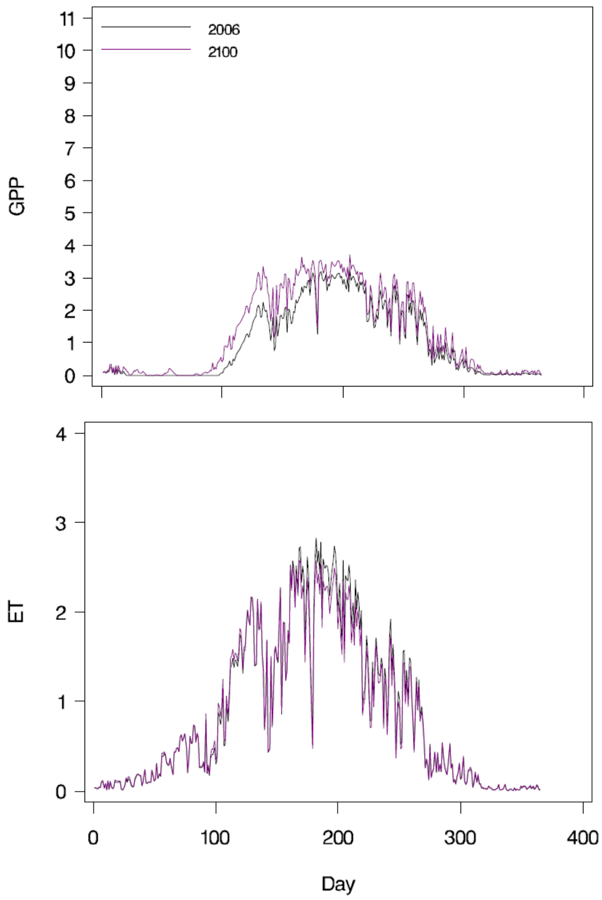

Figure 4, top panel). GPP at the low canopy cover site was less influenced by the soil water dynamics than in the other sites. This can be attributed to evapotranspiration that was a bit lower, and more evenly distributed during the season (

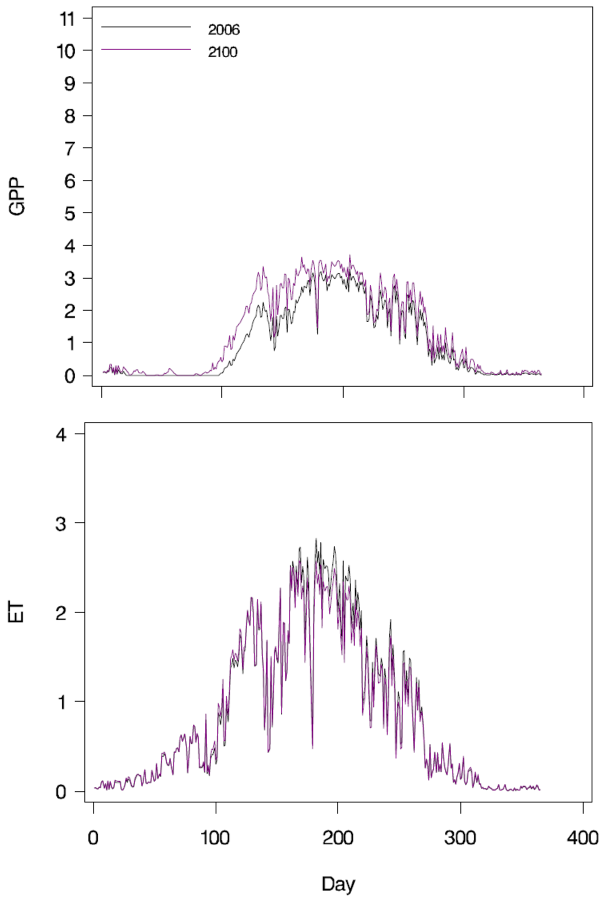

Figure 4, bottom panel). The reason for more uniform distrubution is that the evapotranspiration at low canopy cover site is influenced relatively more by the evaporation term of the evapotranspiration equation, than by the transpiration part (that is influenced by the GPP term) that is more variable by nature.

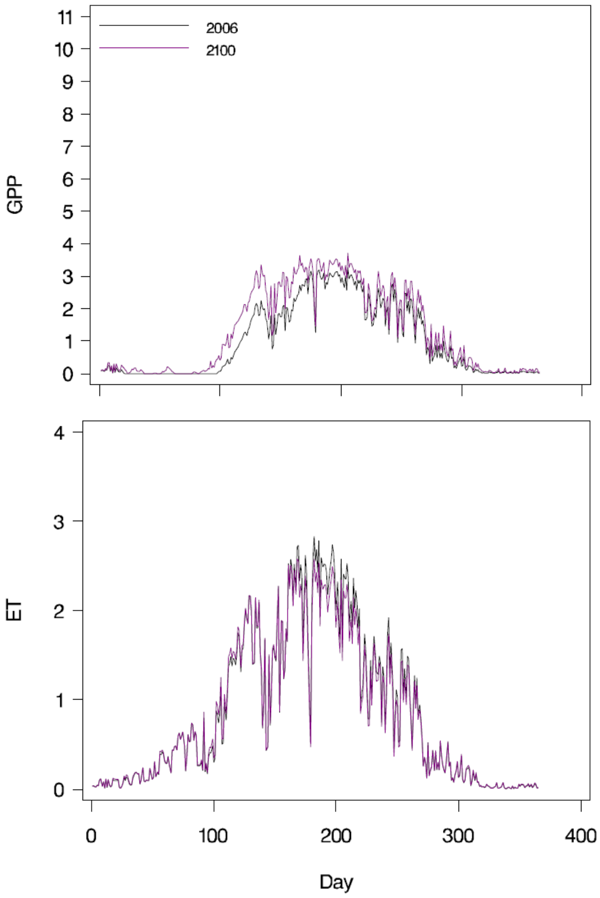

Figure 4 GPP and ET at the hypothetical low canopy cover site

4.2 Model tests at ICP level II sites

The model was also tested against soil water measurements at ICP level II forest sites (Appendix A). In these tests, no attempt to bring plot information to the model was made, but the model was rather run in a mode corresponding to Hyytiälä eddy-covariance site, and it was run with the gridded weather data from the Finnish Meteorological Institute (FMI). The weather grid has the resolution of 10 km x 10 km, and the closest grid point was selected when the simulations were conducted for ICP level II plots. An attempt to use the weather data measured at ICP level II plots was also made but there turned out to be several gaps in the data required for model runs, which means that the data processing would have required a significant effort. Furthermore, for a broad scale test of the model predictions, we were interested whether the model could mimic measured variation in soil water data of these plots if weather data that is broadly available is used. Comparisons were also possible for some of the years when soil water measurements exist.

At the ICP Level II plots soil water content (%) was measured using Theta Probe sensors. Each plot has two sensors several meters apart at a depth of 20cm below the surface. Data was collected at an hourly interval. Here the mean value for both sensors was used. Due to variation in the soil structure there may be considerable differences in the measured values for both sensors, and thus the mean of only two sensors may not provide an accurate value that is representative for the whole plot.

Comparisons revealed that, generally, mean daily air temperature measured at the plots best corresponds to what is estimated in the FMI grid, whereas there is more difference between estimates of photosynthetically active photon flux density (PPFD) derived with a model from global radiation measuments. There is considerable difference in the FMI rainfall estimates and what has been measured at the plots. This is understandable due to the high spatial variability of summer rainfalls, which seems to make any predictions of drought fairly uncertain. Another reason is that the automatic tipping bucket rain gauges used for rainfall measurements at the Level II plots (Model RG306, Lakewood Systems) got easy plugged.

Generally speaking, soil water predicted by the model follows what has been measured at the sites, although there are large level differences between the predictions and the measurements. However, one should not look at the level differences as the model was run with Hyytiälä soil parameters, but rather how the soil water estimates follow each other in time. The effect of soil properties on the measured soil water values is probably the cause of the differences shown between the plots 10 and 11 (see Appendix). Both plots are located close to the Hyytiälä eddy-covariance site. The soil on plot 10 is composed of sorted sand (typical Scots pine site) but on plot 11 of unsorted till with relatively high amount of silt (typical Norway spruce site). The soil properties at plot 10 favour lower soil water values than those at plot 11. It is possible that if the soil parameters differ considerably from those at the Hyytiälä site, then the model would not follow soil water measurements as well as in the case where the soil is fairly similar to that in Hyytiälä.

Given the uncertainties in the input data (mainly rainfall) to the model, one could expect that it is possible to capture long dry periods that are prevalent on large regional scales, but that it is more difficult to capture occasional droughts generated by stochastic nature of the rainfall events in the summer.

5 Conclusions

Modelling fundamental ecosystem processes is needed for various kind of ecosystem impact studies. Spatial variability and non-linearity of ecosystems processes requires that the processes are simulated at high spatial resolution. Modelling them, however, can be challenging and data intensive.

In this report, we described and provided user guidance for a simple model, which can be used for such purposes. The model represents the core processes and linkages between ecosystem photosynthesis and water balance. The model has been implemented in C with tools freely available in any operating system environment.

We intend to use this model for predicting GPP and water balances of forest ecosystems at the scale of Finland, for both retrospective analyses of past climate and for analyses of the effects of climate change. Soil water predictions of the model are intended to be used as the basis of an ecosystem wetness index. Predictions of this index will then be compared to data on pest/pathogen damages of which many have been earlier related to drought periods. As such, the model offers us a tool for ecosystem impact assessments.

Model development continues, which means that new features may be included and computational logic may be improved.

APPENDIX
Input data and modelled and measured soil water at the ICP level II sites. Air T is mean daily air temperature, RH is relative humidity (%), Cumulative rainfall is in units of mm, Global radiation measured at ICP plots has been converted to PPFD and compared to PPFD predicted at closest weather grid points of FMI, SW% is (scaled) soil water content in %. Ticks on x-axis show missing observations in daily ICP level II data. Black dots are ICP level II plot measurements, and red dots are model simulated results.

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