3D-CMCC-FEM

(Coupled Model Carbon Cycle)

BioGeoChemical and Biophysical Forest Ecosystem Model

User's Guide (v.5.x)

Website: www.3d-cmcc-fem.com

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1. How to ask for the code

The 3D-CMCC-FEM (both versions: Light Use Efficiency and the fully BioGeoChemical version). Versions 5.x code are open. You can get a free copy of the code online from: (GitHub Repository) https://github.com/3D-CMCC-CNR-FEM/3D-CMCC-CNR

2. Model description

The 3D-CMCC-FEM model simulates the dynamics occurring in heterogeneous forests with different plant species, also if simultaneously composed by evergreen and deciduous, for different age, diameter, and height classes. The model is able to reproduce forests with a complex canopy structure constituted by cohorts competing with each other for light and water. The model simulates carbon fluxes, in terms of gross and net primary productivity (GPP and NPP, respectively), partitioning and allocation in the main plant compartments (stem, branch, leaf, fruit, fine and coarse root, non-structural carbon). In the recent versions, nitrogen fluxes and allocation, in the same carbon pools, are also reproduced. The 3D-CMCC-FEM also takes into account management practices, as thinning and harvest, to predict their effects on forest growth and carbon sequestration. The 3D-CMCC-FEM is written in C-programming language and divided into several subroutines. To run the model, some input data are required. The meteorological forcing variables, on a daily time step, are represented by average, minimum and maximum air temperature, shortwave solar radiation, precipitation, vapor pressure deficit (or relative humidity). The model also needs some basic information about soil, such as soil depth and texture (clay, silt and sand fractions), as well as the forest stand information referred to plant species, ages, diameters, heights and stand density. An additional input is represented by species-specific eco-physiological data for the model parameterization.

The 3D-CMCC-FEM is primarily a research tool, and many versions have been developed for particular purposes. The CNR and University of Tuscia maintain benchmark code versions for public release and update these benchmark versions periodically as new knowledge is gained on the research front. The code and executables accompanying this file represent the most recent benchmark version.

3. Referencing the 3D-CMCC-FEM versions 5.x

If you use 3D-CMCC-FEM in your research, please include the following acknowledgment in the relevant manuscript:

"*3D-CMCC-FEM, Version 5.x was provided by Alessio Collalti, from:*
- National Research Council of Italy, Institute for Agricultural and Forestry Systems in the Mediterranean (ISAFOM)
- University of Tuscia, Department for Innovation in Biological, Agro-food and Forest systems (DIBAF)

Please also reference the following citation as the most recent and complete description of the current model version:

v.4.0 (not more in use)

"A process-based model to simulate growth and dynamics in forests with complex structure: evaluation and use of 3D-CMCC Forest Ecosystem Model in a deciduous forest in Central Italy". A. Collalti, L. Perugini, T. Chiti, A. Nolè, G. Matteucci, R. Valentini. Ecological modeling 2014. https://doi.org/10.1016/j.ecolmodel.2013.09.016.

Collalti, A. "Sviluppo di un modello dinamico ecologico-forestale per foreste a struttura complessa". April 2011. PhD Thesis, PhD Advisor: Riccardo Valentini. DOI: 10.13140/RG.2.2.17900.92800.
http://dspace.unitus.it/bitstream/2067/2398/1/acollalti_tesid.pdf

v.5.1.1 (not more in use)

"Validation of 3D-CMCC Forest Ecosystem Model (v.5.1) against eddy covariance data for 10 European forest sites". A. Collalti, S. Marconi, A. Ibrom, C. Trotta, A. Anav, E. D'Andrea, G. Matteucci, L. Montagnani, B. Gielen, I. Mammarella, T. Grünwald, A. Knohl, F. Berninger, Y. Zhao, R. Valentini and M. Santini, Geosc. Model Dev., 9, 479-504, 2016. https://doi.org/10.5194/gmd-9-479-2016.

v.PSM (not more in use)

"The Role of Respiration in Estimation of Net Carbon Cycle: Coupling Soil Carbon Dynamics and Canopy Turnover in a Novel Version of 3D-CMCC Forest Ecosystem Model". S. Marconi, T. Chiti, A. Nolè, R. Valentini and A. Collalti. Forests 2017. https://doi.org/10.3390/f8060220.

v.5.4

"Thinning can reduce losses in carbon use efficiency and carbon stocks in managed forests under warmer climate". Collalti A., Trotta C., Keenan T.F., Ibrom A., Lamberty B.B., Gröte R., Vicca S., Reyer C.P.O., Migliavacca M., Veroustraete F., Anav A., Campioli M., Scoccimarro E., Šigut L., Grieco E., Cescatti A., and Matteucci G. Journal of Advances in Modelling Earth System 2018. https://doi.org/10.1029/2018MS001275.

"The sensitivity of the forest carbon budget shifts across processes along with stand development and climate change". Collalti A., Thornton P.E., Cescatti A., Rita A., Borghetti M., Nolè A., Trotta C., Ciais P., Matteucci G. Ecological Applications 2018. https://doi.org/10.1002/eap.1837.

Pellicone G. "Climate change mitigation by forests: a case study on the role of management on carbon dynamics of a pine forest in South Italy". 2018. Ph.D. Thesis.

v.5.5

"Plant respiration: Controlled by photosynthesis or biomass?" Collalti A., Tjoelker M.G., Hoch G., Mäkelä A., Guidolotti G., Heskel M., Petit G., Ryan M.G., Battipaglia G., Matteucci G., Prentice I.C. Global Change Biology. https://doi.org/10.1111/gcb.14857

If you have made any significant modifications to the code, please mention them in your manuscript.
This User's Guide is the only documentation released with 3D-CMCC-FEM.

The code itself contains extensive internal documentation, and users with specific questions about the algorithms used to estimate particular processes should read the comments in the appropriate source code files.
The file ***treemodel.c*** contains references to all the core science routines and is a good starting point for this kind of inquiry. The files ***matrix.c*** defines the data structures that are used to pass information between the process modules and includes both a short text description and the units for each internal variable.
Shall you have questions about the code, appropriate model applications, possible programming errors, etc., please read this entire guide first, then feel free to contact us.

4. How to use the 3D-CMCC-FEM

4.1 Code characteristics

3D-CMCC-FEM is primarily developed on UNIX-Linux, X-Ubuntu with Eclipse IDE Platforms and is compiled using GNU GCC 4.7.2.

IMPORTANT: Be sure to execute 3D-CMCC-FEM on a Linux machine with architecture X86_64 (64 bit), otherwise you firstly need to rebuild code to obtain the object files needed for runs.

4.2 Eclipse usage instructions

To Run the model in Eclipse CDT, using a sub-versioned version of the model simply follow these steps (be sure if you use Eclipse to have installed Git and Egit and to have an internet connection):

1) Save the 3D-CMCC-FEM Model directory in the path you are going to use as Eclipse Workspace;

2) to prevent error from netcdf libraries, open terminal:

$ sudo apt-get install netcdf-bin

$ sudo apt-get install libnetcdf-dev

3) To make the model work under Eclipse CDT (any version) using Git you shall follow this guide:

- download from terminal Git and build-essential
  - *$ sudo apt-get install build-essential*
  - *$ sudo apt-get install git*
- download from Ubuntu software center jre 7-8 or jdk (if not installed)
  - *$ sudo apt-get install default-jdk*

4) Download from eclipse site the most recent version of Eclipse IDE for C/C++ Developers

5) Open Eclipse and set your Workspace as the same path in which you've placed the Model's folder - to do so click on File, then "switch Workspace" and click on "Other..."; here input your current path;

6) File -> Import -> Git -> Projects from Git -> Clone Url and in URL please paste the code version you find over the GitHub https://github.com/3D-CMCC-CNR-FEM/3D-CMCC-FEM

For NETCDF file you need to add libraries within eclipse through:

Project->Properties->C/C++ Build->Settings->Cross G++ Linker->Libraries-> in Libraries (-l) add "netcdf"->OK

4.3 How to increase Eclipse available heap size

Some JVMs put restrictions on the total amount of memory available on the heap. If you are getting OutOfMemoryErrors while running Eclipse, the VM can be told to let the heap grow to a larger amount by passing the -vmargs command to the Eclipse launcher (http://wiki.eclipse.org/FAQ_How_do_I_increase_the_heap_size_available_to_Eclipse%3F). Here follows a short how to:

1) Search for the location of your *eclipse.ini* file (usually *usr/lib/eclipse*);

2) Open eclipse.ini using gedit command from terminal as super user (*sudo gedit eclipse.ini*);

3) BE EXTREMELY CAREFUL TO FOLLOW ECLIPSE DEVELOPERS RULES

- Each option and each argument to an option must be on its own line.

- All lines after -vmargs are passed as arguments to the JVM, so all arguments and options for eclipse must be specified before -vmargs (just like when you use arguments on the command-line).

- Any use of -vmargs on the command-line replaces all -vmargs settings in the .ini file unless –launcher .appendVmargs is specified either in the .ini file or on the command-line. (doc).

4) in line 12 change -Xms40m into -Xms512m (just replace 40 with 512 without changing the rest of the line).

5) in line 13 change -Xmx256m into -Xmx1024m (just replace 256 with 11024 without changing the rest of the line).

6) save eclipse.ini and restart eclipse.

4.6 How to work on Eclipse for bash scripts

To work in Bash Shell scripts within the ECLISPE IDE you need to install ShellED eclipse package through the web.

4.7 3D-CMCC-FEM Usage

3D-CMCC-FEM is a command line program, and its behavior is controlled by several command line options:

-i input path	i.e.: -i c:\input\directory\
-o output path	i.e.: -o c:\output\directory\
-p parameterization directory	i.e.: -i c:\parameterization\directory\
-d dataset filename stored into input directory	i.e.: -d input.txt
-m met filename list stored into input directory	i.e.: -m 1999.txt, 2003.txt, 2009.txt
-s soil filename stored into input directory	i.e.: -s soil.txt or soil.nc
-t topo filename stored into input directory	i.e.: -t topo.txt or topo.nc
-c settings filename stored into input directory	i.e.: -c settings.txt
-k CO_2 atmospheric concentration file	i.e.: -k co2_conc.txt
-n ndep file	i.e.: -n ndep.txt
-r output vars list	i.e.: -r output_vars.lst
-u benchmark path	*(for model developers)*
-h	print this help

More specifically:

-i this is not a mandatory parameter. if not used, input files will be searched where program is.

-o this is not a mandatory parameter. If not used, output files will be created where program is.

-p this is not a mandatory parameter. If not used, parameterization file will be searched where program is.

-d "*stand*" mandatory parameter

This file will be searched in input path, if specified. It can be an ASCII or NETCDF file. You can use '//' for comment it. ASCII file must have following header, separated by a comma:

Year, x, y, Age, Species, Management, N, Stool, AvDBH, Height, Lai

Please see **[SPECIES]*** section and **[MANAGEMENT]**** section to check allowed values. Same columns name applies to variables name in NETCDF version of file.

-m "*meteo*" mandatory parameter

This file will be searched in input path, if specified. It can be an ASCII or NETCDF file. You can specify a .lst (list) file if you have separated values.

List file must contain the name of NETCDF files to import, one row for variable i.e.:

6_WS_f_2000_2001_123_456.nc

6_TOT_PREC_2000_2001_123_456.nc

6_SWC_2000_2001_123_456.nc

6_TMAX_2M_2000_2001_123_456.nc

6_TMIN_2M_2000_2001_123_456.nc

6_TSOIL_2000_2001_123_456.nc

6_VPD_2000_2001_123_456.nc

6_ET_2000_2001_123_456.nc

6_LAI_2000_2001_123_456.nc

6_RADS_2000_2001_123_456.nc

ASCII file must have following header, separated by a tab (/t) :

Year Month n_days Rg_f Ta_f Tmax Tmin Rh_f Ts_f Precip SWC LAI ET WS_f

Same columns name applies to variables name in NETCDF version of file.

-s "*soil*" mandatory parameter

This file will be searched in input path, if specified. It can be an ASCII or NETCDF file. ASCII file must have following header, separated by a comma:

X,Y,LANDUSE,LAT,LON,CLAY_PERC,SILT_PERC, SAND_PERC,SOIL_DEPTH,FR,FN0,FNN,M0,LITTERC, LITTERN,SOILC,SOILN,DEADWOODC

Please see [LANDUSE] section to check allowed values. Same columns name applies to variables name in NETCDF version of file.

-t "*topography*" mandatory parameter

This file will be searched in input path, if specified. It can be an ASCII or NETCDF file.

ASCII file must have following header, separated by a comma: X,Y,ELEV

Same columns name applies to variables name in NETCDF version of file.

-c "*model setting*" mandatory parameter

This file will be searched in input path, if specified.

It must be an ASCII file. You can put comment using '//' token;

The file must contain the rows descripted in the "*Settings file*" section.

-k "*atmospheric CO2*" *concentration*" mandatory parameter only if CO2_trans in settings file is

This file will be searched in input path, if specified.

It must be an ASCII file and must have following header, separated by a tab (/t):

year CO2_ppm

setted on 'on' or 'var'	
-n "*nitrogen deposition*" mandatory parameter only if Ndep_fixed in settings file is setted on 'off'	This file will be searched in input path, if specified. It must be an ASCII file and must have following header, separated by a tab (/t): year ndep
-r	Use it if you want export variables values inside a NETCDF file.
not mandatory	You can specify more variables per row using a comma as delimiter. Each variable must have "**daily_**", "**monthly_**" or "**annual_**" prefix. i.e.: *daily_gpp,* *annual_GPP* *daily_ar* *monthly_ar* *annual_npp* In previous example, daily values for GPP and AR are exported. Monthly values for AR are exported and annual values for GPP and NPP are exported. Files will be created in output path if any or where program is.

[SPECIES]*

Following species can be used on relative column inside an ASCII dataset (without indexes)

Please note that you must use their indexes if you use a NETCDF file.

0,Fagussylvatica

1,Castaneasativa

2,Larixdecidua

3,Piceaabies

4,Pinussylvestris

5,Quercuscerris

6,Quercusilex

7,Quercusrobur

8,quercus_deciduous

9,quercus_evergreen

[MANAGEMENT]**

Following type of management can be used on relative column inside as ASCII dataset (without indexes). Please note that you must use their indexes if you use a NETCDF file.

T is for timber

C is for coppice (under development)

0,T

1,C

[LANDUSE]***

Following type of landuse can be used on relative column inside as ASCII dataset (without indexes).

Please note that you must use their indexes if you use a NETCDF file.

F is for forest

Z is for crop (currently not implemented)

0,F
1,Z

5. Run the model

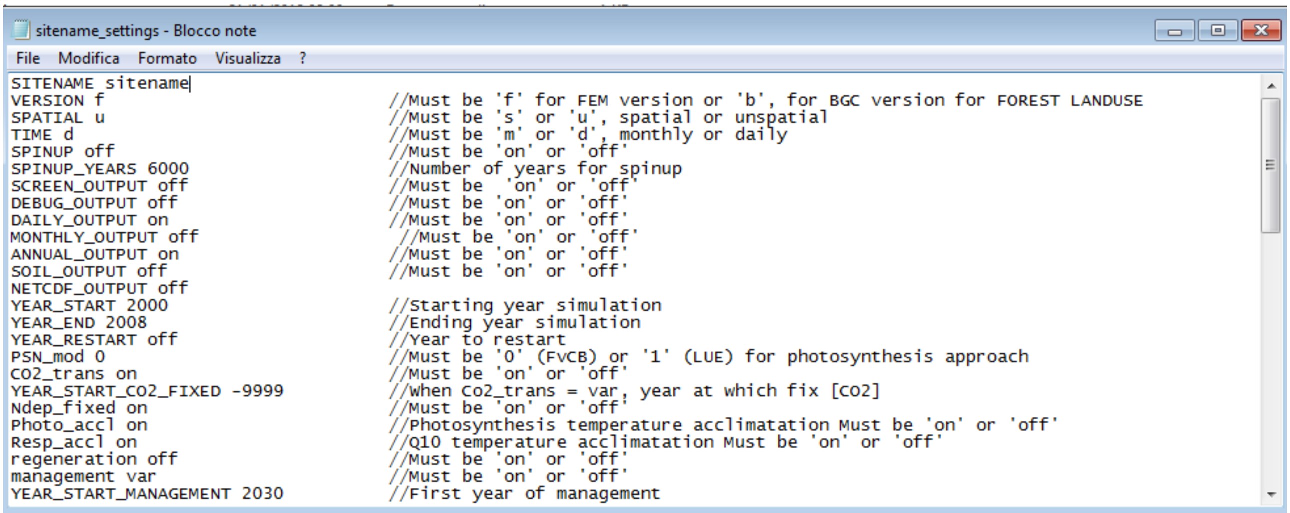
Be sure to set the right arguments passed to the project and go into bin directory:

cd bin

Run executable with default parameters:

3D-CMCC-Forest-Model -i input -o output -p parameterization -d sitename_stand.txt
-m sitename_meteo_firstyear.txt -s sitename_soil.txt -t sitename_topo.txt
-c sitename_settings.txt -k CO2_hist.txt > log.txt

6. Settings file



```
SITENAME sitename
VERSION f                          //Must be 'f' for FEM version or 'b', for BGC version for FOREST LANDUSE
SPATIAL u                          //Must be 's' or 'u', spatial or unspatial
TIME d                             //Must be 'm' or 'd', monthly or daily
SPINUP off                         //Must be 'on' or 'off'
SPINUP_YEARS 6000                  //Number of years for spinup
SCREEN_OUTPUT off                  //Must be  'on' or 'off'
DEBUG_OUTPUT off                   //Must be 'on' or 'off'
DAILY_OUTPUT on                    //Must be 'on' or 'off'
MONTHLY_OUTPUT off                  //Must be 'on' or 'off'
ANNUAL_OUTPUT on                   //Must be 'on' or 'off'
SOIL_OUTPUT off                    //Must be 'on' or 'off'
NETCDF_OUTPUT off
YEAR_START 2000                    //Starting year simulation
YEAR_END 2008                      //Ending year simulation
YEAR_RESTART off                   //Year to restart
PSN_mod 0                          //Must be '0' (FvCB) or '1' (LUE) for photosynthesis approach
CO2_trans on                       //Must be 'on' or 'off'
YEAR_START_CO2_FIXED -9999         //When Co2_trans = var, year at which fix [CO2]
Ndep_fixed on                      //Must be 'on' or 'off'
Photo_accl on                      //Photosynthesis temperature acclimatation Must be 'on' or 'off'
Resp_accl on                       //Q10 temperature acclimatation Must be 'on' or 'off'
regeneration off                   //Must be 'on' or 'off'
management var                     //Must be 'on' or 'off'
YEAR_START_MANAGEMENT 2030         //First year of management
```

Example of settings file

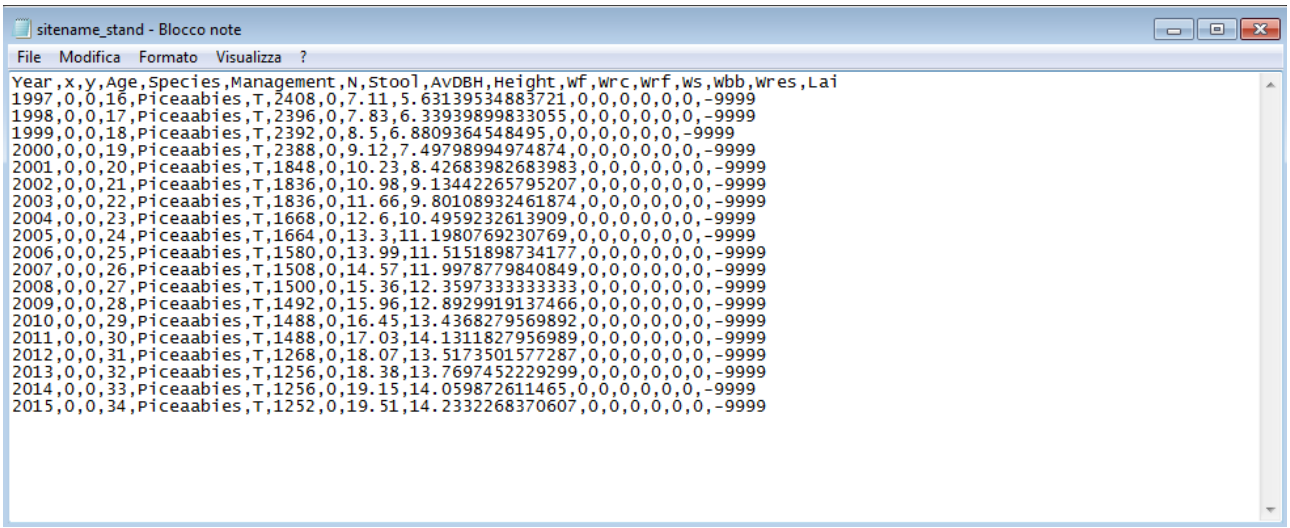
The file "***sitename_settings.txt***" permits to set the model run, choosing:

SITENAME	Name of site
VERSION	Must be 'f' for FEM version or 'b', for BGC version for FOREST LANDUSE
SPATIAL	Must be 's' or 'u', spatial or un-spatial
TIME	Must be 'm' or 'd', monthly or daily
SPINUP	Must be 'on' or 'off'
SPINUP_YEARS	Number of years for spin-up (*under development*)
SCREEN_OUTPUT	Must be 'on' or 'off'
DEBUG_OUTPUT	Must be 'on' or 'off'
DAILY_OUTPUT	Must be 'on' or 'off'
MONTHLY_OUTPUT	Must be 'on' or 'off'
ANNUAL_OUTPUT	Must be 'on' or 'off'
SOIL_OUTPUT	Must be 'on' or 'off'
NETCDF_OUTPUT	Must be 'off'
YEAR_START	Starting year simulation
YEAR_END	Ending year simulation
YEAR_RESTART	Year to restart. Must be 'off'

PSN_mod	Must be '0' (FvCB version) or '1' (LUE version) for photosynthesis approach
CO2_trans	Must be 'on' or 'off'
YEAR_START_CO2_FIXED	-9999 . When Co2_trans = var, year at which fix [CO2]
Ndep_fixed	Must be 'on' or 'off' (*under development*)
Photo_accl	Photosynthesis temperature acclimation Must be 'on' or 'off'
Resp_accl	Q10 temperature acclimation. Must be 'on' or 'off'
regeneration	Must be 'on' or 'off'
management	Must be 'on' or 'off'
YEAR_START_MANAGEMENT	First year of management
Progn_Aut_Resp	Prognostic autotrophic respiration. Must be 'on' or 'off', if off Y values are used
SIZECELL	Its value must be within 10 and 100 (unity measure is meter: 10 = 10x10 = 100m^{-2}2)
Y 0.48	Fixed_Aut_Resp_rate Assimilate use efficiency-Respiration rate-GPP/NPP
CO2CONC 368.865	CO2 concentration refers to 2000 as ISIMIP PROTOCOL
CO2_INCR 0.01	1% increment
INIT_FRAC_MAXASW 1	0.1 Minimum fraction of asw based on maxasw (wilting point) (unchanged)
TREE_LAYER_LIMIT	Define differences among tree heights in meters classes to d define number of layers in un-spatial version
SOIL_LAYER	Define soil layer/s to consider
THINNING_REGIME	Thinning regime (Above or Below)
REPLANTED_SPECIES	Species name of replanted trees (mandatory)
REPLANTED_MANAGEMENT	(T) management of replanted trees (should be only T) (mandatory)
REPLANTED_TREE	Number of replanted trees (mandatory)
REPLANTED_AGE	(yr) age of replanted trees (mandatory)
REPLANTED_AVDBH	(cm) average dbh of replanted trees (mandatory)
REPLANTED_LAI	($m^2 m^{-2}$) LAI for replanted trees (mandatory for evergreen useless for deciduous)
REPLANTED_HEIGHT	(m) height of replanted trees (mandatory)
REPLANTED_WS	(tDM ha^{-1}) stem biomass of replanted trees (optional)
REPLANTED_WCR	(tDM ha^{-1}) coarse root biomass of replanted trees (optional)

REPLANTED_WFR	(tDM ha^{-1}) fine root biomass of replanted trees (optional)
REPLANTED_WL	(tDM ha^{-1}) leaf biomass of replanted trees (optional for evergreen if LAI!= 0, otherwise useless)
REPLANTED_WBB	(tDM ha^{-1}) branch biomass of replanted trees (optional)
REGENERATION_SPECIES none	NOT USED it comes from species that produces seeds
REGENERATION_MANAGEMENT	(T) management of replanted trees (should be only T) (mandatory)
REGENERATION_N_TREE -9999	number of replanted trees (mandatory) (NOT USED)
REGENERATION_AGE 1	(yr) age of regeneration trees (mandatory) (SHOULD BE ALWAYS 1)
REGENERATION_AVDBH	(cm) average dbh of regeneration trees (mandatory)
REGENERATION_LAI 0.0	(m^{2}m^{-2}) LAI for regeneration trees (mandatory for evergreen, useless for deciduous)
REGENERATION_HEIGHT	(m) height of replanted trees (mandatory)
REGENERATION_WS 0.0	(tDM ha^{-1}) stem biomass of regeneration trees (optional)
REGENERATION_WCR 0.0	(tDM/ha) coarse root biomass of regeneration trees (optional)
REGENERATION_WFR 0.0	(tDM ha^{-1}) fine root biomass of regeneration trees (optional)
REGENERATION_WL 0.0	(tDM ha^{-1}) leaf biomass of regeneration trees (optional for evergreen if LAI!= 0, otherwise useless)
REGENERATION_WBB	(tDM ha^{-1}) branch biomass of regeneration trees (optional)
PRUNING	Must be 'on' or 'off'
IRRIGATION	Must be 'on' or 'off'

6.1 Initialization file


sitename_stand - Blocco note

File Modifica Formato Visualizza ?

```
Year,x,y,Age,Species,Management,N,Stool,AvDBH,Height,Wf,Wrc,Wrf,Ws,Wbb,Wres,Lai
1997,0,0,16,Piceaabies,T,2408,0,7.11,5.63139534883721,0,0,0,0,0,0,-9999
1998,0,0,17,Piceaabies,T,2396,0,7.83,6.33939899833055,0,0,0,0,0,0,-9999
1999,0,0,18,Piceaabies,T,2392,0,8.5,6.8809364548495,0,0,0,0,0,0,-9999
2000,0,0,19,Piceaabies,T,2388,0,9.12,7.49798994974874,0,0,0,0,0,0,-9999
2001,0,0,20,Piceaabies,T,1848,0,10.23,8.42683982683983,0,0,0,0,0,0,-9999
2002,0,0,21,Piceaabies,T,1836,0,10.98,9.13442265795207,0,0,0,0,0,0,-9999
2003,0,0,22,Piceaabies,T,1836,0,11.66,9.80108932461874,0,0,0,0,0,0,-9999
2004,0,0,23,Piceaabies,T,1668,0,12.6,10.4959232613909,0,0,0,0,0,0,-9999
2005,0,0,24,Piceaabies,T,1664,0,13.3,11.1980769230769,0,0,0,0,0,0,-9999
2006,0,0,25,Piceaabies,T,1580,0,13.99,11.5151898734177,0,0,0,0,0,0,-9999
2007,0,0,26,Piceaabies,T,1508,0,14.57,11.9978779840849,0,0,0,0,0,0,-9999
2008,0,0,27,Piceaabies,T,1500,0,15.36,12.3597333333333,0,0,0,0,0,0,-9999
2009,0,0,28,Piceaabies,T,1492,0,15.96,12.8929919137466,0,0,0,0,0,0,-9999
2010,0,0,29,Piceaabies,T,1488,0,16.45,13.4368279569892,0,0,0,0,0,0,-9999
2011,0,0,30,Piceaabies,T,1488,0,17.03,14.1311827956989,0,0,0,0,0,0,-9999
2012,0,0,31,Piceaabies,T,1268,0,18.07,13.5173501577287,0,0,0,0,0,0,-9999
2013,0,0,32,Piceaabies,T,1256,0,18.38,13.7697452229299,0,0,0,0,0,0,-9999
2014,0,0,33,Piceaabies,T,1256,0,19.15,14.059872611465,0,0,0,0,0,0,-9999
2015,0,0,34,Piceaabies,T,1252,0,19.51,14.2332268370607,0,0,0,0,0,0,-9999
```

Example of stand file

The first required input file is called the "***sitename_stand.txt***". It provides information about the stand conditions.

Example for a cell resolution of 10 x 10 meters cell X = 0, Y = 0:

Year,x,y,Age,Species,Management,N,Stool,AvDBH,Height,Wf,Wrc,Wrf,Ws,Wbb,Wres,Lai

1997,0,0,16,Piceaabies,T,2408,0,7.11,5.63139534883721,0,0,0,0,0,0,-9999
..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..
..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..,..
2015,0,0,34,Piceaabies,T,1252,0,19.51,14.2332268370607,0,0,0,0,0,0,-9999

The text file must be created following this logic architecture

- for each tree height class define the number of age classes and their values
-- for each height->dbh class
--- for each height->dbh->age class
---- for each height->dbh->age->species class define its state variables:

- **Year**: Reference year
- **X,Y**: 0,0
- **Age**: Age of trees (years)
- **Species**: Name of specie
- **Management**: (T = timber, C = coppice)
- **N**: N of trees per area for that class (Num tree cell size^{-1})
- **Stool**: N of stool per area (if Management is set to C) (Num tree cell size^{-1})
- **AvDBH**: Average diameter at breast height (cm) for that class
- **Height**: Tree height (m) for that class
- **Wf**: 0.0 (foliage biomass in tDM ha^{-1}) for that class
- **Wrc**: 0.0 (coarse root biomass in tDM ha^{-1}) for that class
- **Wrf**: 0.0 (fine root biomass in tDM ha^{-1}) for that class
- **Ws**: 0.0 (stem biomass in tDM ha^{-1}) for that class
- **Wbb**: 0.0 (branch and bark biomass in tDM ha^{-1}) for that class
- **Wres**: 0.0 (reserve in tDM ha^{-1}) for that class
- **LAI**: Leaf area index (m^2 m^{-2}) for that class

7. Parameterization file

The parameterization file is the species eco-physiological constants file, named with specie to simulate (e.g."***Fagussylvatica.txt***").

Comments are allowed in the parameter file. Comments can appear almost anywhere, must begin with two forward slash characters '//', at the end of the line. Example parameter files are provided. Parameter definition and its value must be separated by one-tab character.

It contains the following parameters:

LIGHT_TOL	*Light Tolerance 4 = very shade intolerant (canopy coverage = 90%), 3 = shade intolerant (canopy coverage 100%), 2 = shade tolerant (canopy coverage = 110%), 1 = very shade tolerant (canopy coverage = 120%)*
PHENOLOGY	*0.1 = deciduous broadleaf, 0.2 = deciduous needle leaf, 1.1 = broad leaf evergreen, 1.2 = needle leaf evergreen*
ALPHA	*Canopy quantum efficiency (molC molPAR^{-1})*
EPSILONgCMJ	*Light Use Efficiency (gC MJ^{-1}) (used if ALPHA is not available)*
K	*Extinction coefficient for absorption of PAR by canopy*
ALBEDO	*Canopy albedo*
INT_COEFF	*Precipitation interception coefficient*
SLA_AVG0	*Average Specific Leaf Area m^2 KgC^{-1} for sunlit/shaded leaves (juvenile)*
SLA_AVG1	*Average Specific Leaf Area m^2 KgC^{-1} for sunlit/shaded leaves (mature)*
TSLA	*Age at which SLA_AVG = (SLA_AVG1 + SLA_AVG0)/2*
SLA_RATIO	*(DIM) ratio of shaded to sunlit projected SLA*
LAI_RATIO	*(DIM) all-sided to projected leaf area ratio*
FRACBB0	*Branch and Bark fraction at age 0 (m^2 Kg^{-1})*
FRACBB1	*Branch and Bark fraction for mature stands (m^2 Kg^{-1})*
TBB	*Age at which fracBB = (FRACBB0 + FRACBB1)/2*
RHO0	*Minimum Basic Density for young Trees (tDM m^{-3})*
RHO1	*Maximum Basic Density for mature Trees (tDM m^{-3})*
TRHO	*Age at which rho = (RHOMIN + RHOMAX)/2*
FORM_FACTOR	*Stem form factor (adim)*
COEFFCOND	*Define stomatal response to VPD in m sec^{-1}*
BLCOND	*Canopy Boundary Layer conductance m sec^{-1}*
MAXCOND	*Maximum Leaf Conductance in m sec^{-1}*

CUTCOND	*Cuticular conductance in m sec^{-1}*
MAXAGE	*Maximum tree age (years)*
RAGE	*Relative Age to give fAGE = 0.5*
NAGE	*Power of relative Age in function for Age*
GROWTHTMIN	*Minimum temperature for growth °C*
GROWTHTMAX	*Maximum temperature for growth °C*
GROWTHTOPT	*Optimum temperature for growth °C*
GROWTHSTART	*Thermic sum value for starting growth in °C*
MINDAYLENGTH	*Minimum day length for phenology (days)*
SWPOPEN	*Soil water potential open (MPa)*
SWPCLOSE	*Soil water potential close (MPa)*
OMEGA_CTEM	*Allocation parameter control the sensitivity of allocation to changes in water and light availability*
S0CTEM	*Parameter controlling allocation to stem*
R0CTEM	*Parameter controlling allocation to root*
F0CTEM	*Parameter controlling allocation to foliage*
FRUIT_PERC	*%age of npp to fruit*
CONES_LIFE_SPAN	*Life span for cones (years)*
FINE_ROOT_LEAF	*Allocation new fine root C:new leaf (ratio)*
STEM_LEAF	*Allocation new stem C:new leaf (ratio)*
COARSE_ROOT_STEM	*Allocation new coarse root C:new stem (ratio)*
LIVE_TOTAL_WOOD	*Allocation new live wood C:new total wood C (ratio)*
N_RUBISCO	*Fraction of leaf N in Rubisco (ratio)*
CN_LEAVES	*CN of leaves (kgC kgN^{-1})*
CN_FALLING_LEAVES	*CN of leaf litter (kgC kgN^{-1})*
CN_FINE_ROOTS	*CN of fine roots (kgC kgN^{-1})*
CN_LIVEWOODS	*CN of live woods (kgC kgN^{-1})*
CN_DEADWOOD	*CN of dead woods (kgC kgN^{-1})*
LEAF_LITT_LAB_FRAC	*leaf litter labile fraction (dimension lees)*
LEAF_LITT_CEL_FRAC	*leaf litter cellulose fraction (dimension lees)*
LEAF_LITT_LIGN_FRAC	*leaf litter lignin fraction (dimension lees)*

FROOT_LITT_LAB_FRAC	*fine root litter labile fraction (dimension lees)*
FROOT_LITT_CEL_FRAC	*fine root litter* cellulose fraction *(dimension lees)*
FROOT_LITT_LIGN_FRAC	*fine root litter* lignin fraction *(dimension lees)*
DEADWOOD_CEL_FRAC	*dead wood litter cellulose fraction (dimension lees)*
DEADWOOD_LIGN_FRAC	*dead wood litter* lignin fraction *(dimension lees)*
BUD_BURST	*Days of bud burst at the beginning of growing season (only for deciduous) (days)*
LEAF_FALL_FRAC_GROWING	*Proportions of the growing season of leaf fall*
LEAF_FINEROOT_TURNOVER	*Average yearly leaves and fine root turnover rate*
LIVEWOOD_TURNOVER	*Annual yearly live wood turnover rate*
SAPWOOD_TURNOVER	*Annual yearly live wood turnover rate*
DBHDCMAX	*Maximum dbh crown diameter relationship when minimum density*
DBHDCMIN	*Minimum dbh crown diameter relationship when maximum density*
SAP_A	*a coefficient for sapwood*
SAP_B	*b coefficient for sapwood*
SAP_LEAF	sapwood_max leaf area ratio in pipe model *(m^2 m^{-2})*
SAP_WRES	*Sapwood-Reserve biomass ratio used if no Wres data are available*
STEMCONST_P	*Constant in the stem mass vs. diameter relationship*
STEMPOWER_P	*Power in the stem mass vs. diameter relationship*
CRA	*Chapman-Richards a parameter (maximum height, meter)*
CRB	*Chapman-Richards b parameter*
CRC	*Chapman-Richards c parameter*
HDMAX_A	*A parameter for Height (m) to Base diameter (m) ratio MAX*
HDMAX_B	*B parameter for Height (m) to Base diameter (m) ratio MAX*
HDMIN_A	*A parameter for Height (m) to Base diameter (m) ratio MIN*
HDMIN_B	*B parameter for Height (m) to Base diameter (m) ratio MIN*
CROWN_FORM_FACTOR	*Crown form factor* (0 = cylinder, 1 = cone, 2 = sphere, 3 = ellipsoid)
CROWN_A	*Crown a parameter*
CROWN_B	*Crown b parameter*
MAXSEED	*Maximum seeds number (see TREEMIG)*
MASTSEED	*Masting year (see TREEMIG)*

WEIGHTSEED	*Single fruit weight in g*
SEXAGE	*Age for sexual maturity*
GERMCAPACITY	*Geminability rate (%)*
ROTATION	*Rotation for final harvest (based on tree age)*
THINNING	*Thinning regime (based on year simulation)*
THINNING_REGIME	*Thinning regime (0 = above, 1 = below)*
THINNING_INTENSITY	*Thinning intensity (% of Basal Area/N-tree to remove)*

8. Input files

8.1 Overview

The 3D-CMCC-FEM model uses at least six input files, *meteo*, *soil*, *topo*, *CO_2* and *management* each time it is executed. A brief description of all files is given first, followed by detailed discussions of each file.

8.2 **Meteorological Data File**

sitename_meteo_firstyear - Blocco note

File Modifica Formato Visualizza ?

Year	Month	n_days	Rg_f	Ta_f	Tmax	Tmin	RH_f	Ts_f	Precip	SWC	LAI	ET	WS_f
2000	1	1	2.44	-6.09	-0.93	-8.33	98.02	-9999	0.26	-9999	-9999	-9999	0.86
2000	1	2	2.46	-5.26	-4.14	-7.02	97.35	-9999	0.46	-9999	-9999	-9999	1.24
2000	1	3	1.34	-3.17	-1.79	-4.61	95.19	-9999	0.82	-9999	-9999	-9999	2.27
2000	1	4	2.17	-2.91	-1.50	-3.82	93.40	-9999	0.81	-9999	-9999	-9999	2.22
2000	1	5	1.70	-2.27	0.07	-4.47	89.70	-9999	3.68	-9999	-9999	-9999	3.14
2000	1	6	3.77	-2.62	2.97	-5.25	94.13	-9999	0.11	-9999	-9999	-9999	1.05
2000	1	7	2.18	-4.14	-2.79	-6.31	93.62	-9999	0.28	-9999	-9999	-9999	1.93
2000	1	8	2.22	-2.57	-0.85	-3.42	92.76	-9999	0.27	-9999	-9999	-9999	2.14
2000	1	9	2.32	-3.48	-2.24	-4.32	95.19	-9999	0.22	-9999	-9999	-9999	1.84
2000	1	10	0.86	-3.85	-2.42	-4.88	97.11	-9999	1.65	-9999	-9999	-9999	1.30
2000	1	11	3.14	-4.73	-2.79	-7.21	87.43	-9999	0.51	-9999	-9999	-9999	0.69
2000	1	12	3.56	-6.70	-0.01	-9.39	92.75	-9999	0.00	-9999	-9999	-9999	1.44
2000	1	13	3.15	-7.58	-4.70	-9.72	92.36	-9999	0.00	-9999	-9999	-9999	2.69
2000	1	14	3.46	-5.62	-4.36	-6.80	92.84	-9999	0.00	-9999	-9999	-9999	2.12
2000	1	15	2.61	-5.97	-4.22	-6.94	93.82	-9999	1.36	-9999	-9999	-9999	1.39
2000	1	16	2.81	-6.62	-5.33	-7.32	93.20	-9999	2.45	-9999	-9999	-9999	2.14
2000	1	17	0.45	-2.92	0.02	-6.81	96.76	-9999	13.59	-9999	-9999	-9999	4.51
2000	1	18	2.68	-4.20	-2.58	-5.36	91.68	-9999	9.38	-9999	-9999	-9999	4.76
2000	1	19	2.80	-6.71	-4.72	-7.72	88.48	-9999	6.48	-9999	-9999	-9999	4.57
2000	1	20	2.98	-5.95	-2.94	-7.84	89.69	-9999	8.38	-9999	-9999	-9999	3.95
2000	1	21	1.94	-6.73	-2.65	-11.12	93.60	-9999	19.68	-9999	-9999	-9999	5.09
2000	1	22	3.81	-11.06	-9.16	-13.18	90.74	-9999	1.52	-9999	-9999	-9999	2.39
2000	1	23	1.56	-10.10	-6.59	-14.29	94.77	-9999	4.19	-9999	-9999	-9999	2.02
2000	1	24	5.21	-13.23	-10.87	-15.46	96.40	-9999	0.47	-9999	-9999	-9999	1.78
2000	1	25	4.86	-12.51	-7.03	-15.51	95.56	-9999	0.51	-9999	-9999	-9999	1.60

Example of meteo file

The second required input file is the meteorological data file, which is named using the start year of simulation (e.g. "***sitename_meteo_2000.txt***"), containing the daily meteorological data.

Years of simulation depends on the number years included in the met file.

Some met data are mandatory: temperature, precipitation, vapor pressure deficit (or relative humidity) and short-wave solar radiation, whereas others are optional.

If the model runs in "spatial version" daily or monthly LAI values are mandatory otherwise they are not considered in processes. Each variable must be separated by one-tab character. Model considers leap years, so 29th of February has to be included.

Example for year 2007-200x in daily/un-spatial version:

Year	*Month*	*n_days*	*Rg_f*	*Ta_f*	*Tmax*	*Tmin*	*VPD_f*	*Ts_f*	*Precip*	*SWC*	*LAI*	*ET*	*WS_f*
2007	*1*	*1*	*5.1*	*-9999*	*13.1*	*7.1*	*0.2*	*7.8*	*1*	*-9999*	*0*		
2007	*1*	*2*	*6.1*	*-9999*	*10.4*	*5.8*	*0.2*	*6.3*	*0.2*	*0.27*	*0*		
2007	*1*	*3*	*6.1*	*-9999*	*9.9*	*3.1*	*0.2*	*3.3*	*0*	*0.39*	*0*		
2007	*1*	*4*	*6.1*	*-9999*	*10*	*1.9*	*0.2*	*0.5*	*0*	*0.2*	*0*		

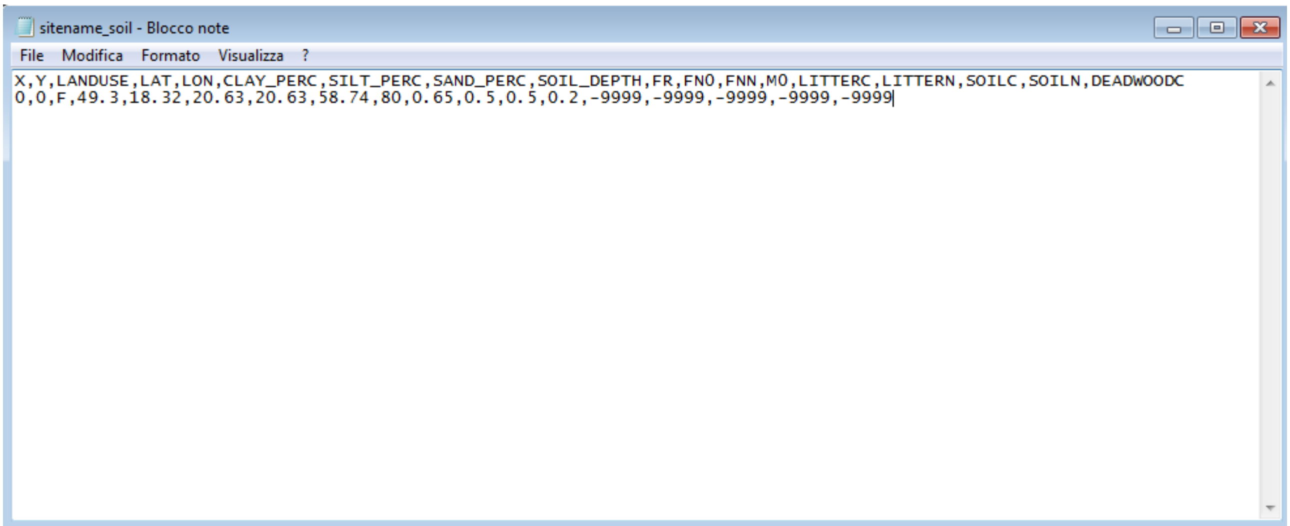
…

Variables:

- **Rg_f**: Mean daily global radiation (MJ m^{-2} day^{-1})
- **Ta_f**: Daily average temperature (°C)
- **Tmax:** Daily Maximum temperature (°C)
- **Tmin:** Daily Minimum temperature (°C)
- **VPD_f** or **RH_f:** Daily Vapor Pressure Deficit (mbar-hPa) or Relative Humidity (%)
- **Ts_f**: Daily Soil temperature (°C)
- **Precip**: Cumulated daily precipitation (mm day^{-1})
- **SWC**: Soil water content (mm m^{-2})
- **LAI**: Leaf area Index (m^2 m^{-2}) (Only in spatial version)
- **ET**: Evapotranspiration (mm m^{-2} day^{-1})
- **WS_f**: Windspeed (m sec^{-1})

NO DATA = -9999

8.3 **Soil file**



Example of soil file

The fourth required input file is "***sitename_soil.txt***". It contains information about soil and fertility of the test site.

Comments are allowed in the parameter file. Comments can appear almost anywhere, must begin with two forward slash characters '//', at the end of the line. Example parameter files are provided.

In general, the format of parameters file is one parameter per line, with the parameter name being enclosed in double quotes, with a tab character separating the parameter name and its value.

<u>IMPORTANT</u>: Values are referred to the *SIZECELL* dimensions specified in the setting.txt file (e.g. if SIZECELL = 100 meters -> tC ha^{-1}).

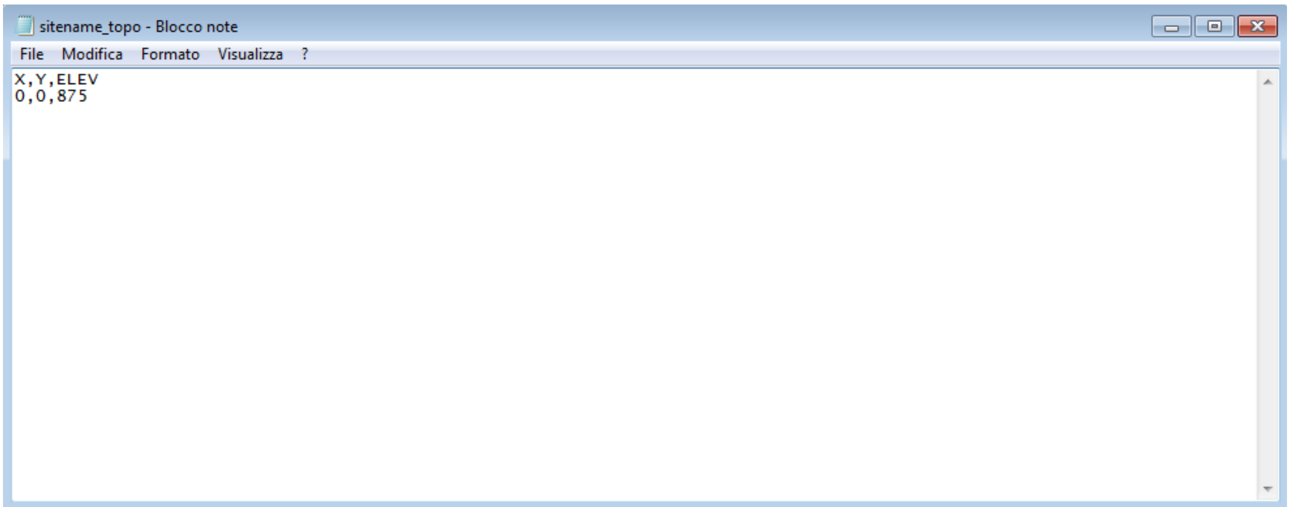
It contains the following parameters:

X,Y,LANDUSE,LAT,LON,CLAY_PERC,SILT_PERC,SAND_PERC,SOIL_DEPTH,FR,FN0,FNN,M,LITTERC,
LITTERN,SOILC,SOILN,DEADWOODC
0,0,F,49.3,18.32,20.63,20.63,58.74,80,0.65,0.5,0.5,0.2,-9999,-9999,-9999,-9999,-9999

- **LANDUSE**:	see the 'LANDUSE' section
- **LAT**:	Latitude (°)
- **LON**:	Longitude (°)
- **CLAY_PERC**:	Soil clay (%)
- **SILT_PERC**:	Soil silt (%)
- **SAND_PERC**:	Soil sand (%)

- **SOIL_DEPTH**: Soil depth (cm)
- **FR**: Fertility rating (dim)
- **FN0**: Value of fertility modifier when FR=0 (dim)
- **FNN**: Power of (1-FR) in fertility modifier (dim)
- **M0**: Value of 'm' when FR=0 (dim)
- **LITTERC**: Litter carbon
- **LITTERN**: Litter nitrogen
- **SOILC**: Soil carbon
- **SOILN**: Soil nitrogen
- **DEADWOODC**: Dead wood carbon

8.4 <u>Topo file</u>



Example of topo file

The fifth required input file is "***sitename_topo.txt***". It contains information about topography of the test site.

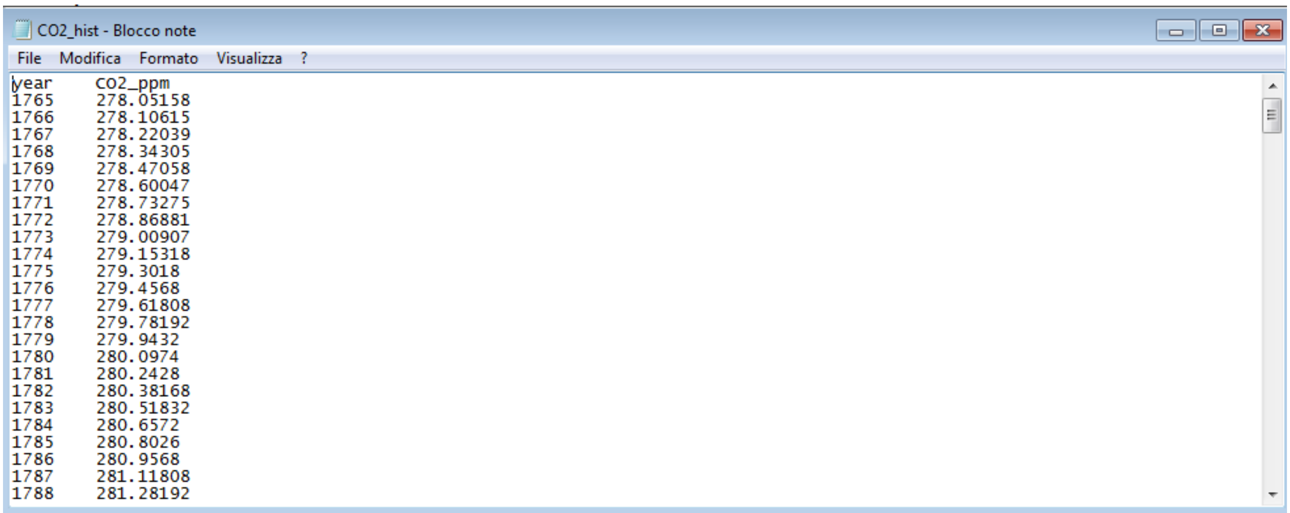
Comments are allowed in the parameter file. Comments can appear almost anywhere, must begin with two forward slash characters '//', at the end of the line. Example parameter files are provided.

In general, the format of parameters file is one parameter per line, with the parameter name being enclosed in double quotes, with a tab character separating the parameter name and its value.

It contains the following parameters:

- **X**: 0
- **Y**: 0
- **ELEV**: Elevation from ancillary data (m)

8.5 <u>CO_2 file</u>



CO2_hist - Blocco note

File Modifica Formato Visualizza ?

year	co2_ppm
1765	278.05158
1766	278.10615
1767	278.22039
1768	278.34305
1769	278.47058
1770	278.60047
1771	278.73275
1772	278.86881
1773	279.00907
1774	279.15318
1775	279.3018
1776	279.4568
1777	279.61808
1778	279.78192
1779	279.9432
1780	280.0974
1781	280.2428
1782	280.38168
1783	280.51832
1784	280.6572
1785	280.8026
1786	280.9568
1787	281.11808
1788	281.28192

Example of CO_2 file

9. Output files

9.1 Overview

For each simulation the Model creates or rewrites into the output folder a file named "output.txt".

In this folder 4 other subfolders based on time scale should created. These files contain every result for debug (if necessary) daily, monthly and annual simulations. It is also useful to check which model functions have been used. These results can be obtained at stand level or for each type of class level (layer, dbh, age or species class) on Unix like platforms, if you need to extrapolate a variable it is advised to use the "grep" tool.

E.g. open a terminal into the output folder and for the variable NPP type:

"cat output.txt | grep 'Stand NPP' " if you want to see grep output into terminal;

"cat output.txt | grep 'Stand NPP' > NPP.txt" if you want to redirect grep output into an NPP file inside the output folder

<u>IMPORTANT: be sure to use the correct declaration of the output as grep parameter</u>.

9.2 Annual Outputs

<u>At class level</u>:

YEAR	*Year of simulation*
LAYER	*Layer of tree class*
HEIGHT	*Average height of a species (m)*
DBH	*Average diameter at breast height of a species (cm)*
AGE	*Age of trees (years)*
SPECIES	*Tree Species*
MANAGEMENT	*T = Timber*
GPP	*Yearly Gross Primary Production (gC m^{-2} $year^{-1}$)*
GPP_SUN:GPP	*Yearly Gross Primary Production for sun leaves (gC m^{-2} $year^{-1}$)*
GPP_SHADE:GPP	*Yearly Gross Primary Production for shaded leaves (gC m^{-2} $year^{-1}$)*

Av_SUN:A_SUN	*Carboxylation rate/Final assimilation rate ratio for sun leaves*
Aj_SUN:A_SUN	*RuBP regeneration/Final assimilation rate ratio for sun leaves*
Av_SHADE:A_SHADE	*Carboxylation rate/Final assimilation rate ratio for shaded leaves*
Aj_SHADE:A_SHADE	*RuBP regeneration/Final assimilation rate ratio for shaded leaves*
Av_TOT:A_TOT	*Carboxylation rate/Final assimilation rate ratio*
Aj_TOT:A_TOT	*RuBP regeneration/Final assimilation rate ratio*
GR	*Growth respiration (gC m^{-2} $year^{-1}$)*
MR	*Maintenance Respiration (gC m^{-2} $year^{-1}$)*
RA	*Autotrophic respiration (gC m^{-2} $year^{-1}$)*
NPP	*Net Primary Production (gC m^{-2} $year^{-1}$)*
BP	*Yearly Biomass Production (gC m^{-2} $year^{-1}$)*
reser_as_diff	-
ResAlloc	*Annual reserve allocated (tNSC $cell^{-1}$ $year^{-1}$)*
ResDeple	*Annual reserve depleted (tNSC $cell^{-1}$ $year^{-1}$)*
ResUsage	*Annual reserve used (tNSC $cell^{-1}$ $year^{-1}$)*
BP/NPP	*Biomass productivity vs. Net Primary Production*
ResAlloc/NPP	*Annual reserve allocated vs. Net Primary Production*
ResAlloc/BP	*Annual reserve allocated vs. Biomass productivity*
ResDeple/NPP	*Annual reserve depleted vs. Net Primary Production*
ResDeple/BP	*Annual reserve depleted vs. Biomass productivity*
ResUsage/NPP	*Annual reserve used vs. Net Primary Production*
ResUsage/BP	*Annual reserve used vs. Biomass productivity*
CUE	*Annual Carbon Use Efficiency (gC NPP gC GPP^{-1})*
BPE	*Biomass Production Efficiency (gC BP gC GPP^{-1})*
diffCUE-BPE	*CUE - BPE*
Y(PERC)	*RA/GPP * 100*
PeakLAI	*Peak LAI (maximum attainable LAI) ($m^2 m^{-2}$)*
MaxLAI	*Maximum of LAI (maximum reached LAI) ($m^2 m^{-2}$)*
SLA	*Specific Leaf Area ($m^2 Kg^{-1}$)*
SAPWOOD_AREA	*Tree sapwood area (cm^2)*
CC-Proj	*Projected Canopy Cover (frac)*
DBHDC	*DBH/Crown diameter relationship*
CROWN_DIAMETER	*Crown Projected Diameter (m)*
CROWN_HEIGHT	*Crown Height (m)*
CROWN_AREA_PROJ	*Crown Projected Area (at zenith angle) (m^2)*
APAR	*Absorbed Photosynthetically Active Radiation (molPAR$m^{-2}$$year^{-1}$)*
LIVETREE	*Number of live trees (ntree $cell^{-1}$)*
DEADTREE	*Number of dead trees (ntree $cell^{-1}$)*
THINNEDTREE	*Number of thinned trees (ntree $cell^{-1}$)*
VEG_D	*Annual number of vegetative days (days $year^{-1}$)*
FIRST_VEG_DAY	*First annual day of vegetative period (DIM)*
CTRANSP	*Canopy Transpiration (mm $m^{-2}$$year^{-1}$)*
CINT	*Canopy Interception (mm $m^{-2}$$year^{-1}$)*
CLE	*Canopy Latent Heat (W $m^{-2}$$year^{-1}$)*
WUE	*Annual Water Use Efficiency (DIM)*
MIN_RESERVE_C	*Current Minimum reserve carbon pool (tC $cell^{-1}$)*
RESERVE_C	*Current Reserve carbon pool (tC $cell^{-1}$)*
STEM_C	*Current Stem carbon pool (tC $cell^{-1}$)*
STEMSAP_C	*Current Stem sapwood carbon pool (tC $cell^{-1}$)*

STEMHEART_C	*Current Stem heartwood carbon pool (tC cell^{-1})*
STEMSAP_PERC	*Stem Sapwood vs. Total Stem (%age)*
STEMLIVE_C	*Current Stem live wood carbon pool (tC cell^{-1})*
STEMDEAD_C	*Current Stem dead wood carbon pool (tC cell^{-1})*
STEMLIVE_PERC	*Live stem vs. Total stem (%age)*
MAX_LEAF_C	*Maximum Current Leaf carbon pool (tC cell $^{-1}$year^{-1})*
MAX_FROOT_C	*Maximum Current Fine Root carbon pool (tC cell $^{-1}$year^{-1})*
CROOT_C	*Current Coarse Root carbon pool (tC cell^{-1})*
CROOTLIVE_C	*Current Coarse root live wood carbon pool (tC cell^{-1})*
CROOTDEAD_C	*Current Coarse root dead wood carbon pool (tC cell^{-1})*
CROOTLIVE_PERC	*Live Coarse Root vs. Total stem (%age)*
BRANCH_C	*Current Branch carbon pool (tC cell^{-1})*
BRANCHLIVE_C	*Current Branch live wood carbon pool (tC cell^{-1})*
BRANCHDEAD_C	*Current Branch dead wood carbon pool (tC cell^{-1})*
BRANCHLIVE_PERC	*Live Branch vs. Total stem (%age)*
FRUIT_C	*Current Fruit carbon pool (tC cell^{-1})*
MAX_FRUIT_C	*Annual Fruit carbon pool (tC cell^{-1}year^{-1})*
RESERVE_N	*Current Reserve nitrogen pool (tC cell^{-1})*
STEM_N	*Current Stem nitrogen pool (tC cell^{-1})*
STEMLIVE_N	*Current Live Stem nitrogen pool (tN cell^{-1})*
STEMDEAD_N	*Current Dead Stem nitrogen pool (tN cell^{-1})*
CROOT_N	*Current Coarse Root nitrogen pool (tN cell^{-1})*
CROOTLIVE_N	*Current Coarse root live wood nitrogen pool (tN cell^{-1})*
CROOTDEAD_N	*Current Coarse root dead wood nitrogen pool (tN cell^{-1})*
BRANCH_N	*Current Branch nitrogen pool (tN cell^{-1})*
BRANCHLIVE_N	*Current Branch live wood nitrogen pool (tN cell^{-1})*
BRANCHDEAD_N	*Current Branch dead wood nitrogen pool (tN cell^{-1})*
FRUIT_N	*Current Fruit nitrogen pool (tN cell^{-1})*
STANDING_WOOD	*Standing wood carbon (tC cell^{-1})*
DELTA_WOOD	*Annual wood increment (tC cell^{-1}year^{-1})*
CUM_DELTA_WOOD	*Cumulated annual wood increment (tC cell^{-1}year^{1})*
BASAL_AREA	*Individual basal area (m^{2}ha^{-1})*
TREE_CAI	*Single Tree Current Annual Volume Increment (m^{3}tree^{-1}year^{1})*
TREE_MAI	*Single Tree Mean Annual Volume Increment (m^{3}tree^{-1}year^{1})*
CAI	*Current Annual Volume Increment (m^{3}class^{-1}year^{-1})*
MAI	*Mean Annual Volume Increment (m^{3}class^{-1}year^{-1})*
VOLUME	*Stem volume (m^{3}class^{-1})*
TREE_VOLUME	*Single tree volume (m^{3}tree^{-1})*
DELTA_TREE_VOL (perc)	*Tree volume increment (%)*
DELTA_AGB	*Aboveground biomass increment (tC cell^{-1}year^{-1})*
DELTA_BGB	*Belowground biomass increment (tC cell^{-1}year^{-1})*
AGB	*Aboveground Biomass pool (tC cell^{-1})*
BGB	*Belowground Biomass pool (tC cell^{-1})*
BGB.AGB	*BGB/AGB*
DELTA_TREE_AGB	*Aboveground biomass increment (tC cell^{-1}year^{-1})*
DELTA_TREE_BGB	*Belowground biomass increment (tC cell^{-1}year^{-1})*
C_HWP	*Annual harvested woody products removed from stand (tC cell^{-1}year^{-1})*
VOLUME_HWP	*Annual volume harvested woody products removed from stand (m^{3}cell^{-1}year^{-1})*

STEM_RA	*Stem autotrophic respiration (gC $m^{-2}year^{-1}$)*
LEAF_RA	*Leaf autotrophic respiration (gC $m^{-2}year^{-1}$)*
FROOT_RA	*Fine root autotrophic respiration (gC $m^{-2}year^{-1}$)*
CROOT_RA	*Coarse root autotrophic respiration (gC $m^{-2}year^{-1}$)*
BRANCH_RA	*Branch autotrophic respiration (gC $m^{-2}year^{-1}$)*

At cell level:

gpp	*Gross Primary Production (gC $m^{-2}year^{-1}$)*
npp	*Net Primary Production (gC $m^{-2}year^{-1}$)*
ar	*Autotrophic respiration (gC $m^{-2}year^{-1}$)*
hr	*Heterotrophic Respiration (gC $m^{-2}year^{-1}$)*
rsoil	*Soil respiration flux (gC $m^{-2}year^{-1}$)*
rsoilCO2	*Soil respiration flux (gC $m^{-2}year^{-1}$)*
reco	*Annual ecosystem respiration (gC $m^{-2}year^{-1}$)*
nee	*Annual net ecosystem exchange (gC $m^{-2}year^{-1}$)*
nep	*Annual net ecosystem production (gC $m^{-2}year^{-1}$)*
et	*Annual evapotranspiration (mm $m^{-2}year^{-1}$)*
le	*Latent heat flux (W $m^{-2}year^{-1}$)*
soil.evapo	*Annual soil evaporation (mm $m^{-2}year^{-1}$)*
asw	*Current available soil water (mm $volume^{-1}$)*
iWue	*Annual intrinsic Water Use Efficiency (DIM)*
vol	*Current volume (m^{-3}cell)*
cum_vol	*Cumulated volume (m^{-3}cell)*
run_off	*Current amount of water outflow (runoff) (mm $m^{-2}year^{-1}$)*
litrC	*Litter carbon (gC m^{-2})*
litr1C	*Litter labile carbon (gC m^{-2})*
litr2C	*Litter unshielded carbon (gC m^{-2})*
litr3C	*Litter shielded carbon (gC m^{-2})*
litr4C	*Litter lignin carbon (gC m^{-2})*
cwd_C	*Cwd carbon (gC m^{-2})*
cwd_2C	*Cwd unshielded (gC m^{-2})*
cwd_3C	*Cwd shielded (gC m^{-2})*
cwd_4C	*Cwd lignin (gC m^{-2})*
soilC	*Soil carbon (gC m^{-2})*
soil1C	*Microbial recycling pool carbon (fast) (gC m^{-2})*
soil2C	*Microbial recycling pool carbon (medium) (gC m^{-2})*
soil3C	*Microbial recycling pool carbon (slow) (gC m^{-2})*
soil4C	*Recalcitrant SOM carbon (humus, slowest) (gC m^{-2})*
litterN	*Litter nitrogen (gN m^{-2})*
litter1N	*Litter labile nitrogen (gN m^{-2})*
litter2N	*Litter unshielded cellulose nitrogen (gN m^{-2})*
litter3N	*Litter shielded cellulose nitrogen (gN m^{-2})*
litter4N	*Litter lignin nitrogen (gN m^{-2})*
cwd_N	*Cwd nitrogen (gN m^{-2})*
cwd_2N	*Cwd unshielded nitrogen (gN m^{-2})*
cwd_3N	*Cwd shielded nitrogen (gN m^{-2})*
cwd_4N	*Cwd lignin nitrogen (gN m^{-2})*
soilN	*Soil nitrogen (gN m^{-2})*
soil1N	*Microbial recycling pool nitrogen (fast) (gN m^{-2})*

soil2N	*Microbial recycling pool nitrogen (medium) (gN m^{-2})*
soil3N	*Microbial recycling pool nitrogen (slow) (gN m^{-2})*
soil4N	*Recalcitrant SOM nitrogen (humus, slowest) (gN m^{-2})*
solar_rad	*Incoming short-wave radiation (MJ m^{-2} $year^{-1}$)*
tavg	*Average air temperature (°C)*
tmax	*Maximum air temperature (°C)*
tmin	*Minimum air temperature (°C)*
tday	*Daylight average air temperature (°C)*
tnight	*Nightime average air temperature (°C)*
vpd	*Vapour Pressure Deficit (hPa-mbar)*
prpc	*Cumulated Precipitation (mm m^{-2} $year^{-1}$)*
tsoil	*Average soil temperature (°C)*
rh	*Relative Humidity (%)*
avg_asw	*Average available soil water (mm $volume^{-1}$)*
[co2]	*CO2 concentration (ppmv)*

9.3 Monthly Outputs

<u>At class level</u>:

YEAR	*Year of simulation*
MONTH	*Month of simulation*
LAYER	*Layer of tree class*
HEIGHT	*Average height of a species (m)*
DBH	*Average diameter at breast height of a species (cm)*
AGE	*Age of trees (years)*
SPECIES	*Tree species*
MANAGEMENT	*T = Timber*
GPP	*Gross Primary Production (gC m^{-2} $month^{-1}$)*
NET_ASS	*Monthly net assimilation (gC m^{-2} $month^{-1}$)*
RA	*Autotrophic Respiration (gC m^{-2} $month^{-1}$)*
NPP	*Net Primary Production (gC m^{-2} $month^{-1}$)*
CUE	*Monthly Carbon Use Efficiency (0→1) (gC_{NPP} gC_{GPP}^{-1})*
CTRANSP	*Canopy Transpiration (mm m^{-2} $month^{-1}$)*
CET	*Canopy Evapotranspiration (mm m^{-2} $month^{-1}$)*
CLE	*Canopy Latent Heat (W m^{-2} $month^{-1}$)*
CC	*Canopy Cover*
DBHDC	*DBH/Crown diameter relationship*
HD_EFF	*Effective Height/Diameter ratio (DIM)*
HDMAX	*Height (m) to Base diameter (m) ratio MAX (DIM)*
HDMIN	*Height (m) to Base diameter (m) ratio MIN (DIM)*
N_TREE	*Number of trees (n tree $cell^{-1}$)*
WUE	*Monthly Water Use Efficiency (DIM)*
Wres	*Reserve carbon pool (tC $cell^{-1}$)*
WS	*Stem carbon pool (tC $cell^{-1}$)*
WSL	*Stem live wood pool (tC $cell^{-1}$)*
WSD	*Stem dead wood (tC $cell^{-1}$)*
PWL	*Maximum leaf wood (tC $cell^{-1}$)*
PWFR	*Maximum fine root wood (tC $cell^{-1}$)*
WCR	*Coarse root biomass (tC $cell^{-1}$)*
WCRL	*Coarse root live wood biomass (tC $cell^{-1}$)*

WCRD	*Coarse root deadwood biomass (tC $cell^{-1}$)*
WBB	*Branch biomass (tC $cell^{-1}$)*
WBBL	*Branch live wood biomass (tC $cell^{-1}$)*
WBBD	*Branch dead wood biomass (tC $cell^{-1}$)*

At cell level:

gpp	*Gross Primary Production (gC $m^{-2}month^{-1}$)*
npp	*Net Primary Production (gC $m^{-2}month^{-1}$)*
ar	*Autotrophic respiration (gC $m^{-2}month^{-1}$)*
et	*Monthly evapotranspiration (gC $m^{-2}month^{-1}$)*
le	*Latent heat flux (W m^{-2})*
asw	*Available soil water (mm $volume^{-1}$)*
iWue	*Intrinsic Water Use Efficiency*

9.4 Daily Outputs

At class level:

YEAR	*Year of simulation*
MONTH	*Month of simulation*
DAY	*Day of simulation*
LAYER	*Layer of forest structure*
HEIGHT	*Average height of a specie (m)*
DBH	*Average diameter at breast height of a specie (cm)*
AGE	*Age of trees (years)*
SPECIES	*Tree species*
MANAGEMENT	*T = Timber*
GPP	*Gross Primary Production (gC $m^{-2}day^{-1}$)*
Av_TOT	*Carboxylation rate for limited assimilation (μmol $m^{-2}s^{-1}$)*
Aj_TOT	*RuBP regeneration limited assimilation (μmol $m^{-2}s^{-1}$)*
A_TOT	*Final assimilation rate (μmol $m^{-2}s^{-1}$)*
RG	*Growth respiration (gC $m^{-2}day^{-1}$)*
RM	*Maintenance Respiration (gC $m^{-2}day^{-1}$)*
RA	*Autotrophic respiration (gC $m^{-2}day^{-1}$)*
NPP	*Net Primary Production (gC $m^{-2}day^{-1}$)*
BP	*Daily biomass production (gC $m^{-2}day^{-1}$)*
CUE	*Daily carbon Use Efficiency (gC_{NPP} gC_{GPP}^{-1})*
BPE	*Daily biomass production efficiency (gC $m^{-2}day^{-1}$)*
LAI_PROJ	*LAI for Projected Area covered (at zenith angle) (m^2 m^{-2})*
PEAK-LAI_PROJ	*Peak Projected LAI (maximum attainable LAI) (m^2 m^{-2})*
LAI_EXP	*LAI for Exposed Area covered (m^2 m^{-2})*
D-CC_P	*Projected Canopy Cover (frac)*
DBHDC	*DBH/Crown diameter relationship*
CROWN_AREA_PROJ	*Crown Projected Area (at zenith angle) (m^2)*
PAR	*Photosynthetically Active Radiation (molPAR $m^{-2}day^{-1}$)*
APAR	*Absorbed Photosynthetically Active Radiation (molPAR m^2day^{-1})*
fAPAR	*Fraction of Absorbed Photosynthetically Active Radiation (unitless)*
NTREE	*Number of trees*
VEG_D	*Day of vegetative period for class (Days/Year)*
INT	*Canopy Interception (mm $m^{-2}day^{-1}$)*

WAT	*Canopy Water stored (mm m^{-2})*
EVA	*Canopy Evaporation (mm $m^{-2}day^{-1}$)*
TRA	*Canopy Transpiration (mm $m^{-2}day^{-1}$)*
ET	*Canopy Evapotranspiration (mm $m^{-2}day^{-1}$)*
LE	*Canopy Latent Heat (W m^{-2})*
WUE	*Water Use Efficiency (DIM)*
RESERVE_C	*Current Reserve carbon pool (tC $cell^{-1}$)*
STEM_C	*Current Stem carbon pool (tC $cell^{-1}$)*
STEMSAP_C	*Current Stem sapwood carbon pool (tC $cell^{-1}$)*
STEMLIVE_C	*Current Stem live wood carbon pool (tC $cell^{-1}$)*
STEMDEAD_C	*Current Stem dead wood carbon pool (tC $cell^{-1}$)*
LEAF_C	*Current Leaf carbon pool (tC $cell^{-1}$)*
FROOT_C	*Current Fine root carbon pool (tC $cell^{-1}$)*
CROOT_C	*Current Coarse root carbon pool (tC $cell^{-1}$)*
CROOTSAP_C	*Current Coarse root sapwood carbon pool (tC $cell^{-1}$)*
CROOTLIVE_C	*Current Coarse root live wood carbon pool (tC $cell^{-1}$)*
CROOTDEAD_C	*Current Coarse root dead wood carbon pool (tC $cell^{-1}$)*
BRANCH_C	*Current Branch carbon pool (tC $cell^{-1}$)*
BRANCHSAP_C	*Current Branch sapwood carbon pool (tC $cell^{-1}$)*
BRANCHLIVE_C	*Current Branch live wood carbon pool (tC $cell^{-1}$)*
BRANCHDEAD_C	*Current Branch dead wood carbon pool (tC $cell^{-1}$)*
FRUIT_C	*Current Fruit carbon pool ((tC $cell^{-1}$)*
DELTARESERVE_C	*Daily allocation to reserve (tC $cell^{-1}day^{-1}$)*
DELTA_STEM_C	*Daily allocation to stem (tC $cell^{-1}day^{-1}$)*
DELTA_LEAF_C	*Daily allocation to leaf (tC $cell^{-1}day^{-1}$)*
DELTA_FROOT_C	*Daily allocation to fine root (tC $cell^{-1}day^{-1}$)*
DELTA_CROOT_C	*Daily allocation to coarse root (tC $cell^{-1}day^{-1}$)*
DELTA_BRANCH_C	*Daily allocation to branch (tC $cell^{-1}day^{-1}$)*
DELTA_FRUIT_C	*Daily allocation to fruit (tC $cell^{-1}day^{-1}$)*
RESERVE_N	*Current reserve nitrogen pool (tN $cell^{-1}$)*
STEM_N	*Current stem nitrogen pool (tN $cell^{-1}$)*
STEMLIVE_N	*Current Live Stem nitrogen pool (tN $cell^{-1}$)*
STEMDEAD_N	*Current Dead Stem nitrogen pool (tN $cell^{-1}$)*
LEAF_N	*Current leaf nitrogen pool (tN $cell^{-1}$)*
FROOT_N	*Current Fine Root nitrogen pool (tN $cell^{-1}$)*
CROOT_N	*Current Coarse Root nitrogen pool (tN $cell^{-1}$)*
CROOTLIVE_N	*Current Coarse root live wood nitrogen pool (tN $cell^{-1}$)*
CROOTDEAD_N	*Current Coarse root dead wood nitrogen pool (tN $cell^{-1}$)*
BRANCH_N	*Current Branch nitrogen pool (tN $cell^{-1}$)*
BRANCHLIVE_N	*Current Branch live wood nitrogen pool (tN $cell^{-1}$)*
BRANCHDEAD_N	*Current Branch dead wood nitrogen pool (tN $cell^{-1}$)*
FRUIT_N	*Current Fruit nitrogen pool (tN $cell^{-1}$)*
DELTARESERVE_N	*Daily allocation to reserve (tN $cell^{-1}day^{-1}$)*
DELTA_STEM_N	*Daily allocation to stem (tN $cell^{-1}day^{-1}$)*
DELTA_LEAF_N	*Daily allocation to leaf ((tN $cell^{-1}day^{-1}$)*
DELTA_FROOT_N	*Daily allocation to fine root (tN $cell^{-1}day^{-1}$)*
DELTA_CROOT_N	*Daily allocation to coarse root (tN $cell^{-1}day^{-1}$)*
DELTA_BRANCH_N	*Daily allocation to branch (tN $cell^{-1}day^{-1}$)*
DELTA_FRUIT_N	*Daily allocation to fruit (tN $cell^{-1}day^{-1}$)*

STEM_AR	*Stem autotrophic respiration (gC $m^{-2}day^{-1}$)*
LEAL_AR	*Leaves autotrophic respiration (gC $m^{-2}day^{-1}$)*
FROOT_AR	*Fine Roots autotrophic respiration (gC $m^{-2}day^{-1}$)*
CROOT_AR	*Coarse Roots autotrophic respiration (gC $m^{-2}day^{-1}$)*
BRANCH_AR	*Branch autotrophic respiration (gC $m^{-2}day^{-1}$)*
F_CO2	*CO2 fertilization effect (DIM) (as choiced in script)*
F_CO2_VER	*CO2 fertilization effect (DIM) (Veroustraete's version)*
F_CO2_FRA	*CO2 fertilization effect (DIM) (Franks et al's version)*
FCO2_TR	*CO2 fertilization effect (DIM) (for stomatal conductance)*
FLIGHT	*Light modifier*
FAGE	*Age modifier (0→1)*
FT	*Air temperature modifier (0→1)*
FVPD	*VPD modifier (0→1)*
FN	*Soil nutrient modifier (0→1)*
FSW	*Soil water modifier (0→1)*
LITR_C	*Current Litter Carbon Pool (tC $cell^{-1}$)*
CWD_C	*Coarse Woody Debris Carbon (tC $cell^{-1}$)*

At cell level:

gpp	*Gross Primary Production (gC $m^{-2}day^{-1}$)*
npp	*Net Primary Productivity (gC $m^{-2}day^{-1}$)*
ar	*Autotrophic respiration (gC $m^{-2}day^{-1}$)*
hr	*Heterotrophic respiration (gC $m^{-2}day^{-1}$)*
rsoil	*Soil respiration flux (gC $m^{-2}year^{-1}$)*
reco	*Daily ecosystem respiration (gC $m^{-2}day^{-1}$)*
nee	*Daily net ecosystem exchange (gC $m^{-2}day^{-1}$)*
nep	*Daily net ecosystem production (gC $m^{-2}day^{-1}$)*
et	*Daily evapotranspiration (mm $m^{-2}day^{-1}$)*
le	*Daily latent heat flux (W m^{-2})*
soil_evapo	*Daily soil evaporation (mm $m^{-2}day^{-1}$)*
snow_pack	*Current Amount of Snow (Kg m^{-2})*
asw	*Current available soil water (mm $volume^{-1}$)*
moist_ratio	*Soil moisture ratio (DIM)*
iWue	*Daily intrinsic Water Use Efficiency (DIM)*
litrC	*Litter carbon (gC m^{-2})*
litr1C	*Litter labile carbon (gC m^{-2})*
litr2C	*Litter unshielded carbon (gC m^{-2})*
litr3C	*Litter shielded carbon (gC m^{-2})*
litr4C	*Litter lignin carbon (gC m^{-2})*
cwd_C	*Cwd carbon (gC m^{-2})*
cwd_2C	*Cwd unshielded (gC m^{-2})*
cwd_3C	*Cwd shielded (gC m^{-2})*
cwd_4C	*Cwd lignin (gC m^{-2})*
soilC	*Soil carbon (gC m^{-2})*
soil1C	*Microbial recycling pool carbon (fast) (gC m^{-2})*
soil2C	*Microbial recycling pool carbon (medium) (gC m^{-2})*
soil3C	*Microbial recycling pool carbon (slow) (gC m^{-2})*
soil4C	*Recalcitrant SOM carbon (humus, slowest) (gC m^{-2})*
litterN	*Litter nitrogen (gN m^{-2})*

litter1N	*Litter labile nitrogen (gN m^{-2})*
litter2N	*Litter unshielded cellulose nitrogen (gN m^{-2})*
litter3N	*Litter shielded cellulose nitrogen (gN m^{-2})*
litter4N	*Litter lignin nitrogen (gN m^{-2})*
cwd_N	*Cwd nitrogen (gN m^{-2})*
cwd_2N	*Cwd unshielded nitrogen (gN m^{-2})*
cwd_3N	*Cwd shielded nitrogen (gN m^{-2})*
cwd_4N	*Cwd lignin nitrogen (gN m^{-2})*
soilN	*Soil nitrogen (gN m^{-2})*
soil1N	*Microbial recycling pool nitrogen (fast) (gN m^{-2})*
soil2N	*Microbial recycling pool nitrogen (medium) (gN m^{-2})*
soil3N	*Microbial recycling pool nitrogen (slow) (gN m^{-2})*
soil4N	*Recalcitrant SOM nitrogen (humus, slowest) (gN m^{-2})*
tsoil	*Soil Temperature (°C)*
daylenght	*Day length*

10. Questions or comments

Shall you have issues with the code or for any suggestions, please let us know. For any questions on how to parameterize or run the code, please read this file first.

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