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Chapter 13

Coupling a Forest Growth Model with a Soil Carbon Simulator

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Additional information is available at the end of the chapter

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1. Introduction

The impact of climate change on forests can be assessed with simulation models. The obvious advantage is the possibility of running a large number of case studies, without the need for field trials for each specific case. Especially in the context of climate change effects simulation models have become a standard tool. The alternative approach of evaluating the forest growth at sites with site conditions that may resemble the future conditions of the target site has numerous weaknesses. Therefore, models are deemed superior for the interpretation of the consequences of climate change. Simulation models are representative for the state-of-knowledge. Upon their development they are validated against data of existing forests, *i.e.* either data from national forest inventories or long-term forest productivity experiments [1–4].

The available models vary widely with respect to the model structure and the embedded modules. *Productivity models* are often conceived as a practical tool where forest practitioners find the opportunity to directly define specific silvicultural treatments such as thinning interventions, and the model provides information on the consequence of these actions on the temporal trend of stem growth. An important incentive for the development of this model type was that formerly used yield tables proved to be less reliable for several reasons. Yield tables were often derived from a rather limited number of field experiments and neither their species composition nor their management is reconcilable with present concepts and requirements of forestry [5, 6].

Succession models place their emphasis on the regeneration success of different tree species under future climate conditions. The focus is on the identification of site conditions, with the potential of changing the tree species combination. The strong part of these models is

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the description of the competition between the different tree species within a forest and the success of trees for natural regeneration [7–10].

Biogeochemical models such as Biome-BGC are large scale models that model primary productivity [11]. The simulation results mostly apply for large regions and are skillfully broken down for smaller regions. Although the models are generally not conceived for the description of silvicultural treatments, there are efforts underway to introduce options of forest management [12].

We chose a productivity model, because we wanted to properly depict management options that are expressed in terms of generally understandable silvicultural interventions. In productivity models the emphasis is typically on the effect of silvicultural interventions, but not necessarily on the provision of ecosystem services such as carbon sequestration.

The sequestration of carbon in forest soils is often not integrated in the productivity models. Instead, the carbon dynamics are calculated separately. A notable exception is a Swiss study were the impact of storm damage on the soil carbon pool had been evaluated [13]. The effect of tree species on the forest soil carbon pool has been shown [14–17]. Therefore, we are convinced that a full assessment of forest management options needs to comprise both the carbon pools in the total biomass and the soil.

Our objective was the linkage of a soil productivity model with a soil carbon model in order to emphasize the implication of forest management on the soil carbon pool.

2. Sites and methods

2.1. Site

The chosen site for our simulation exercise in the Ossiacher Tauern. It is a montane forest area on silicatic bedrock. Although the site would be naturally dominated by deciduous trees, it is currently ideal for growing Norway spruce (*Picea abies* (L.) Karst.) [18].

2.2. The forest productivity model CALDIS

CALDIS is derived from the celtic term ”Caldis Vâtis” translating to ”forest prognosticator”. The core of CALDIS is a module simulating the basal area increment of individual trees of the dominating tree species in Austria, *i.e.* Norway spruce, fir, larch, three pines, European beech, oak, and other deciduous species. In recognition of the scarcity of georeferenced single trees the model was intentionally developed as distance-independent model. The data for model development were taken from the Austrian National Forest Inventory. The model handles competition between trees with the basal area as the parameter. The basal area increment of individual trees; BAI, was derived from ?tree size?, ?competition? and ?site properties?. The by far most important parameter for the basal area increment is ’tree size”, represented by stem diameter and size of the canopy. The competitive situation of a single tree is captured as the sum of the basal area of all trees with a larger diameter than the sample tree. Site factors such as topography, elevation, aspect, depth of the organic soil layer, and soil type contribute a small, yet significant, improvement of the model. Besides the diameter and height growth module, the model contains a mortality module and a regeneration module. The model has been used with the acronym ”PrognAus” [6]. The productivity model has been amended

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with several additional modules. In order to capture the long-term development of a forest, an ingrowth module was added describing the recruitment of naturally regenerating trees. ”Recruitment” is the estimation of the number of trees exceeding a predefined threshold value of height and diameter. The recruitment of trees was estimated from the appearance of new small trees in the fixed plots of the Austrian National Forest Inventory that were observed in consecutive inventories. A model component estimates the probability of the successful regeneration for 13 tree species. An important site factor for most tree species was soil moisture. Several additional site parameters such as exposition and elevation are have a significant influence. The module describes the regional situation of Austria particularly well, but may be less valid in other countries, because the impact of site factors on the natural regeneration is derived from the data set and therefore the amplitude of Austrian forests is well described [19]. A climate-sensitive part of the model was developed in order to make the productivity programme available for long-term scenarios. Additional climatic parameters used were the annual temperature sum (sum of daily mean temperatures above 3 °C), the annual precipitation, the temperature sum and the precipitation during the growing season. In order to capture the impact of the past, the precipitation during the growing season of the previous year and the average of temperature sum and precipitation in the past 30 years are used as parameters. Dryness is derived from a transformation of the monthly precipitation and temperature. The response of different tree species to climate is embedded in the model. The basal area increment of European beech responds strongly to increases in the temperature sum, and is greatly reduced at lower precipitation rates. Oak responsds similarly to the temperature sum, and is less affected by declining precipitation rates. At lower temperature sums, the basal area increment of Norway spruce is higher than the increment of beech and oak. Nevertheless, the increment rate remains high, even under warmer conditions. The dependence on the precipitation shows that spruce can tolerate dry conditions rather poorly [20].

An important element of forest development is the disturbance regime. Prominent factors in the Alpine Space are insect attacks, storm damages, and possibly fire [21–23]. It has been shown that the pressure is not solely caused by climate change effects, but also by forest management effects, that potentially can be modified by means of strategies for adaptive forest management [24, 25].

The influence of storm events on forests was derived from field evidence for tree mortality due to disturbance, and wind speed data from the Zentralanstalt für Meteorologie und Geodynamik. A challenge was linking forest damage to a particular storm event, because the data of the Austrian Forest Inventory allow to assign a damage event to a period of a few years whereas the wind-speed is recorded with a resolution of 2 seconds. The pragmatic assumption was that the strongest storm in the observation period of the Forest Inventory was responsible for the observed forest damage. It was shown that Norway spruce is particularly vulnerable to storms during the dormant season, whereas the fully developed canopy of beech forests makes them more vulnerable during the growing season. The storm module represents the strong influence of tree size parameters. Larger trees and trees with a high height/diameter ratio are more vulnerable to storm damages [26, 27].

The future pressure from insects is difficult to predict for a particular site in a certain time span, although clear indicators for the potential danger are available [22, 28, 29].

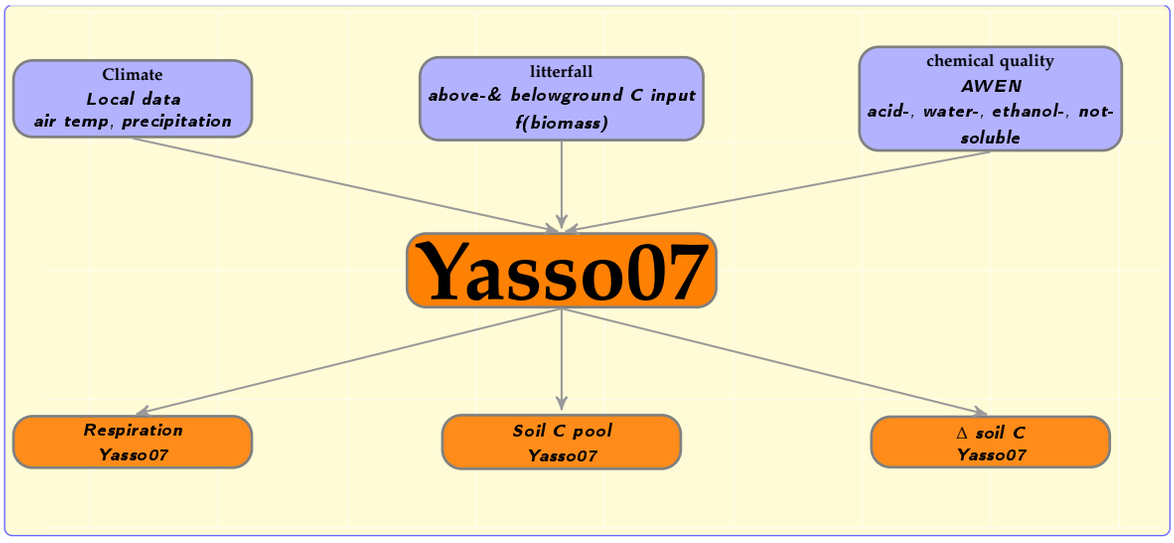


Figure 1. Yasso07 is a simulation model for the decomposition of soil organic matter. The input parameters are the annual climate, represented by the mean annual temperature, the difference of temperatures between the coldest and the warmest month, and the annual precipitation, the total carbon input to the soil, and its chemical quality.

The annual output of CALDIS comprises stem volume, tree height, and stem diameter of the individual trees of stand. The disturbance regime is focused on storm damages, because the storm-inflicted damages are well described in measurable parameters. Disturbances by an inadequately high density of the deer population and by pests and pathogens are not incorporated in the simulation model and need to be taken into account in the interpretation of the simulation results.

The CALDIS model was fed by climate data from A1B and B1 scenarios. The A1B scenario foresees a stronger warming trend, the B1 scenario is more optimistic with respect to controlling the warming trend [30].

2.3. The soil carbon simulator Yasso07

Yasso is an intentionally simple soil carbon simulation model. Its general concept is shown in Figure 1: The user supplies air temperature and precipitation as climate parameters, the quantity of the above- and belowground influx of carbon to the soil, and information on the chemical quality of the incoming carbon. The model can deal with different temporal resolutions of the input information. The core of Yasso is a decomposition model of soil organic material [31, 32]. In our simulation Yasso was run 10 times for each data set in order to account for the uncertainty about the parameter values. These repetitions do not account for the variability in the user-provided input data.

As output Yasso gives a time series of the total soil C pool, which is divided into carbon in woody matter, non-woody matter and the acid-, water-, ethanol and insoluble fractions. It can be understood that carbon in woody material describes the coarse woody debris and the forest floor material and the sum of the remaining fractions are carbon in the mineral soil. Yasso does not distinguish between soil horizons and does not explicitly state a soil depth. Operationally, a soil depth of 1 m can be assumed, although the reference to the ”total soil C pool” is more appropriate, because all incoming carbon is processed by Yasso07.

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3. Building a bridge between CALDIS and Yasso07

3.1. Data and folders

The CALDIS forest management model produces output in annual time steps. Folders, named corresponding to the year of the simulation, are located in one major CALDIS output folder. Each of these folders contains yet another set of subfolders which, at last, comprise the data: Content of folder [`sim`] describes the standing biomass, folder [`mort`] contains data about trees discarding from the simulation due to natural mortality events, and folders [`VN`] and [`EN`] comprise tree data about harvesting removals. Folder [`verb`] contains information about remaining trees, after a disturbance event or harvest has taken place.

Every line in an output file represents one tree of a sample plot. At the time this work was conducted, the forest management model CALDIS was still under development. Forty-two comma-separated output parameters described each tree. Depending on the number of model runs and the timeframe of the simulation the output can become quite extensive and may therefore present considerable data-handling challenges. A strategy for accessing the data generated by CALDIS and for skimming the data in order to assemble the parameters for the Yasso07 input file is shown in figure 1.

In this approach advanced options of the SAS® 9.2 datastep were used to access and process the data generated by CALDIS [33, 34]. If more than one model run was conducted, the program which is presented here is able to access all model runs at once.

3.1.1. The import of CALDIS output data into a SAS®9.2 dataset

First, a list is created, storing all data-paths and filenames of CALDIS output files in a SAS®9.2 dataset. The SAS Command [`pipe`] enables the SAS application to access MS-DOS/UNIX commands [35]. The output of the command is accessed by SAS again, and written to a dataset. In this case, it is the common MS-DOS® command [`dir`] which displays the content of a defined folder. Three sub-options are used, in order to prevent the input of non-relevant information.

```
filename DIR_FILE pipe "dir /b/s d:\XYZ\YOUR_CALDIS_OUTPUT\*.cds";
```

`/s` causes the inclusion of the content of all subfolders.

`/b` Only filenames and the full data-path, but no additional information are displayed.

`*.cds` Only files which have [cds] (relevant CALDIS output files) as file type extension are displayed.

Thereby a dataset which lists all CALDIS output files inside a stated folder is created. Its only parameter is the full data-path plus the filename stored as a character string. To avoid truncation of data path descriptions, the length of the variable is set to a maximum of 256 characters.

```
data FILE_LIST;
length data_path $256;
infile DIR_FILE length=reclaeng;
input data_path $ varying256. reclaeng ;
run;
```

In the next step, this list is used to import the data files into one major data record, consisting of the output of all model scenarios and runs. This is achieved by running a macro loop from the first observation of the generated list to the last. Each cycle of the loop the character string parameter at the current observation is stored as a global macro variable. Then this string is used in a data step behind an [`infile`] statement. A temporary data record is created which contains data of the current CALDIS output file. The global variable, in which location and filename are defined, is also stored as parameter making it possible to identify the origin of the data. If this is the first iteration of the loop, a new dataset is created by storing the temporary one. For all following iterations the temporary dataset is appended on this new dataset. After this event the next run of the loop starts. After the last iteration of the loop the data import is complete. This way all observations of all CALDIS output files are gathered in one dataset.

```
%macro data_import;
    %do o=1 %to &Num_Of_Obs;
        data _NULL_; set FILE_LIST;
            if _n_ = &o; call symput('path_to_file',data_path);
        run;
        data temp;
            infile "&path_to_file"
            DLM=',';
            INPUT all input parameters;
            data_path_key ="&path_to_file";
        run;
        %if &o ne 1 %then %do;
            proc append base=full_dataset data=temp; run;
        %end;
        %else %do;
            data full_dataset; set temp; run;
        %end;
    %end;
%mend data_import;
```

3.1.2. The break-up of the data location into key parameters

The labeling of the storage location provides information about the comprised data itself. In this next step, the path to the output data is used to create key parameters, which can be used as filter criteria at a given point of time. This is achieved by 'breaking down' the variable [`data_path`] into single 'words'. Every element of the location is stored as an own parameter. In our case numerous CALDIS runs of different base conditions were conducted. It seems reasonable to store the output with consistent labeling. The name of the subfolder, which comprises the output of one single run, was formatted containing information about CALDIS model setting details. An example is *P*_12_*S*_3_*C*_2_*R*_30 describing:

- Plot 12
- Scenario 3
- Climate 2 [e.g. IPCC - B1]
- Run 30

This string is also split into its 'words' which are used to create a numeric key variable. Then the dataset which contains information that is gained from labeling of subfolders [FILE_LIST_key] is merged with the dataset which contains all the simulation results [full_dataset].

3.1.3. Compressing the dataset

Every CALDIS output file represents a sample plot, which was examined by the angle-count method. The parameter [nrepjeha] tells how many trees of the same characteristics exist on one hectare and serves as a multiplier for scaling up the sample plot to one hectare. The content of folders [sim], [verb], [mort], [VN] and [EN] differs exclusively in this parameter. We merged corresponding datasets of folders [sim], [verb], [mort], [VN] and [EN] via previously generated key variables, introducing [nrepjeha_sim], [nrepjeha_verb], [nrepjeha_mort], [nrepjeha_VN] and [nrepjeha_EN] as new parameters.

3.1.4. Editing climate data according needs of Yasso07

In the framework of this project, a regional downscaling of 2 different climate scenarios was conducted for the region of Ossiach (Carinthia). 100 Years were modeled, starting 2001. Furthermore daily time-step weather parameters were generated. These results were edited for the forest management model CALDIS as well as for the soil carbon model Yasso07.

In the Yasso07 model, the only factors which are driving litter decomposition are the composition of the material and the climatic conditions that can be described simply by using temperature and precipitation [36]. Climate data is assessed in quite a simple manner. Different ways of formatting are possible. The software accepts monthly or yearly time-steps. In our simulation exercise we used yearly time-steps. The input data consists of the time-interval, yearly annual mean temperature, the amplitude of mean temperatures of the coldest and the hottest month and the annual precipitation sum.

The data input of different climate parameter files was conducted analogue to the input of CALDIS data (see Chapter 3.1.1). Via the command [pipe] a list is generated. Afterwards the data locations (which are stored as macro variables) are passed to a data step, where they are used behind an [infile] statement to read in the files. One precipitation and one temperature file per climate scenario is generated. Annual mean temperature, the amplitude of the mean values of coldest and hottest month and the annual precipitation sum are calculated. Then they are stored in a permanent library for later access.

3.2. Estimating biomass compartments

In this step, different biomass estimations, according to tree species and compartment, are applied. These estimations are used to assess annual biomass fluxes, which are used later on as Yasso07 input parameters. Some biomass parameters which are going to be

output parameters in the final release of CALDIS, were not yet defined and were computed externally. The parameters "stem volume" [m^3] and "mass of dry branches" [kg] were already defined output parameters of the forest management model.

For calculating other compartments the "diameter at breast height" (dbh) [cm] and the "height of the modeled tree" (h) [m] was used. A wet-to-dry stem volume shrinkage factor 0.881 was applied for all tree species [37]. A stem wood dry density of 430 and 680 kg/m^3 was assumed for coniferous and deciduous trees, respectively. For calculation of foliage biomass a discrimination was made between deciduous and coniferous trees:

Needle mass was calculated as

$$\text{needle weight} = \exp^{-1.6386} + 2.0005 \times \log \text{bhd} - 0.5944 \times \log \text{h} \quad (1)$$

$$\text{leaf weight} = 0.0057 \times \text{bhd}^{1.9836} \quad (2)$$

where the needle and leaf weight are given in kg [37–39].

The estimation of the root biomass is supported by only a few field measurements. In a Finnish 35-year-old and in a mature 100-year-old Scots pine stand (*Pinus sylvestris L.*) the belowground biomass (located in the organic surface layer and the upper 30 cm of the mineral soil) accounted for 21% and 13.2% of total biomass, with fine roots, defined as roots with a diamterof the mineral soil) accounted for 21% and 13.2% of total biomass, where fine roots (defined as roots with a diameter < 2 mm contributed 31.8% and 15% to the belowground biomass, respectively [40]. In a modeling exercise of coupling the EFIMOD model with the module of soil organic matter ROMUL, the biomass of the fine roots was set to 10% of the coarse-root biomass [41–45].

In our model root biomass was set to 21% of the aboveground compartments, accounting for 17.4% of the total biomass. The ratio between the coarse root fraction (> 2 mm) and the fine root fraction was set to 20:1 [46].

Among uncertainties are wood density and the standard deviation of the utilized biomass expansion functions. The wood density might vary between sites; furthermore a single wood density might not adequately represent an entire tree species. The wood density is often not measured for individual sampling sites. Hence, a reference value is chosen, based on the judgment of the modeler. – The inherent uncertainty of biomass-expansion functions, as reflected in the standard deviation of its parameters, is often not propagated in the modeling exercise.

3.3. Estimating annual carbon fluxes

The input to Yasso07 calls for estimates of carbon fluxes, due to the aboveground and belowground litterfall of the standing tree biomass, mortality and harvesting (Figure 1). Especially for underground biomass compartments there are only vague figures to assess these fluxes. The ones which are applied here might be adapted intuitively for model calibration. For Scots pine and Norway spruce stands in southern Finland an annual needle turnover of 21% (turnover time 4.76 years) and 10% (turnover time 10 years), respectively, was measured, accounting for 49 to 75% of the total aboveground litter production of Scots

pine stands [47–49]. For northern Germany spruce stands a lifespan of 4.2 to 5.7 years, and a positive correlation between lifespan and altitude was reported [50, 51] . For the coniferous tree species except for larch (*Larix decidua*), we set the annual needle turnover rate to 20%; resulting in a lifespan of 5 years [52]. The foliage of deciduous trees and of larch needles are recycled annually, and the turnover time was set to one year.The possibility, that site conditions might influence the lifespan of tree needles [50], was neglected in this model exercise. The foliage of deciduous trees as well as the needles of larch are recycled annually; their turnover time was set to one year.

The belowground plant structures contribute an important fraction to annual carbon fluxes [53] Yet the magnitude of these fluxes is difficult to quantify [54]. It was claimed that the belowground net primary production of trees might exceed its aboveground counterpart and that the fine root turnover is playing a major role [55]. The fine root biomass in a boreal forest accounted for 32% of the annual net primary production. Fine roots were turned over at an average of 1.07 times per year leading to a turnover time of 0.93 years [56]. For approximately 40-year-old Norway spruce stands in Germany the turnover time of fine roots in the upper 20 *cm* of the soil ranged from 1.18 to 2.29 times a year, resulting in turnover times of 0.85 and 0.42 years, respectively [57]. – Without discrimination between either stand-age or tree species we set the fine root turnover to 0.9 years.

The modeled annual branch litterfall for Norway spruce and Scots pine in Finland was 1.25% and 2.7% of the total branch biomass, respectively. Averaging branch turnover rates of European forest sites from the IBP Woodlands Data Set [58], the annual turnover of branches was set to 2.5% [52]. – In this work the annual branch litterfall was intuitively set to 3% of the total branch mass, leading to a lifespan of 33.3 years. Only little is known about the senescence rate of coarse roots [59]. Following a common practice we set it to the same level as branch litterfall [52].

Possible biomass inputs, originating from an understory shrub- and an herbaceous plant layer, were not taken into account, because no data was available to assess these fluxes.

Without discrimination between, either tree species, or biomass compartment, the carbon content of dry matter was assumed to be 50% [52].

3.3.1. Treatment of mortality events

The National Forest Inventory and regional repeated forest resource assessments are capable of informing about tree mortality. Trees are recorded as ”dead” when they hold no living needles or leaves during the growing season, or when they have been removed and only a stump is left behind. In the simulation model CALDIS mortality is driven by a submodule. For consistently dealing with mortality events, the following assumptions about biomass fluxes were made:

- We made no distinction between natural mortality and harvesting events. Stem biomass is withdrawn from the stand, leaving behind a stump.
- The stump was assumed to have the shape of a cylinder with a diameter of bhd and a height of 20 *cm*. The stump volume $\mathrm{vol}_{\mathrm{stump}}$ was calculated as

$$vol_{\text{stump}} = r_{d/w} \times \left(\frac{\text{bhd}}{2}\right)^2 \times \pi \times 0.2 \quad (3)$$

where $\text{vol}_{\text{stump}}$ is reported in $[m^3]$ and the bhd is entered in $[m]$.

- 60% of the branch biomass and 100% of the needles/foliage remain on the plot.
- 100% of the belowground biomass remains on site.

3.4. Assigning chemical characteristics to the carbon fluxes

The Yasso07 model is based on the assumption, that the components of organic litter can be classified in 4 types, according to their decomposition characteristics [36] These components can be either totally decomposed; releasing CO_2, or can be transferred into humus. The classes are

- components soluble in a non-polar solvent, ethanol or dichloromethane (waxes),
- water soluble components (simple sugars),
- acid hydrolysable components (cellulose),
- insoluble and non-hydrolysable components (lignin).

The chemical qualities are model input parameters and differ between tree species and litter type. In case the variability of the chemical qualities within litter types of single tree species is known, the mean value and its standard deviation can be used in the model in order to reflect the uncertainty of the model parameters. A database of chemical qualities of litter types is available from the Yasso07 manual [31, appendix]. In cases were no matching data for a certain tree species were available in the database, the respective parameter was represented with values that seemed most suitable. For the chemical composition of coarse roots and branch litter the same parameters were used as for decaying stems. – In our modeling exercise, no information on the standard deviation of the parameter values was available. The standard deviation was therefore set to zero.

Considering the size of the litter particles as a physical attribute, which is affecting their decomposition [43], the diameter of stump carbon is set to the mean breast height diameter of tree species per plot. For coarse roots and branch biomass we assume a diameter of 1 *cm*. The size of all other biomass compartments is set to zero. The size limit of woody litter was set to 3 *cm*. Hence, only stump necromass with a diameter exceeding 3 *cm* was treated as woody litter by the model.

3.5. Exporting Yasso07 input files

The final product of the last 4 steps is a dataset [`Influx`] which comprises storage locations of processed data, the height of annual carbon fluxes [*ton/ha*] of every tree and biomass compartment, plus the associated decomposition qualities. Via the parameter `data_path` this dataset is merged with `FILE_LIST_key` in order to retrieve required key parameters, resulting in a dataset named `combine`.

Yasso07 input files start with time-step '0' or '1'. If a zero time-step is stated, Yasso07 uses input from time '0' to derive initial steady-state soil conditions. If the input file contains no time step '0', but starts with year '1' the input from the first year of the simulation is used to estimate the initial soil carbon pool, irrespective whether year '1' represents steady-state conditions or not [31]. – In our modeling exercise we chose the option of estimating steady-state conditions with a time step '0'.

Yasso07 simulations require only one single input file which is providing carbon flux and climate information. These two data blocks are headed by captions `[Yearly soil carbon input]` and `[Yearly climate]`. The macro `export_single_runs` is the centrepiece of the output procedure. It exports data from SAS files to text files that are directly accessible by Yasso07.

```
%macro export_single_runs;
%do s=&firstscenario %to &lastscenario;
  %do c=&firstclimate %to &lastclimate;
    %do p = &firstplot %to &lastplot;
      %do r =&firstrun %to &lastrun;

        data temp;
    set combine
    (where=(Plot_ID = &p and
            Scenario_ID = &s and
    Climate_ID = &c and
    Run_ID =&r));
          call symput('lenght_Influx',_N_);
        run;

        %LET DSID=%SYSFUNC(OPEN(temp,IN));
        %LET Observations=%SYSFUNC(ATTRN(&DSID,NOBS));
        %IF &DSID > 0 %THEN %LET RC=%SYSFUNC(CLOSE(&DSID));

          %if &Observations ne 0 %then %do;

            data _NULL_; set temp climate.IPCC_&c;
              file
     "D:\your_YASSO_input\SINGLERUN_Scn&s._Clm&c._Plt&p._Run&r..in";

              if _N_<=&lenght_Influx then do;
                if _N_=1 then put "[Yearly soil carbon input]";

                put NEW_year flux flux_std acid a_std watr w_std
    ethn e_std nsol n_std hums h_std size "# "
    comp species "Scen " Scenario_ID
    "Plot " Plot_ID "Clim " Climate_ID "Run " Run_ID;

                if _N_=&lenght_Influx then do;
                  put " ";
```

```
                put "[Yearly climate]";
              end;
            end;
            else do; /* if _N_>&lenght_Influx */
              put simyear annual_mean precsum
    month_diff "# " IPCC;
            end;
          run;

        %end;
      %end;
    %end;
  %end;
%end;
%mend export_single_runs;
```

The macro consists of one loop comprising 3 nested loops, iteratively running through every possible combination of the incrementers `scenario`, `climate`, `run`, and `plot`. A `temp` dataset is created out of the content of `combine` where the values of the incrementers match `scenario`, `climate`, `run`, and `plot`. The observation length of this dataset is stored as a macro variable [`length_Influx`]. – In our case, not all possible combinations of the incrementers represent valid data in `combine`. In this case the group of functions starting with [`%LET DSID`] returns zero as a value for `&Observations` [34], i. e., the combination of `scenario`, `climate`, `run`, and `plot` does not represent an existing data record. Hence, the next step is skipped, the next iteration of the loops starts. If the created dataset contains valid data (more than zero observations) the next [`%IF &END`] clause becomes active. A `_NULL_` dataset is created which consists of the previously created `temp` dataset, and appending, the final product of the climate calculations. So flux data and the corresponding climate data exist in one record! Then a file is created. Its name contains the current values of the incrementers. The file extension [`.in`] marks Yasso07 input files. If a `put` statement is set after the `file` statement, the output is written not to the SAS®9.2 log-file, but to the defined external output file.

The headlines, used by Yasso07 for the denomination of the subsequent data records, need to be supplied by the code. This is implemented by adding the text line `[Yearly soil carbon input]` above the first observation record. The parameters, which are subsequently output to file, are the annual carbon inputs at each time step. The information contains the mean values and their standard deviation, followed by the decomposition characteristics and their standard deviation, and finally the diameter of the litter compartments. Eventually added comments to the input lines enable an easier interpretation of the input files by the model user. Such comments can be added after the # character.

After writing out the last observation of the carbon input subset (at position `length_Influx`), a blank line is inserted, marking the end of carbon flux data. In the following line the next headline, *i.e.* `[Yearly climate]`, is added. It indicates the beginning of the climate input data. The variables which are then written to external output file are the annual mean temperature, the annual precipitation sum, and the temperature difference between the hottest and the coldest month. The data are written out for each

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time step. – After the last iteration of the central loop of the script, the export routine is completed and the macro is terminated. Thereby, individual Yasso07 input files, for each case that has been modeled in CALDIS, are created. The Yasso07 modeling runs need to be run individually, by loading the respective external files into the Yasso07 interface.

In the current modeling exercise the soil model Yasso07 was run with the following settings:

Initial soil carbon stock: The chosen option was 'steady state'. In this mode the model estimates the initial carbon stock from the incoming amount of carbon by above- and belowground litterfall. The model does not use eventually measured soil carbon stocks. The field data can therefore be used for the validation of the modeling results.

Sample size: The sample size defines how often one particular case (site) is simulated. If a sample size of '1' is chosen the model uses the most likely parameters of the decomposition model. Increasing the sample size invokes additional simulation runs where less likely parameter values are chosen. The sample size therefore allows the representation of the model uncertainty. – In our modeling exercise the sample size was set to 10.

Time: The model was run 100 time-steps with a step length of 1 year.

Size: The size of the incoming aboveground and belowground litter is affecting the decomposability of the organic matter. Smaller particles are decomposing quicker; we set the threshold to woody litter at 3 *cm*.

4. The outcome of the modeling exercise

The used regionalized climate scenarios show a warming trend in the next 100 years between 3 and 5 °C. The amplitude between the coldest and the warmest month remains constant (Figure 2).

Running the growth model CALDIS several times yields widely different results, because the probability of being affected by storms is variable. In addition, the ingrowth module contains a probability element. The by far largest impact on the standing volume has the storm module. The variability due to these stochastic processes by far exceeds the impact of the chosen climate scenarios on forest growth (Figure 3); in order to obtain a representative stem volume, the individual model runs were averaged with the statistical package SAS®.

Introducing the output of CALDIS into the soil model Yasso07 allows the estimation of the anticipated development of the soil carbon stock. Figure 4 shows an example for the temporal trend of soil carbon over 100 years and compares the effect of two climate scenarios and two dominant tree species. - In the presented example the soils would gain organic carbon. In a more realistic model run a major harvesting operation would reset the stand conditions and the soil carbon stock would be rather stable. Nevertheless, the comparison suggests that Norway spruce is able to accumulate substantial amounts of organic carbon. The climate effect is very strong. The warmer A1B scenario is reflected by smaller soil carbon stocks, because the increasing temperature stimulates the heterotrophic respiration in the soil and leads to elevated rates of CO_2-emissions. – More detailed interpretations of the modeling outcomes are given in the description of the case study area [18].

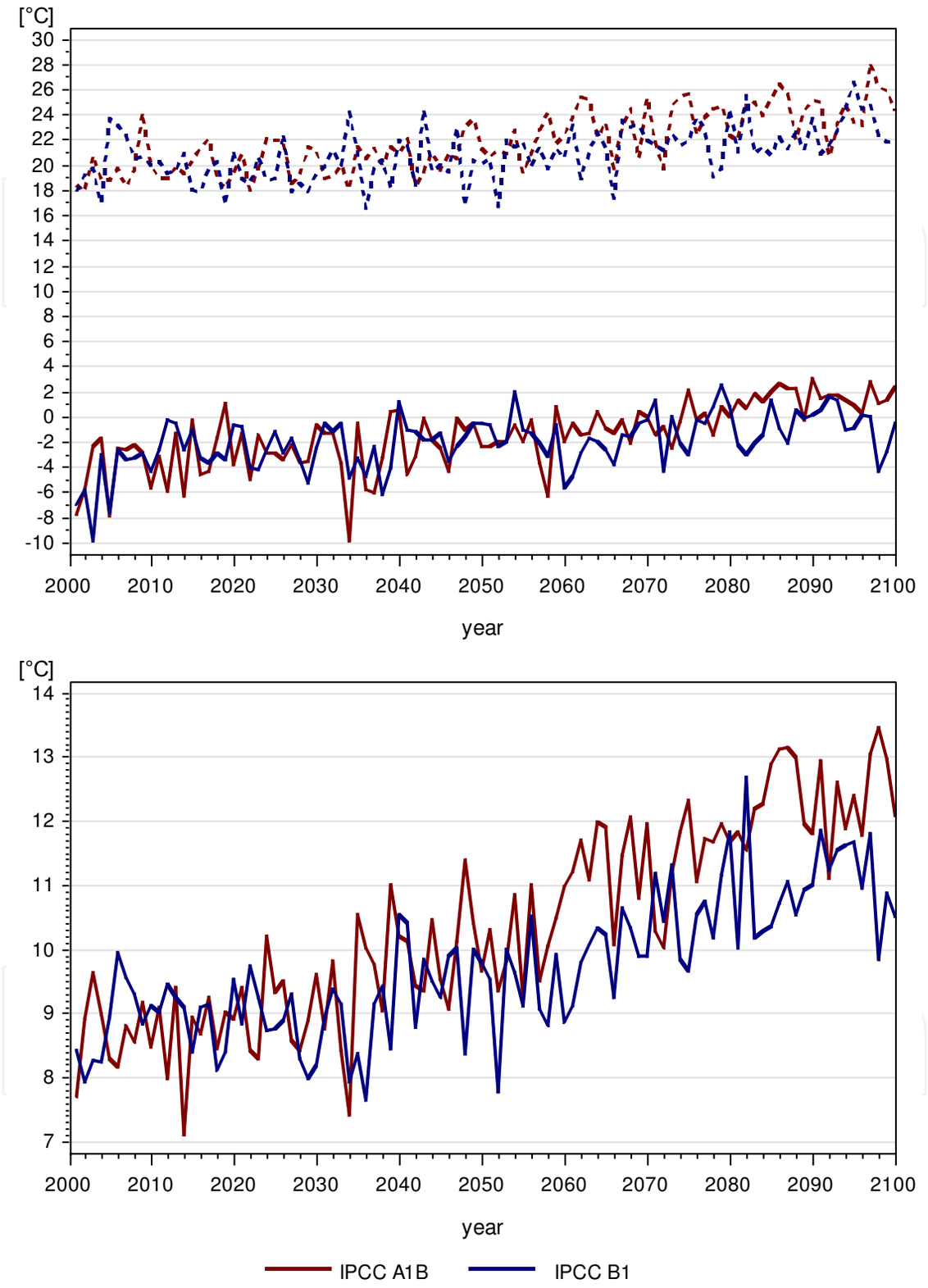


Figure 2. Difference between the coldest and the warmest month (upper panel) and mean annual air temperature (lower panel) for the test region Ossiach between the years 2000 and 2100. Blue: The IPCC climate scenario B1; red: the scenario A1B.

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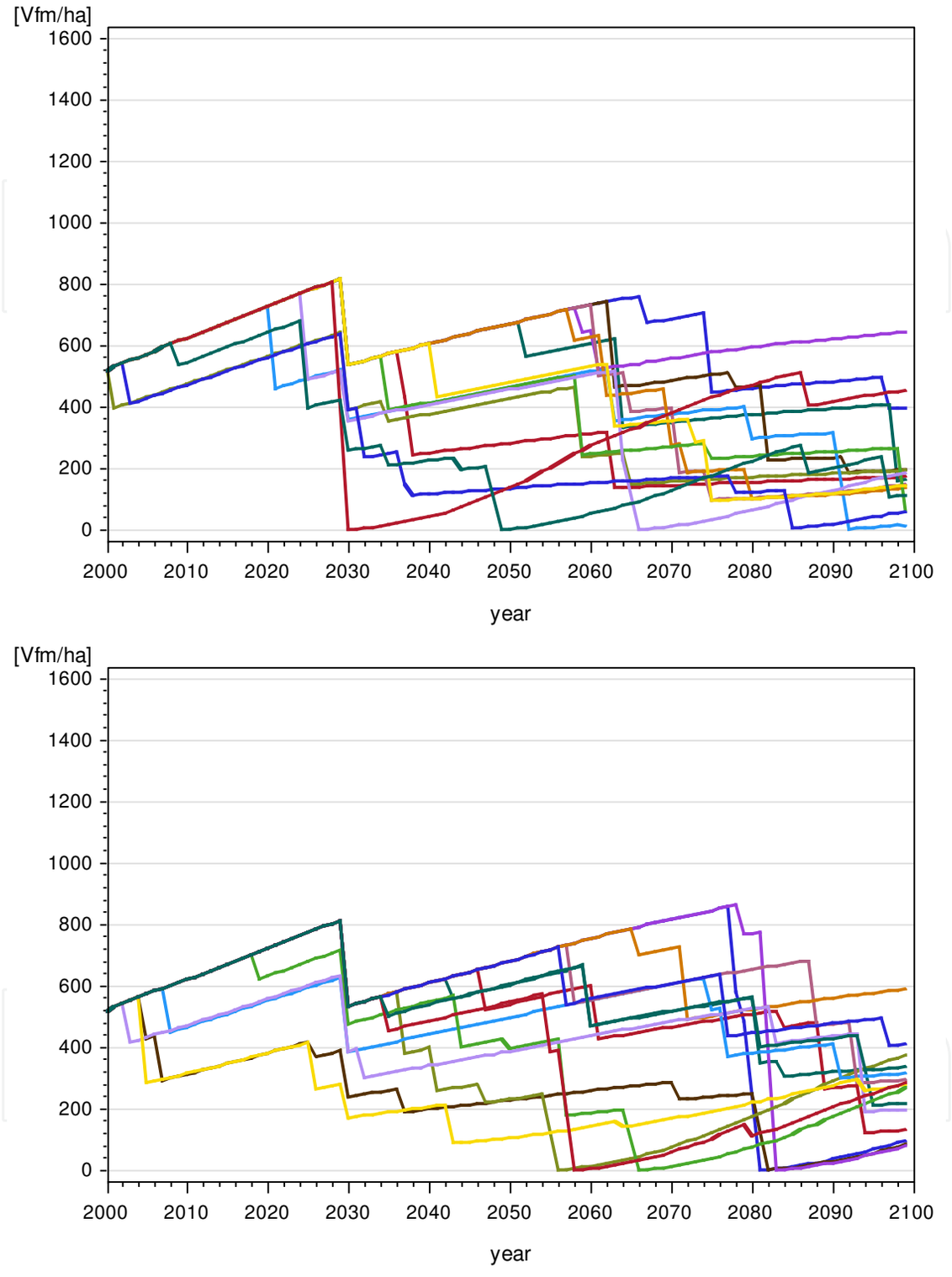


Figure 3. Simulated stem volume $[m^3/ha]$ of an example stand in the Ossiacher Tauern. Different runs of simulation model CALDIS yield widely different stocks of the stem volume at one particular site for the simulation run from year 2000 to 2100. Upper panel: forest stand experiences climate according to the IPCC scenario A1B; lower panel: forest stand experiences climate according to the IPCC scenario B1.

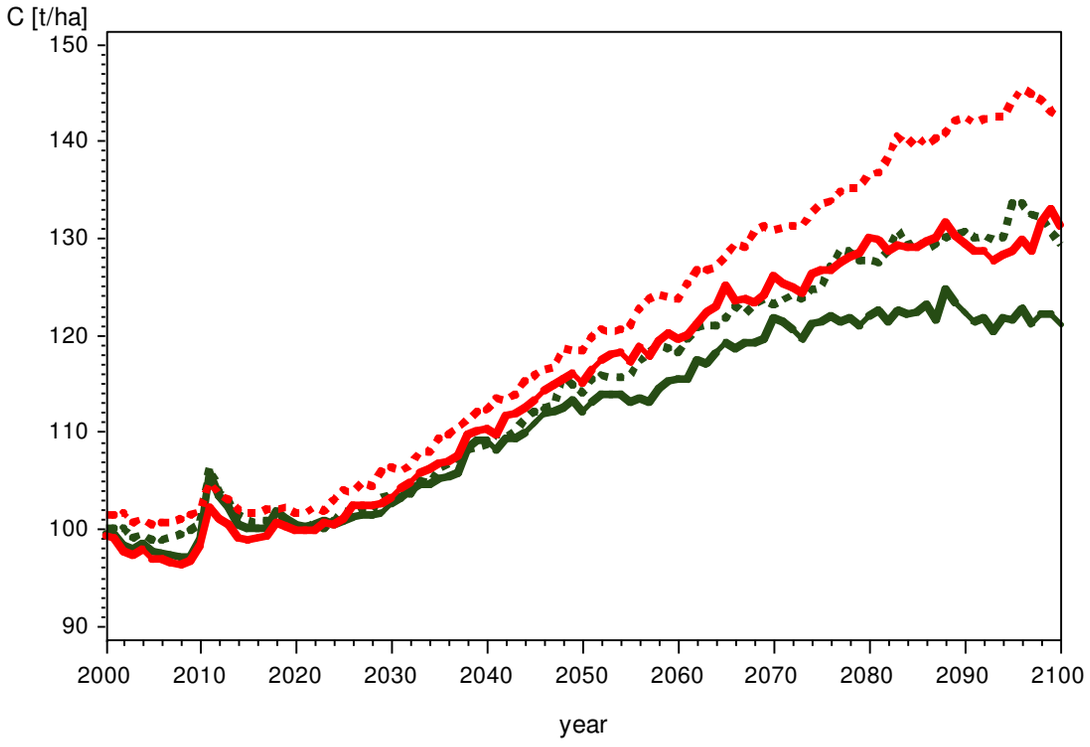


Figure 4. Simulated temporal trend of the soil carbon stock (C $[ton/ha]$) for an example stand in the Ossiacher Tauern between the year 2000 and 2100. Red: beech dominated forest, green: spruce dominated forest; full lines: climate scenario A1B; dashed lines: climate scenario B1.

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