# I modelli di simulazione per la previsione del potenziale di mitigazione delle foreste

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www.forest-modelling-lab.com

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# What is climate change?

"Climate change refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer."
(IPCC – SR15, 2018)

## Causes?

ENVIRONMENTAL RESEARCH
LETTERS

LETTER • OPEN ACCESS

**Greater than 99% consensus on human caused climate change in the peer-reviewed scientific literature**

Mark Lynas[4,1], Benjamin Z Houlton[2] and Simon Perry[3]

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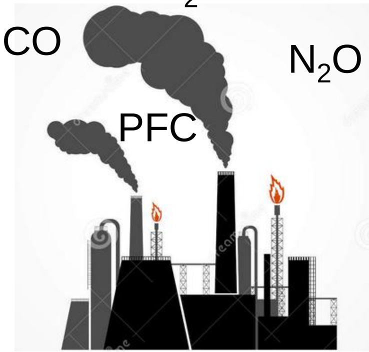
Environmental Research Letters, Volume 16, Number 11




(not only from industries!)

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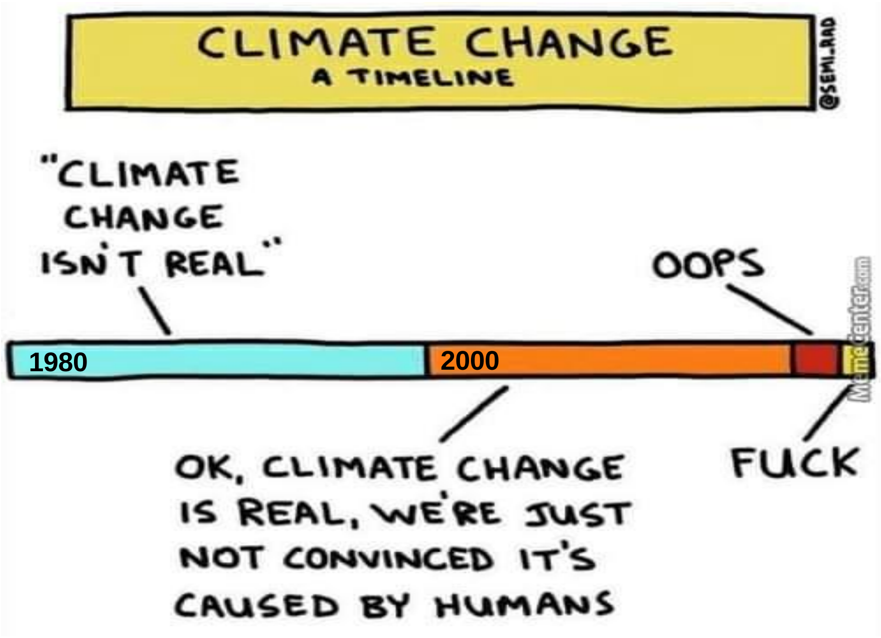
# Is climate change really an evidence?





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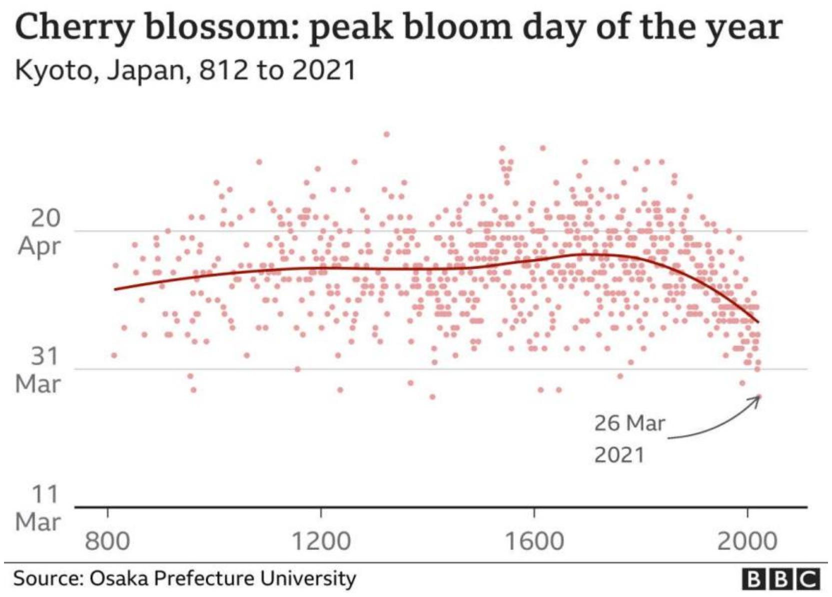
# There is evidence of climate change





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# Methodologies for studying Carbon, Water and Nitrogen Cycles and Forest Dynamics

| | | |
|---|---|---|
| Eddy covariance | → | No predictive |
| Remote sensing | → | No predictive |
| Allometric equations and biometric estimates | → | No predictive at varying site conditions |
| Modelling | → | Predictive but highly uncertain |

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# How (and why) study climate change and the mitigation/adaptation role of forests?

## MITIGATION

it acts on the **causes,** to drastically decrease the anthropogenic causes of climate warming (greenhouse gas emissions)

## ADAPTATION

it deals with the **effects**, i.e. the impacts that directly and indirectly affect humans and the environment

**Can <u>models</u> deal with both??**

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# But what is a “model”?
# (some definitions)

“***A model is an informative representation of an object, person or system*** “
(Wikipedia 2021)

“***A model can be considered as a synthesis of the knowledge elements of a system***”
(Jørgensen 1997)

“***Models are simplified representations of the real world***”
(Wainwright and Mulligan 2004)

REALTÀ MODELLO MATEMATICO

# In its extreme essence a model is a tool:

***(1) to describe a system (dynamic or not),***

***(2) to make useful predictions and***

***(3) to test hypotheses***

*(we will see same examples later)*


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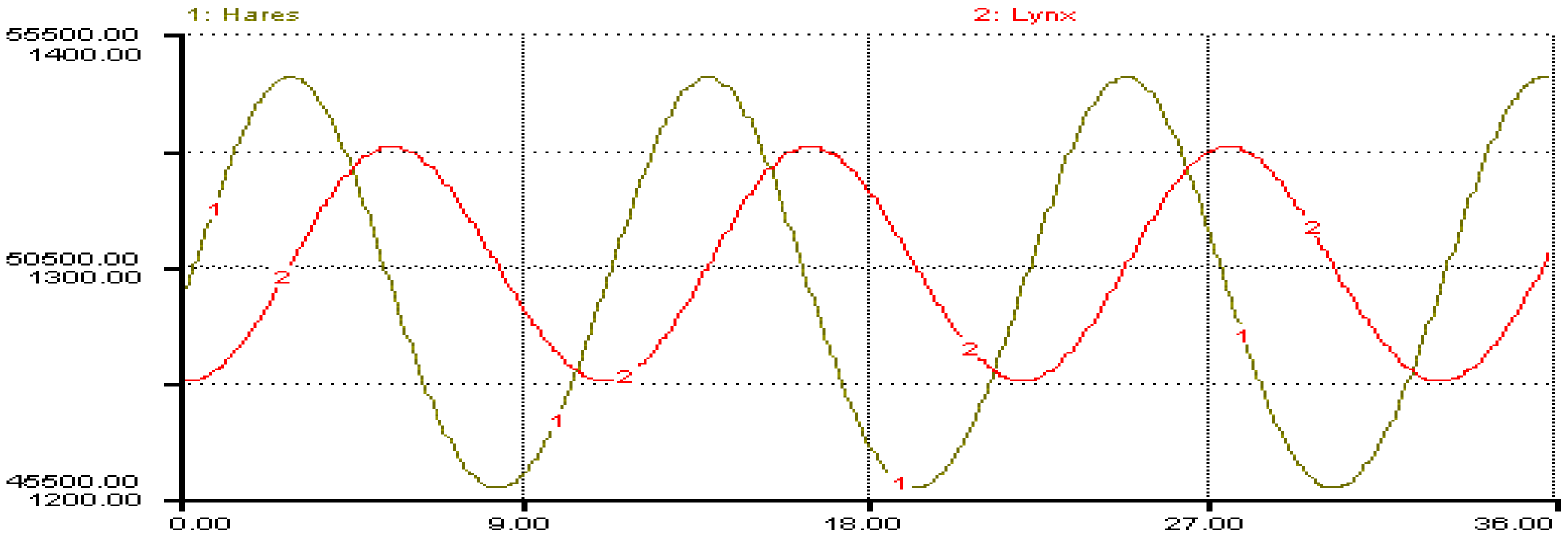
# The first and potentially the most known model…

## The Lotka-Volterra model (1925) (aka "*the Predator-Prey model*")




**Growth rate for species 1**

$$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1}{K_1} - \frac{\alpha_{12} N_2}{K_1}\right)$$

**Growth rate for species 2**

$$\frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2}{K_2} - \frac{\alpha_{21} N_1}{K_2}\right)$$

System of derivates

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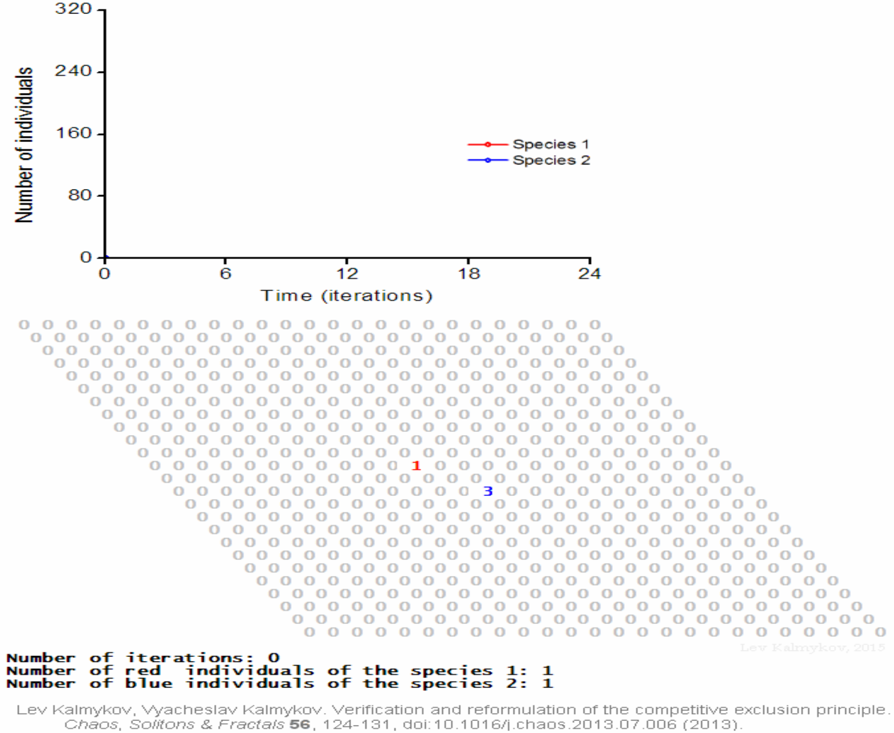
# … a example of ecological model:

**“*The competitive exclusion principle*” (aka Gause’s low):**

“two species competing for the same limited resource cannot coexist at constant population values”




**Cellular automaton model** of interspecific competition for a single limited resource

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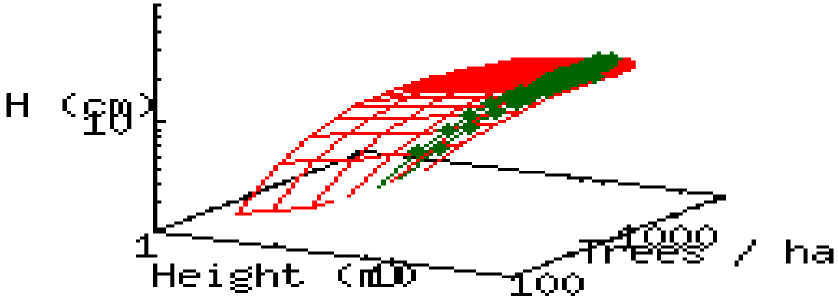
When one species has even the slightest advantage over another, the one with the advantage will dominate in the long term. This leads either to the extinction of the weaker competitor or to an evolutionary or behavioral shift toward a different ecological niche.

**but there are, of course, also models in forestry:**

DBH vs. Tree Height vs. Stand Density



# What’s inside a model?


**Basically, a model is an equation or a chain of equations to describe something:**

$$ASW = ASW - \Delta ASW$$

$$A =$$

$$\Delta ASW = P \times \left(1 - \sum_{z=\text{layer index}}^{N} i_{R_{x,y,k}}\right) - \left(\sum_{z=\text{layer index}}^{N} i_{T_{x,y,k}} + E_s\right)$$

$$a_{S_{x,y,z,k}} = \frac{}{1 + \omega_{x,y,k,z}(2 - L_{x,y,k,z} - f_{SW_{x,y,k,z}})}$$

$$a_{R_{x,y,z,k}} = \frac{\varepsilon_{R_x} + \omega_x(1 - f_{SW_{x,y,k,z}})}{1 + \omega_{x_{x,y,k,z}}(2 - L_{x,y,k,z} - f_{SW_{x,y,z,k}})}$$

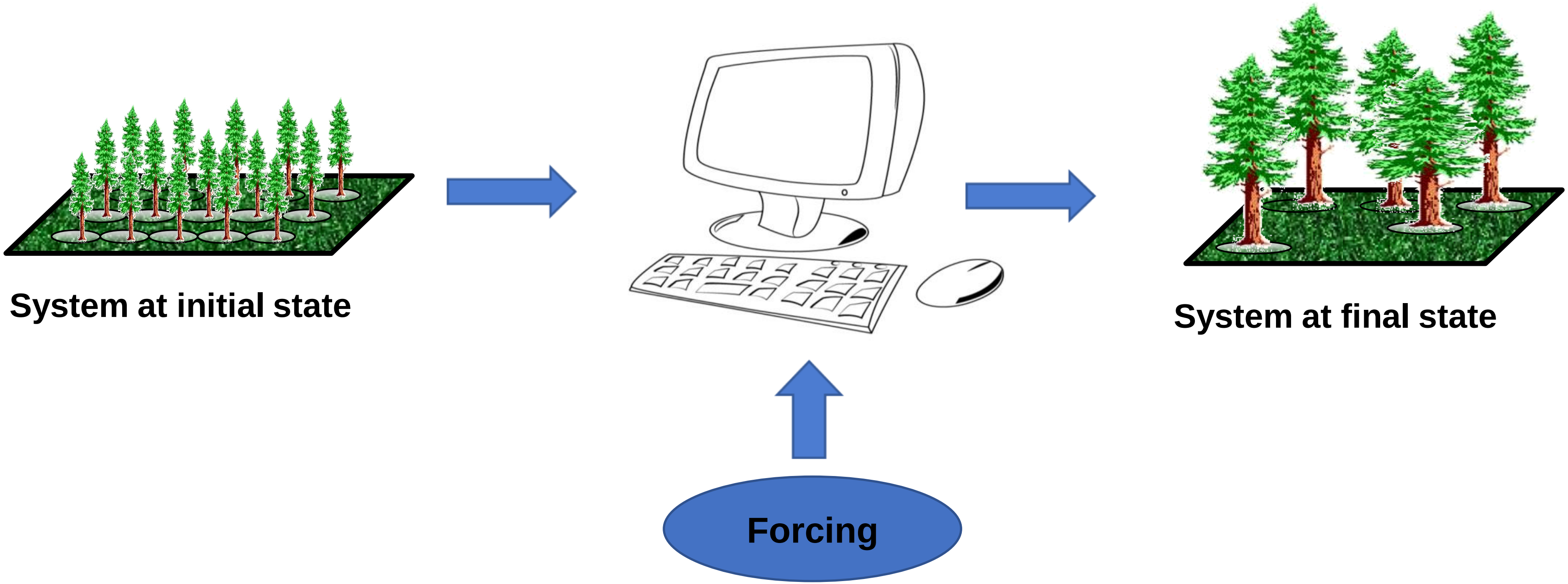
$$a_{L_{x,y,z,k}} = \frac{}{1 +}$$

$$F_{AGE} = \frac{1}{1 + (age / r_{age}\ age_{max})^{n_{age}}}$$

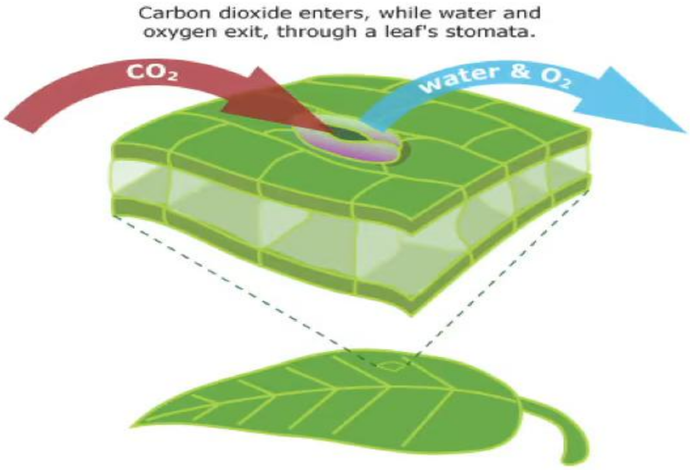
$$e = \frac{s * RAD + \left(\frac{}{r_{HR}}\right)}{\left(\frac{\rho * c_p * r_V}{AirPa * \varepsilon * r_{HR}}\right) + s}$$

$$3 * 10^5 * \exp(36(T - 25)/(298 R(T + 273)))$$

# …and in practice



**Modelling means breaking down and representing the system in its main processes happening at different temporal and spatial scale**



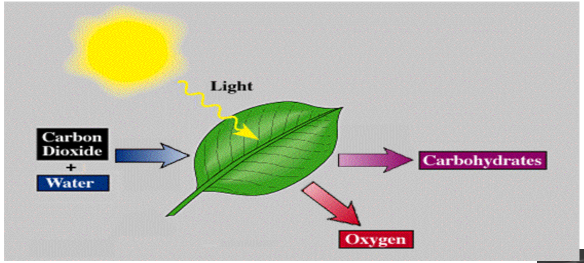

(e.g. *photosynthesis and stomatal transpiration*)

# The scales

**Spatial**

**Temporal**

# The spatial scale




Cellular/Leaf level

$$A = \min\{A_v, A_j\} - MR_{leaf_{day}}$$

$$A_v = \frac{V_{C\,max}(C_i - \Gamma^*)}{C_i + K_c\left(1 + \frac{O_2}{K_O}\right)}$$

$$A_j = \frac{J(C_i - \Gamma^*)}{4.5C_i + 10.5 *}$$

$$a_{S_{x,y,z,k}} = \frac{\varepsilon_{S_x} + \omega_x(1 - L_{x,y,k,z})}{1 + \omega_{x,y,k,z}(2 - L_{x,y,k,z} - f_{SW_{x,y,k,z}})}$$

$$a_{R_{x,y,z,k}} = \frac{\varepsilon_{R_x} + \omega_x(1 - f_{SW_{x,y,k,z}})}{1 + \omega_{x_{x,y,k,z}}(2 - L_{x,y,k,z} - f_{SW_{x,y,z,k}})}$$

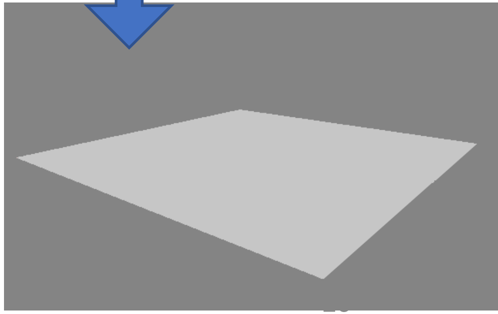
$$a_{L_{x,y,z,k}} = \frac{\varepsilon_{Lx}}{1 + \omega_x(2 - L_{x,y,z,k} - f_{SW_{x,y,z,k}})} = 1 - a_{R_{x,y,z,k}} - a_{S_{x,y,z,k}}$$

Canopy/Tree level

$$F_{AGE} = \frac{1}{1 + \left(age / r_{age}\ age_{max}\right)^{n_{age}}}$$

Big tree level

$$e = \frac{s * RAD + \left(\frac{\rho * c_p * VPD}{r_{HR}}\right)}{\left(\frac{\rho * c_p * r_V}{AirPa * \varepsilon * r_{HR}}\right) + s}$$



Stand level

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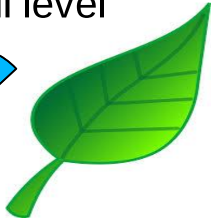
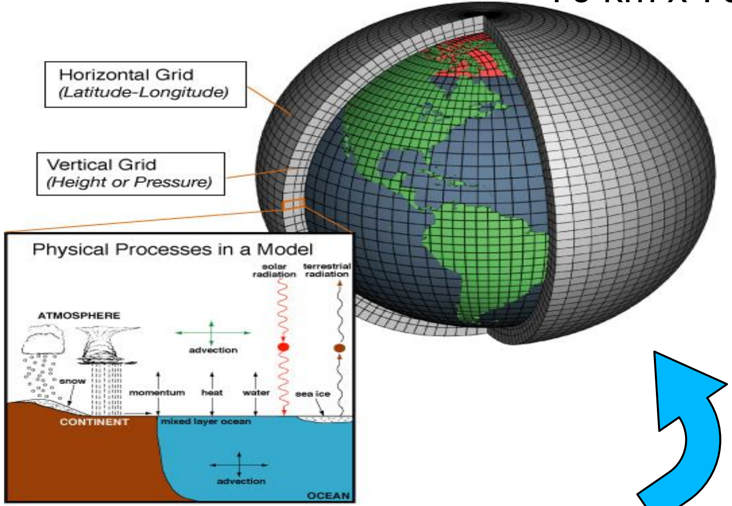
# The spatial scale

70 km x 70 km

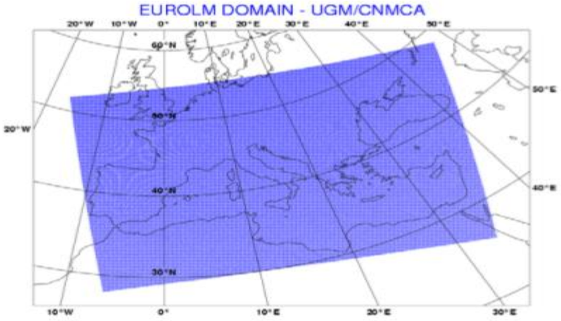
Cell level



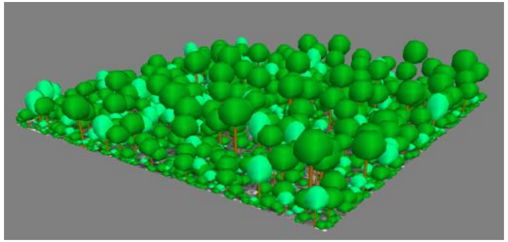




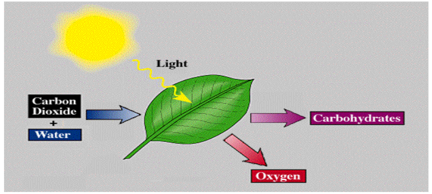
From single cell to 70 km x 70 km





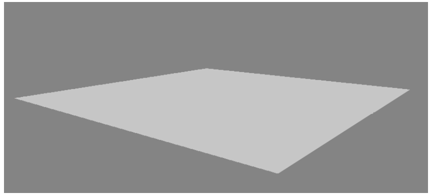


# The temporal scale




Semi-hourly

(e.g. photosynthesis)



Multi-decadal

(e.g. forest succession)

Different temporal representations for different processes
(e.g. radiative fluxes, water fluxes, carbon allocation)

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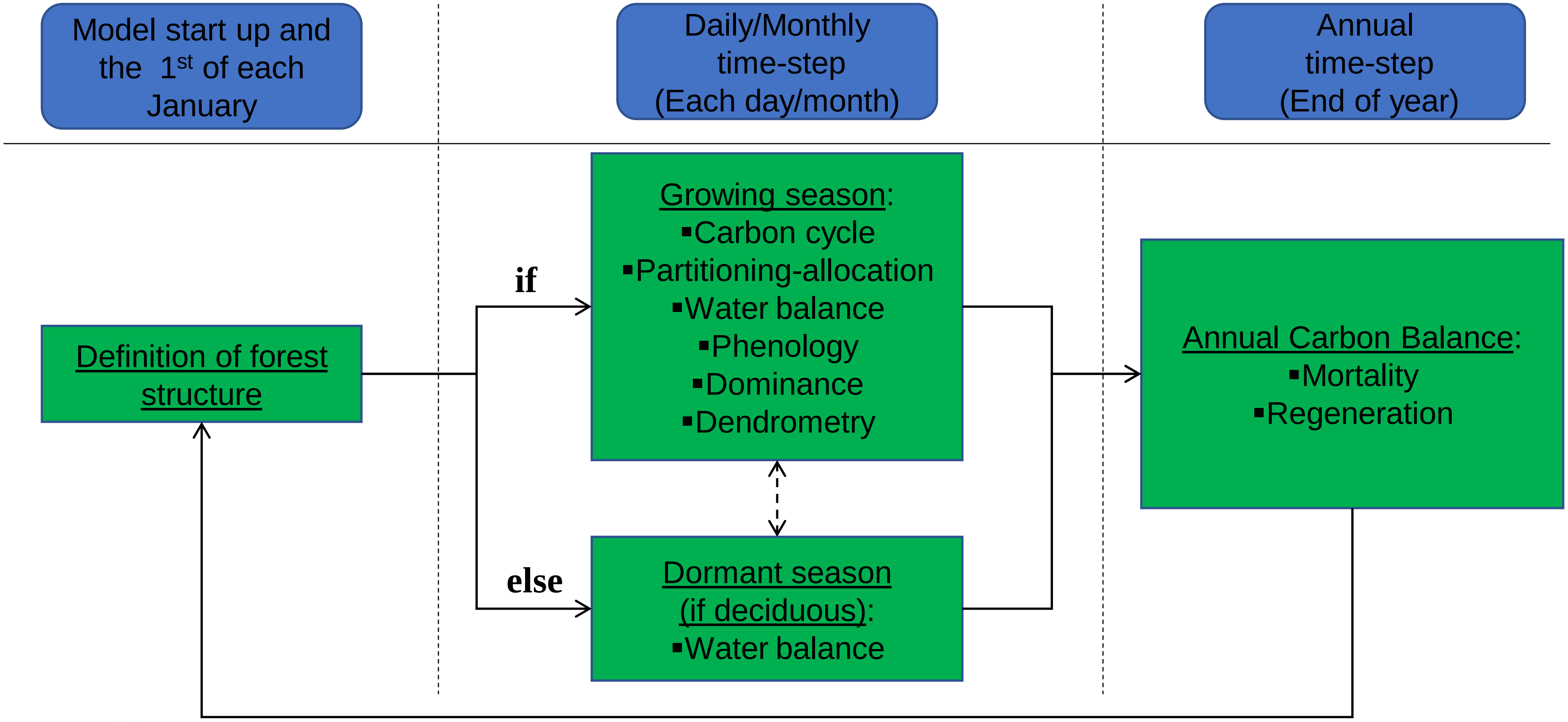
# How to simulate forest dynamic temporally

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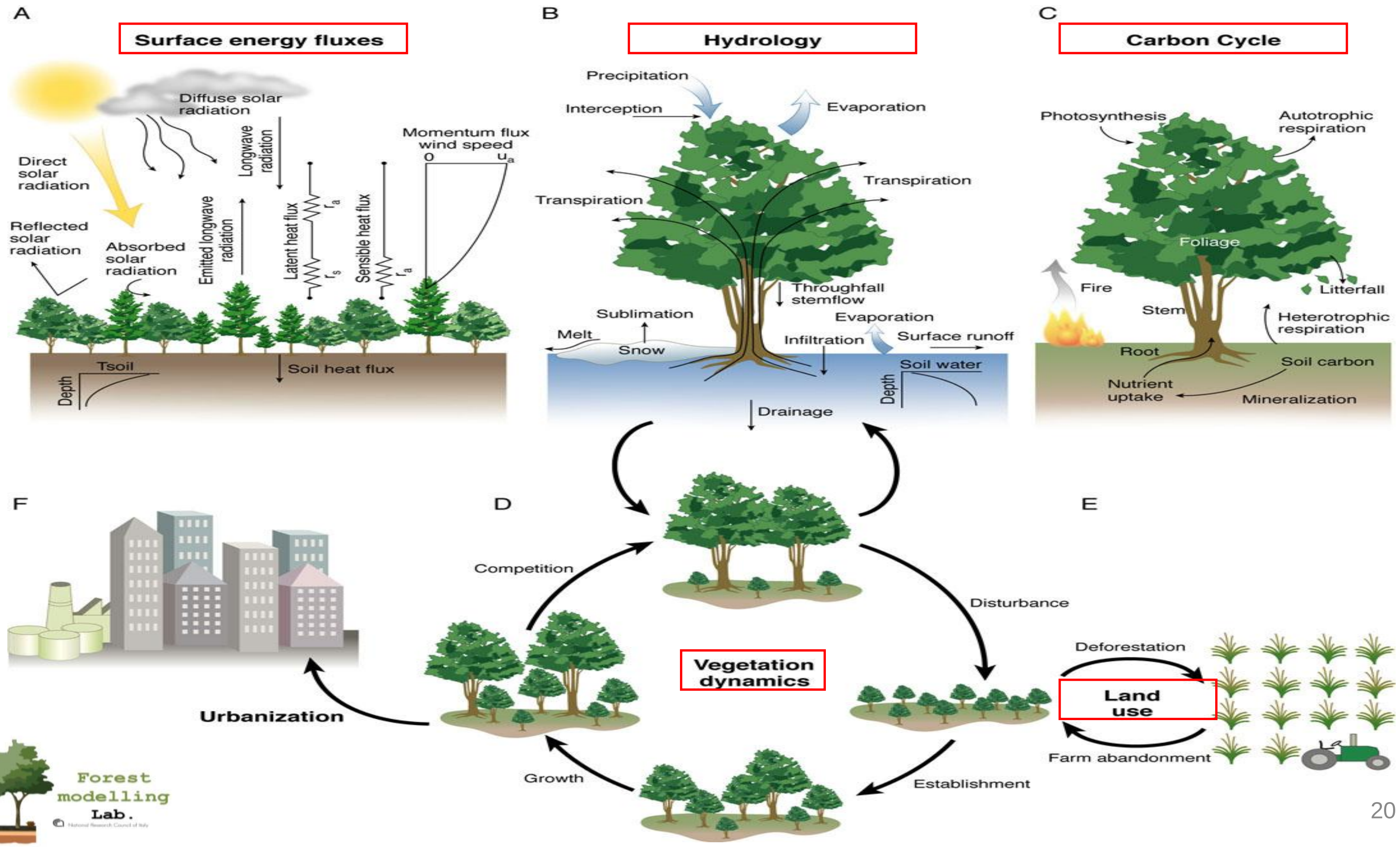
# The main processes represented in vegetation models

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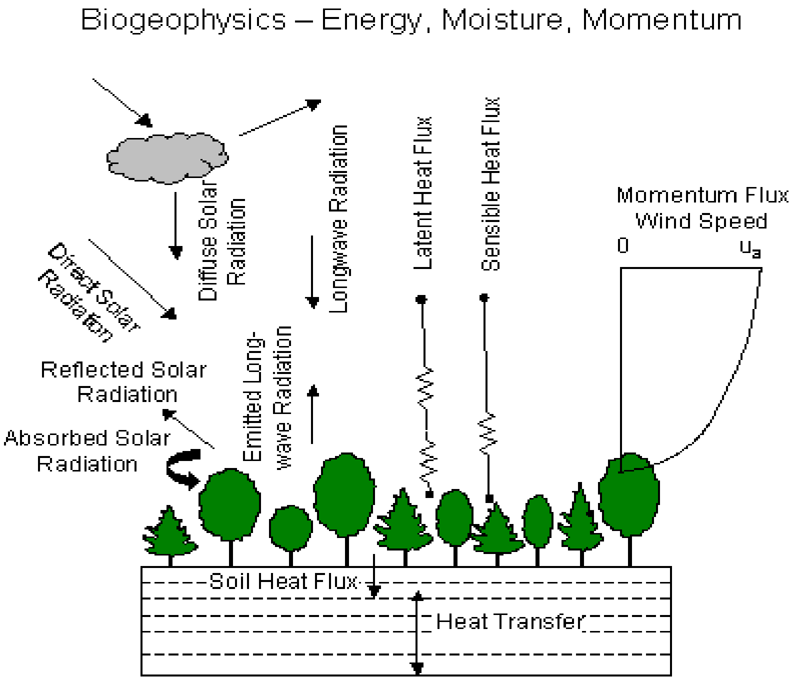
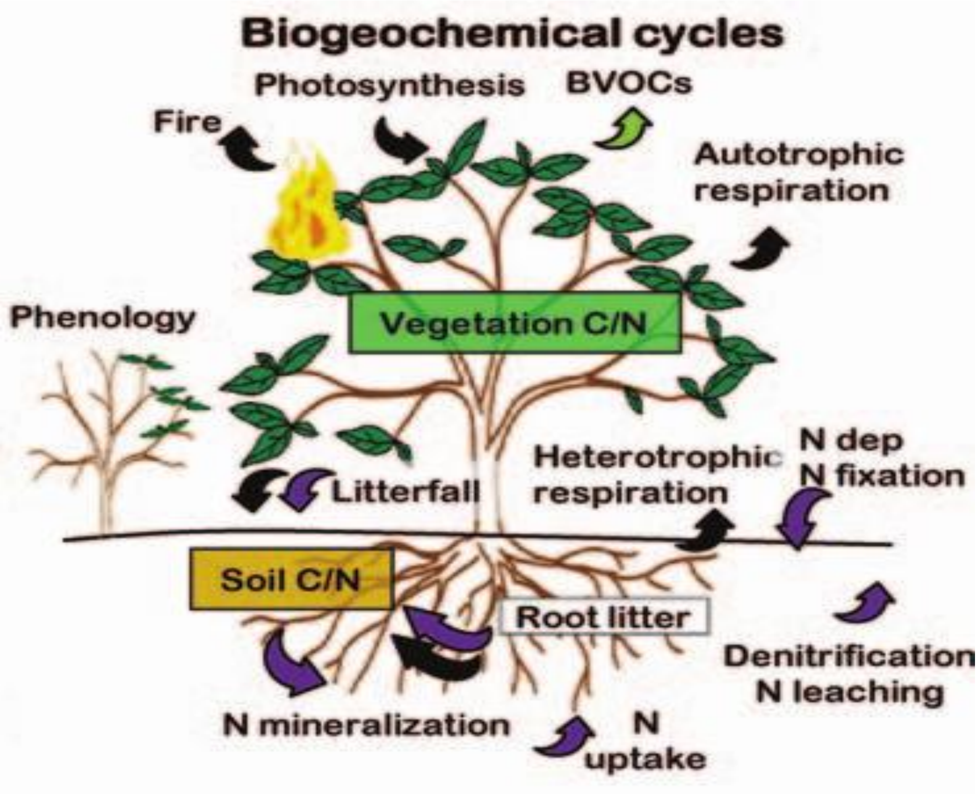
# The main processes represented in vegetation models – Biophysical processes

- SURFACE ALBEDOS
- Canopy radiative transfer
- Ground albedos
- Solar zenith angle
- RADIATIVE TRANSFER
- Solar fluxes
- Longwave fluxes
- SENSIBLE HEAT AND LATENT HEAT FLUXES
- Sensible and latent heat fluxes for vegetated and not
- Saturation vapor pressure
- SOIL AND SNOW TEMPERATURE



# The main processes represented in vegetation models – Biogeochemical processes

- CANOPY PHOTOSYNTHESIS
- AUTOTROPHIC RESPIRATION
- Heterotrophic respiration
- C-N ALLOCATION
- PHENOLOGY
- Fire and mortality
- Vegetation structure
- Litterfall
- “CARBON CYCLE”
- “NITROGEN CYCLES”

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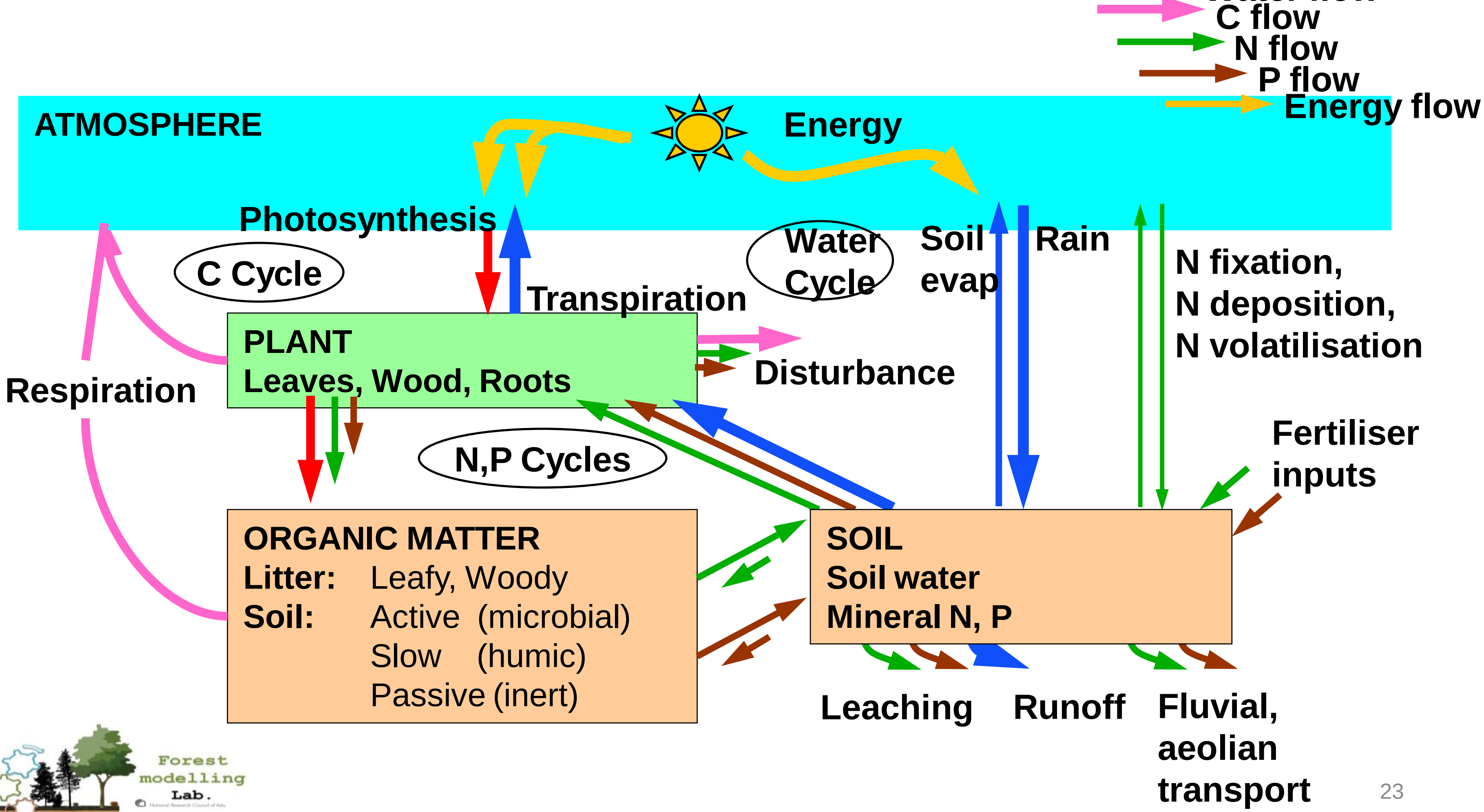
## Grouped and summarizing in a conceptual framework

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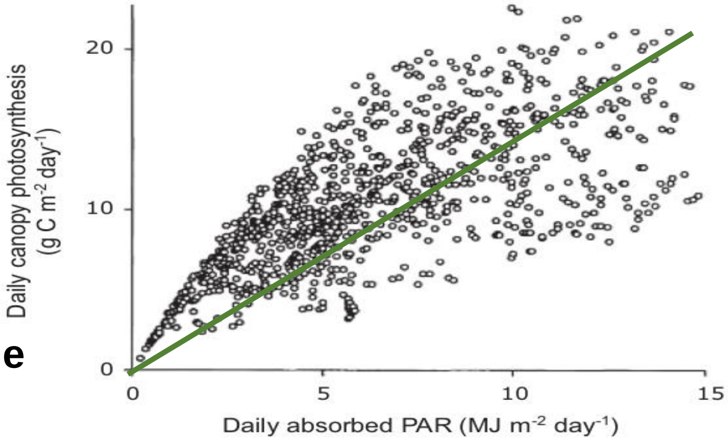
# A **simple** model in vegetation science. How to simulate a process (e.g. photosynthesis)

The process: *photosynthesis*.
Observations (roughly) say: *photosynthesis increases linearly at increasing absorbed light and is limited by environment*

*Waring et al. (2016), Tamm Review*




**Parameter** **Constant**

$$GPP = \alpha_X * \text{“environment”} * PAR * (1 - e^{-K * LAI})$$

**Driver/forcing** **Variable**

**GPP** = photosynthesis
**$\alpha_X$** = maximum canopy quantum efficiency (optimum photosynthesis *per* absorbed PAR)
**PAR** = Photosynthetically Active Radiation
**LAI** = Leaf Area Index
**K** = coefficient of extinction
**Environment** = environmental modifiers (0–1) that limit optimum photosynthesis

# A simple model in vegetation science. How to simulate a process (e.g. productivity)

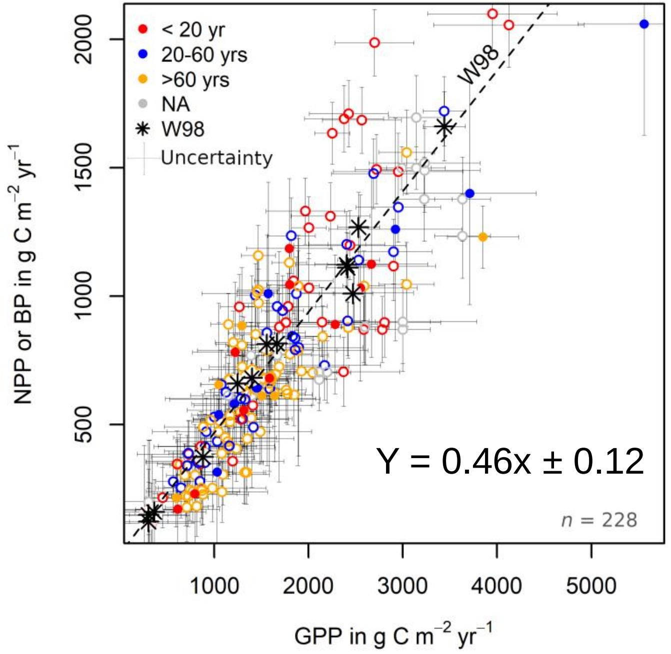
The process: *productivity*.
Observations (roughly) say: the existence of pervasive acclimation mechanisms that tend to stabilize the NPP:GPP ratio

**Constant**

$$NPP = GPP * Y$$

**Variable**

*Collalti et al. (2020), Nature Comm.*




**NPP**= Net Primary Production
**Y** = coefficient of extinction

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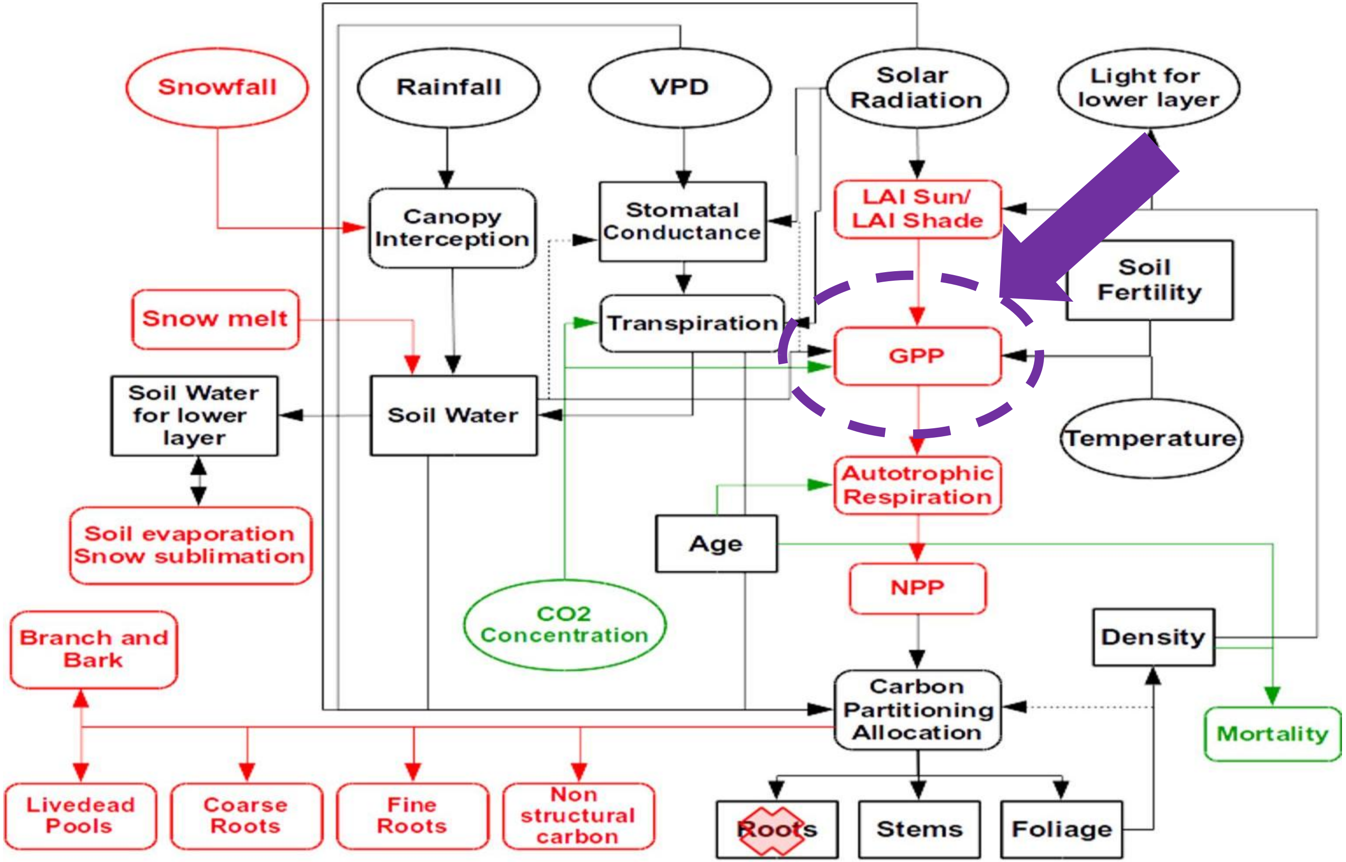
# A complex model in vegetation science. How to simulate all process




## …and models and codes can become very complex….

**Margaret Hamilton** , computer scientist, director of the Software Engineering Division of the MIT Instrumentation Laboratory, which developed on-board flight software for **NASA's Apollo program**

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# …but more practically the GPP (a code)

```c
void photosynthesis_LUE(cell_t *const c, const int layer, const int height, const int dbh, const int age, const int species, const meteo_annual_t *const meteo_annual)
{
    double Alpha_C;
    double Epsilon_C;
    double GPPmolC;
    double GPP_sun_molC;
    double GPP_shade_molC;
    double Lue;
    double Lue_max;
    double Lue_sun;
    double Lue_sun_max;
    double Lue_shade;
    double Lue_shade_max;

    species_t *s;
    s = &c->heights[height].dbhs[dbh].ages[age].species[species];

    /**********************************************************************/

    if ( s->value[ALPHA] != NO_DATA )
    {
        /* compute actual light use efficiency from potential one */
        //fixme use or not s->value[F_CO2_TR]???????
        Alpha_C   = s->value[ALPHA] * s->value[F_CO2] * s->value[F_NUTR] * s->value[F_T] * s->value[PHYS_MOD] /* * s->value[F_CO2_TR] */;

        /* molC/molPAR/m2/day --> gC/MJ/m2/day */
        Epsilon_C = Alpha_C * MOLPAR_MJ * GC_MOL;
    }
    else
    {
        /* compute actual light use efficiency from potential one */
        //fixme use or not s->value[F_CO2_TR]???????
        Epsilon_C = s->value[EPSILONgCMJ] * s->value[F_CO2] * s->value[F_NUTR] * s->value[F_T] * s->value[PHYS_MOD] /* * s->value[F_CO2_TR] */;

        s->value[ALPHA] = s->value[EPSILONgCMJ] / (MOLPAR_MJ * GC_MOL);

        /* gC/MJ/m2/day --> molC/molPAR/m2/day */
        Alpha_C   = Epsilon_C / (MOLPAR_MJ * GC_MOL);
    }

    /* note: special case when fSW <= WATER_STRESS_LIMIT for coupling with canopy transpiration */
    /* to be fixed once */
    if ( s->value[F_SW] <= WATER_STRESS_LIMIT )
    {
        if ( ! s->value[CANOPY_TRANSP] )
        {
            Alpha_C   = 0.;
        }
        else
        {
            Alpha_C *=  s->value[F_SW];
        }
    }
```

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# …but more practically (some model inputs)

```
Year,x,y,Age,Species,Management,N,Stool,AvDBH,Height
1950,0,0,29,Fagussylvatica,T,1326,0,5.961357466,8.814479638
```

**Stand data for model initialization**

```
X,Y,LANDUSE,LAT,LON,CLAY_PERC,SILT_PERC,SAND_PERC,SOIL_DEPTH,FR,FN0,FNN,M0,LITTERC
0,0,F,55.29,11.38,15.33,21.59,63.08,180,0.90,0.5,0.5,0.2,-9999,-9999,-9999,-9999,-9
```

**Climate forcing data**

```
Year    Month   n_days  Rg_f    Ta_f    Tmax    Tmin    RH_f    Ts_f    Precip  SWC     LAI     ET      WS_f
1996    1       1       1.011096        -3.6090625      -3.302  -4.086  93.6399526015545       -9999   1.332   -9999   -
1996    1       2       1.0734138       -3.33170833333333       -2.63   -3.723  90.3779847933055        -9999   1.13    -
1996    1       3       1.4199408       -5.3066875      -3.492  -6.291  99.2751001746145        -9999   0.032   -9999   -
1996    1       4       1.5142032       -6.81502083333333       -6.18   -7.298  99.7222269427755        -9999   0       -
1996    1       5       1.3848732       -4.58025        -2.718  -6.599  98.1872053425175        -9999   0.291   -9999   -
1996    1       6       1.2437874       -2.4601875      -1.469  -2.993  95.4609050296131        -9999   1.118   -9999   -
1996    1       7       0.6736788       -1.724375       1.154   -3.356  94.7818497205114        -9999   2.373   -9999   -
1996    1       8       1.583577        0.2525625       1.565   -0.911  100     -9999   0.906   -9999   -9999   -9999   3
1996    1       9       0.8853246       -0.0287708333333333     0.503   -0.553  100     -9999   0.474   -9999   -9999   -
1996    1       10      0.5837922       -0.628541666666667      0.331   -1.098  100     -9999   0.804   -9999   -9999   -
1996    1       11      0.8660754       -0.554208333333333      -0.068  -0.967  100     -9999   1.092   -9999   -9999   -
1996    1       12      0.6812334       0.178541666666667       0.731   -0.333  99.9784985124904        -9999   0.969   -
1996    1       13      1.8782874       0.993979166666667       2.341   -0.122  99.6951326527565        -9999   0.833   -
1996    1       14      1.6573896       -0.561520833333333      1.371   -1.415  100     -9999   0.295   -9999   -9999   -
1996    1       15      1.2636  -2.43466666666667       -1.468  -2.884  100     -9999   0.545   -9999   -9999   -9999   4
1996    1       16      1.0278684       -2.7741875      -2.341  -3.236  100     -9999   0.522   -9999   -9999   -9999   2
1996    1       17      0.6174108       -2.30297916666667       -2.059  -2.661  100     -9999   0.4     -9999   -9999   -
1996    1       18      1.1812914       -2.01714583333333       -1.443  -2.544  100     -9999   0.515   -9999   -9999   -
1996    1       19      1.3088088       -1.6066875      -0.724  -2.72   100     -9999   0.786   -9999   -9999   -9999   4
1996    1       20      2.2823964       -2.5606875      -1.34   -3.6    90.4072451907435        -9999   0.728   -9999   -
1996    1       21      2.1834018       -2.7654375      -2.265  -3.224  86.5034915790072        -9999   0.637   -9999   -
1996    1       22      2.281104        -3.4424375      -2.481  -4.566  90.1515955744099        -9999   0.753   -9999   -
1996    1       23      2.3972112       -5.20008333333333       -4.615  -5.805  94.265959601704 -9999   0.796   -9999   -
1996    1       24      2.3097006       -5.1308125      -4.634  -5.77   94.0612062814829        -9999   0.89    -9999   -
1996    1       25      2.2666446       -4.96322916666667       -4.443  -5.717  85.415256828771 -9999   2.428   -9999   -
1996    1       26      2.4256368       -4.83754166666667       -3.634  -6.285  85.3798298986317        -9999   1.974   -
1996    1       27      3.5293662       -4.07264583333333       -3.344  -5.031  89.2121215009884        -9999   0.256   -
1996    1       28      3.7351908       -6.22558333333333       -5.098  -7.232  100     -9999   0       -9999   -9999   -
1996    1       29      3.573513        -5.64322916666667       -4.296  -7.248  100     -9999   0       -9999   -9999   -
1996    1       30      2.7856098       -4.23422916666667       -3.258  -4.93   100     -9999   0.199   -9999   -9999   -
1996    1       31      2.8225296       -5.12995833333333       -4.656  -5.515  98.2368807949429        -9999   0.293   -
1996    2       1       3.913029        -6.17510416666667       -5.163  -7.516  99.8886247872708        -9999   0.048   -
1996    2       2       2.6451648       -6.82460416666667       -5.346  -7.825  99.8809831068128        -9999   0.47    -
```

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# but more practically (some model inputs)…

```
//Fagus_sylvatica parameterization file
LIGHT_TOL                    1   //4 = very shade intolerant (cc = 90%), 3 = sh
PHENOLOGY                  0.1   //PHENOLOGY 0.1 = deciduous broadleaf, 0.2 = d
ALPHA                    0.057   //Canopy quantum efficiency (molC/molPAR) (0.0
EPSILONgCMJ               0.69   //Light Use Efficiency  (gC/MJ)(used if ALPHA
GAMMA_LIGHT                  0   //Empirical parameter for Light modifiers
K                          0.5   //Extinction coefficient for absorption of PAR
ALBEDO                    0.15   //Albedo, 0.15 (varying from 0.13-0.17) from O
INT_COEFF                  0.3   //precip interception coefficient for F. sylva
SLA_AVG0                    40   //Average Specific Leaf Area m^2/KgDM (juvenil
SLA_AVG1                    20   //Average Specific Leaf Area m^2/KgDM (mature)
TSLA                        35   //Age at which SLA_AVG = (SLA_AVG1 + SLA_AVG0
SLA_RATIO                  2.3   //(DIM) ratio of shaded to sunlit projected SL
LAI_RATIO                    2   //(DIM) all-sided to projected leaf area ratio
FRACBB0                   0.20   //Branch and Bark fraction at age 0
FRACBB1                  0.125   //Branch and Bark fraction for mature stands (
TBB                         20   //Age at which fracBB = (FRACBB0 + FRACBB1 )/
RHO0                      0.64   //Minimum Basic Density for young Trees tDM/m^
RHO1                      0.64   //Maximum Basic Density for young Trees tDM/m^
TRHO                       100   //Age at which rho = (RHOMIN + RHOMAX )/2
FORM_FACTOR              0.433   //Form factor Seidl et al., 2012
COEFFCOND                 0.08   //Define stomatal responsee to VPD in mbar see
BLCOND                    0.01   //Canopy Boundary Layer conductance see 0.01 f
MAXCOND                  0.003   //Maximum Stomatal Conductance in m/sec 0,005
CUTCOND                  6e-05   //Cuticular conductance in m/sec for F sylvati
MAXAGE                     400   //Determines rate of "physiological decline" o
RAGE                      0.95   //Relative Age to give fAGE = 0.5
NAGE                        10   //Power of relative Age in function for Age
GROWTHTMIN                   0   //Minimum temperature for growth 5  Rasse et a
GROWTHTMAX                  40   //Maximum temperature for growth 40 from Willi
GROWTHTOPT                  20   //Optimum temperature for growth 19.4 Rasse et
GROWTHSTART                 60   //(5 °C)average temperature or (GDD) thermic s
MINDAYLENGTH                12   //minimum day length for fagus from ettore, 12
SWPOPEN                  -0.34   //Leaf water potential: start of reduction for
SWPCLOSE                  -2.2   //Leaf water potential: complete reduction for
OMEGA_CTEM                 0.8   //ALLOCATION PARAMETER control the sensitivity
S0CTEM                    0.10   //0.35 //PARAMETER CONTROLLING ALLOCATION TO S
R0CTEM                    0.55   //0.35 //PARAMETER CONTROLLING ALLOCATION TO R
F0CTEM                    0.35   //PARAMETER CONTROLLING ALLOCATION TO LEAVES s
FRUIT_PERC                 0.2   //fraction of NPP allocated for reproduction d
CONES_LIFE_SPAN              0   //Life span for cones (yr)
FINE_ROOT_LEAF             1.2   //allocation new fine root C:new leaf (ratio)
STEM_LEAF                  3.8   //allocation new stem C:new leaf (ratio) 3.8 p
COARSE_ROOT_STEM          0.36   //allocation new coarse root C:new stem (ratio
LIVE_TOTAL_WOOD           0.13   //new live C:new total wood (ratio) 0.15 for d
```

**Species–specific parameters (species ecophys. traits)**

# …to produce model daily output


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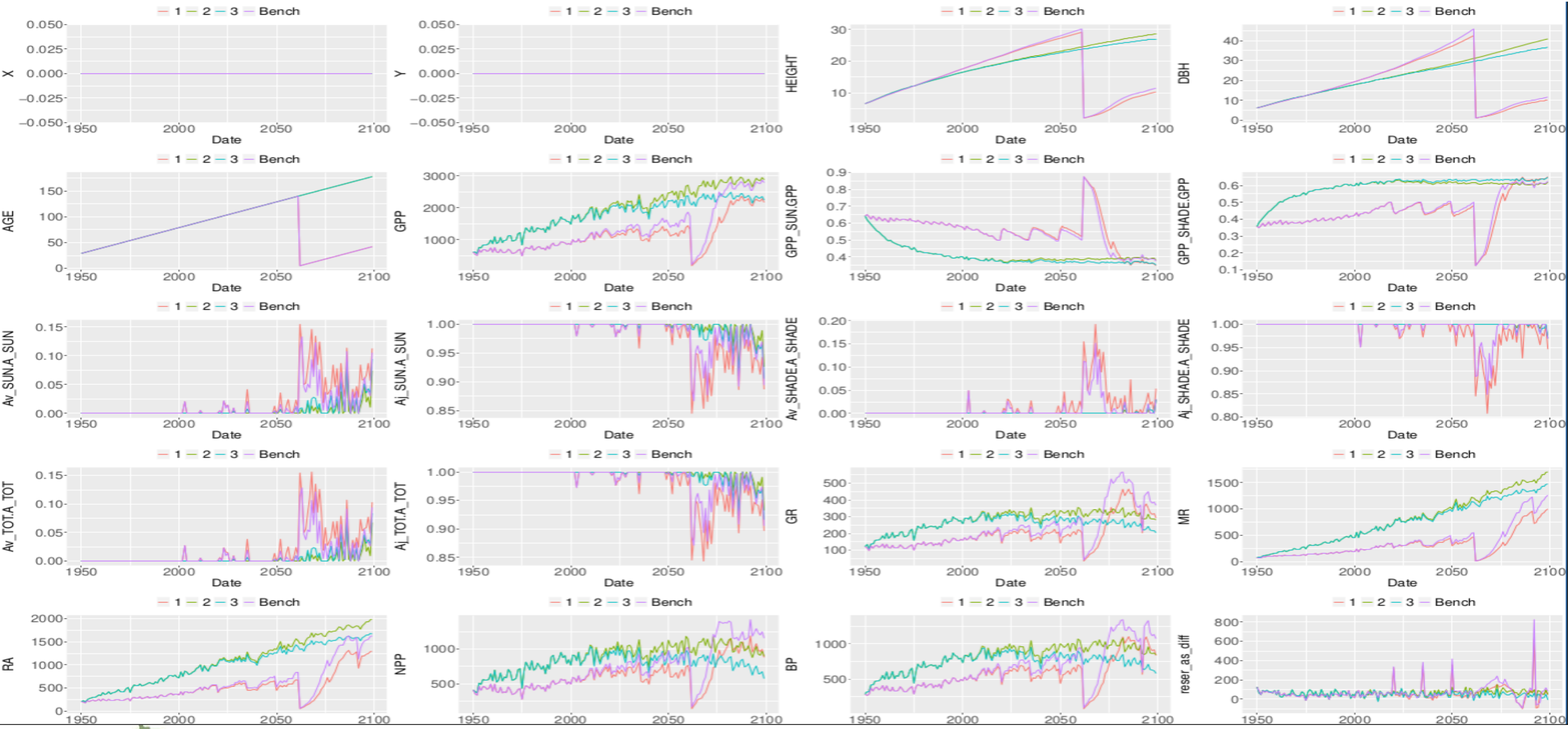
# …but more practically (an understandable annual model output)

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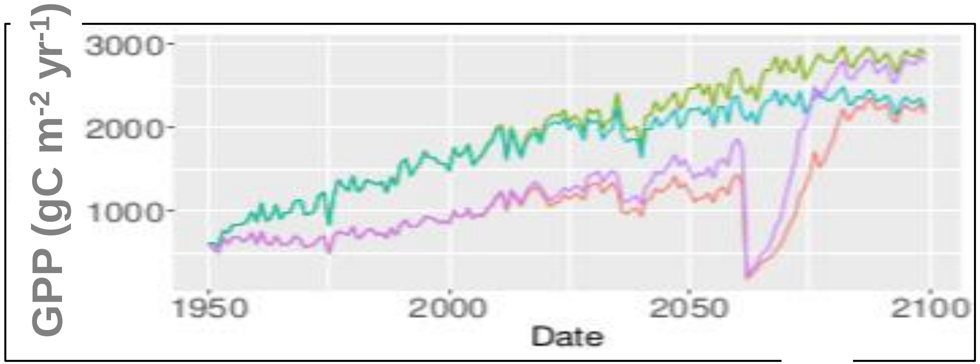
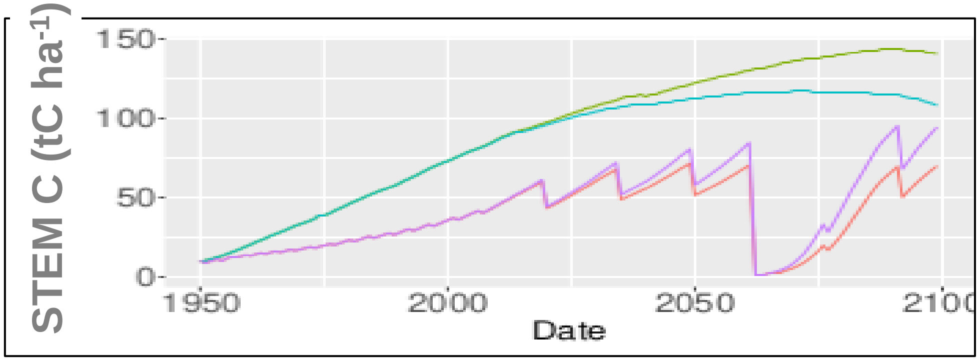
# …but more practically (an understandable annual model output)




- $[CO_2]$ on; No Management
- $[CO_2]$ off; No Management
- $[CO_2]$ on; Management
- $[CO_2]$ off; Management




**Climate forcing**: MIROC-ESM-CHEM rcp8.5

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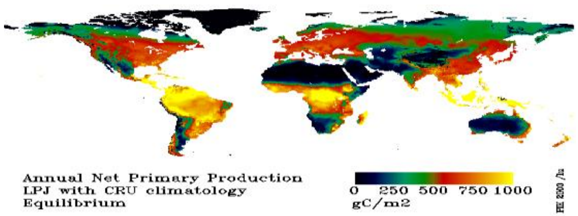
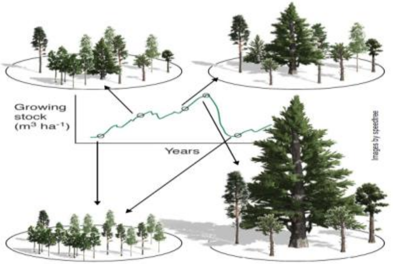
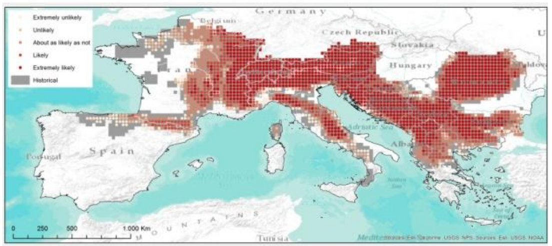
# Different models for different purposes (and some examples with strengths and limitations)




*Dynamic Global Vegetation Models*

*Gap Models*

*Species Distribution Models*

## LPJ

•from regional to global (0,5° * 0,5°)
•PFT's
•Process-Based Model
•Low spatial and temporal resolution

**Limited applicability to species level and low processes' resolution representation**

## ForClim

•stand level (1/12ha ca. 833m$^2$)
•Few numbers of input data
•Low process resolution representation
•Low computational demand

**Limited applicability to regional and potentially impossible to global level**

## BIOMOD

•No biological explanation
•Statistical model
•Wide applicability
•Black box

**No explation of the behaviour observed**

Màrecheux et al. 2021

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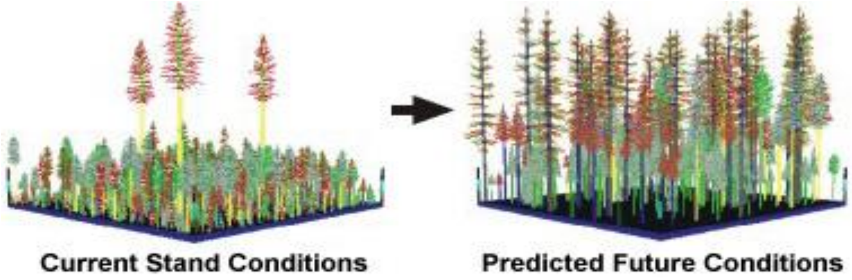
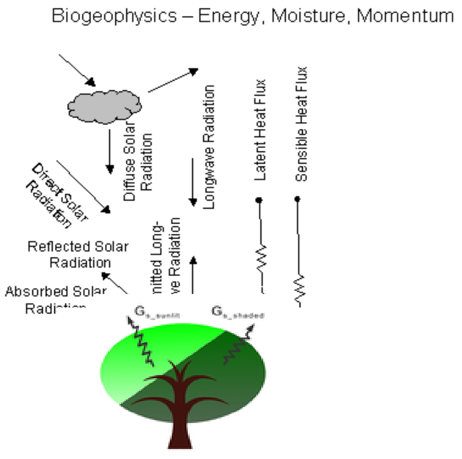
# What about the Forest Modelling Lab. (the 3D–CMCC–FEM)



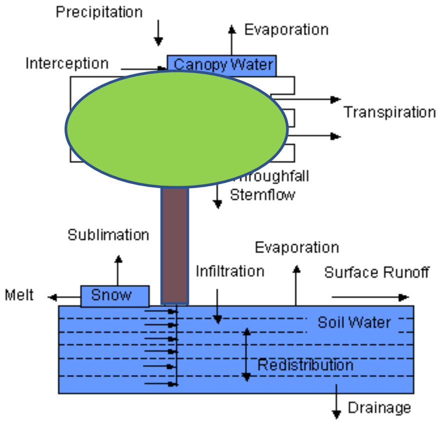

- Simulate **stand growth and development** under current and future environmental conditions
- **Bio-chemical, Bio-physical, Process-Based Model**
- Couple the **Process-Based** models' **robustness** of the layer and cohort models
- Variable **temporal** scale(daily to annual)
- Variable **spatial** scale (1ha to *x* $Km^2$)
- Management (thinning, harvest, replanting)

# 3D-CMCC-FEM **Biophysical processes**:

- SURFACE ALBEDOS
- RADIATIVE TRANSFER
- SENSIBLE HEAT (under development) AND LATENT HEAT FLUXES
- SOIL AND SNOW TEMPERATURE
- CANOPY TRANSPIRATION
- CANOPY INTERCEPTION
- SOIL EVAPORATION
- SNOW
- SURFACE RUNOFF AND INFILTRATION
- SOIL WATER CONTENT

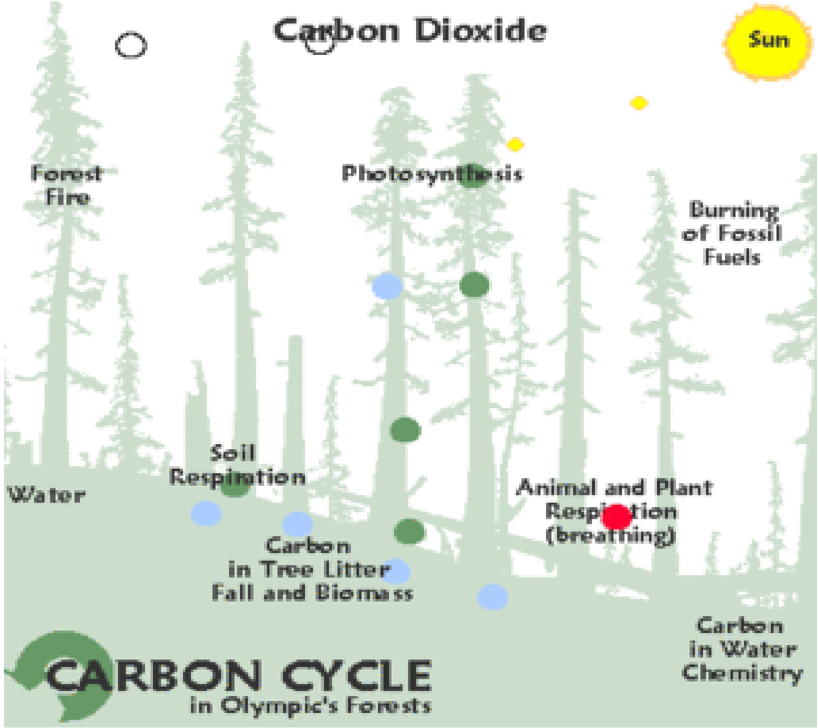


The two-big-leaf scheme

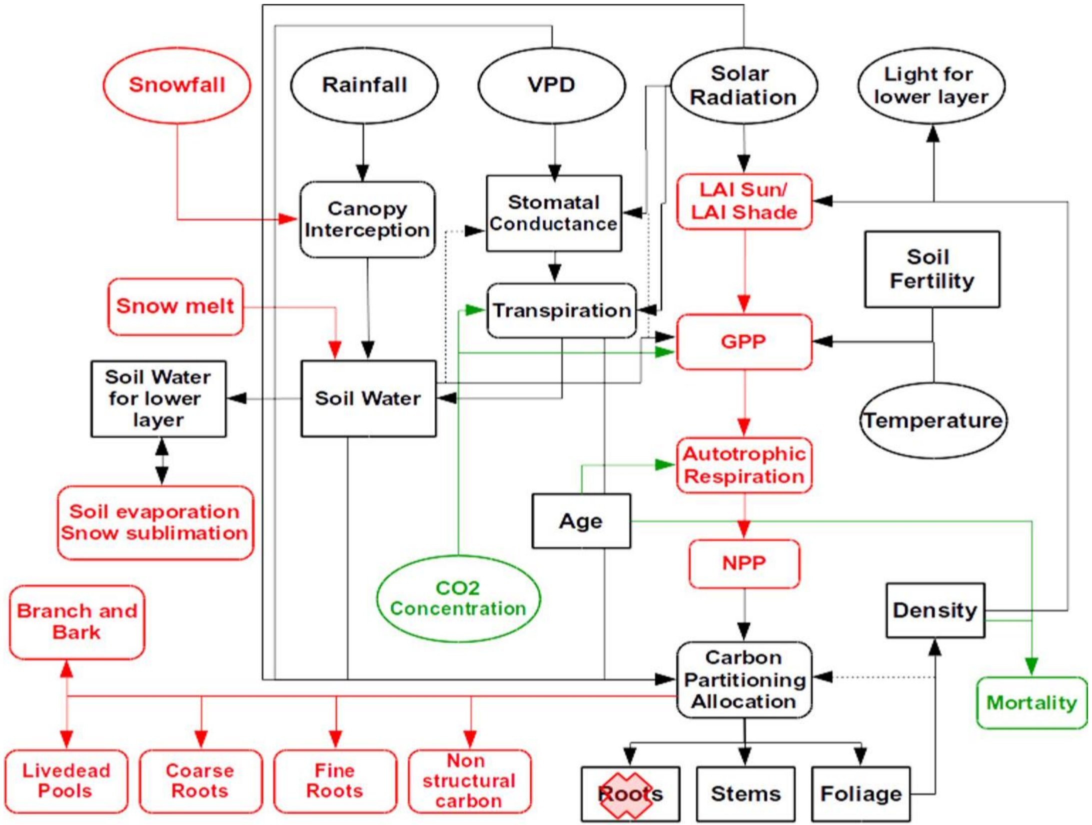


# 3D-CMCC-FEM **Biochemical processes**:

- CANOPY PHOTOSYNTHESIS
- AUTOTROPHIC RESPIRATION
- HETEROTROPHIC RESPIRATION
- CARBON ALLOCATION
- NSC-Dynamic
- WOOD PRODUCTION
- PHENOLOGY
- Changes in Forest STRUCTURE
- LITTERFALL production
- …



# 3D-CMCC-FEM  Model Flowchart:

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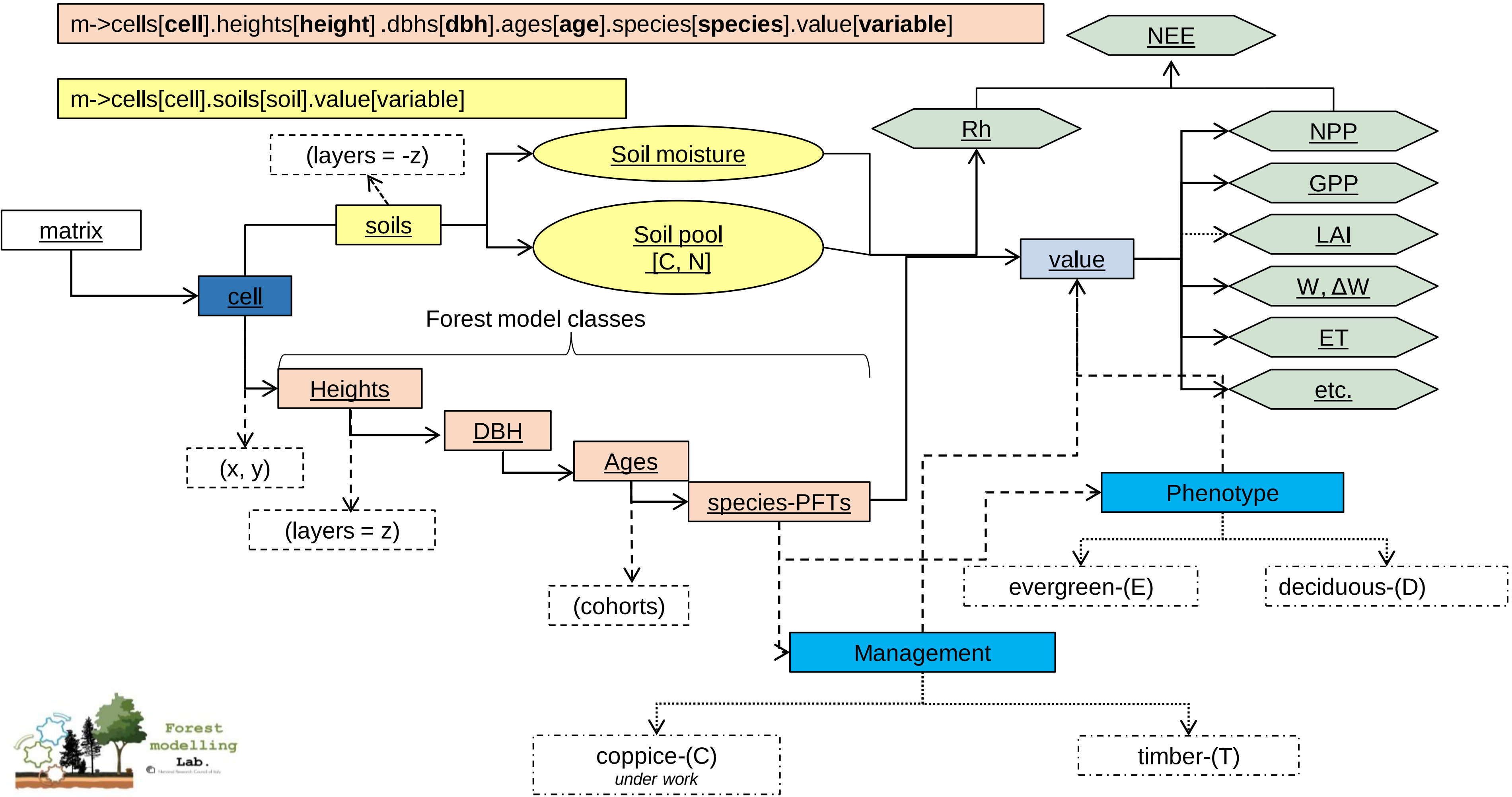
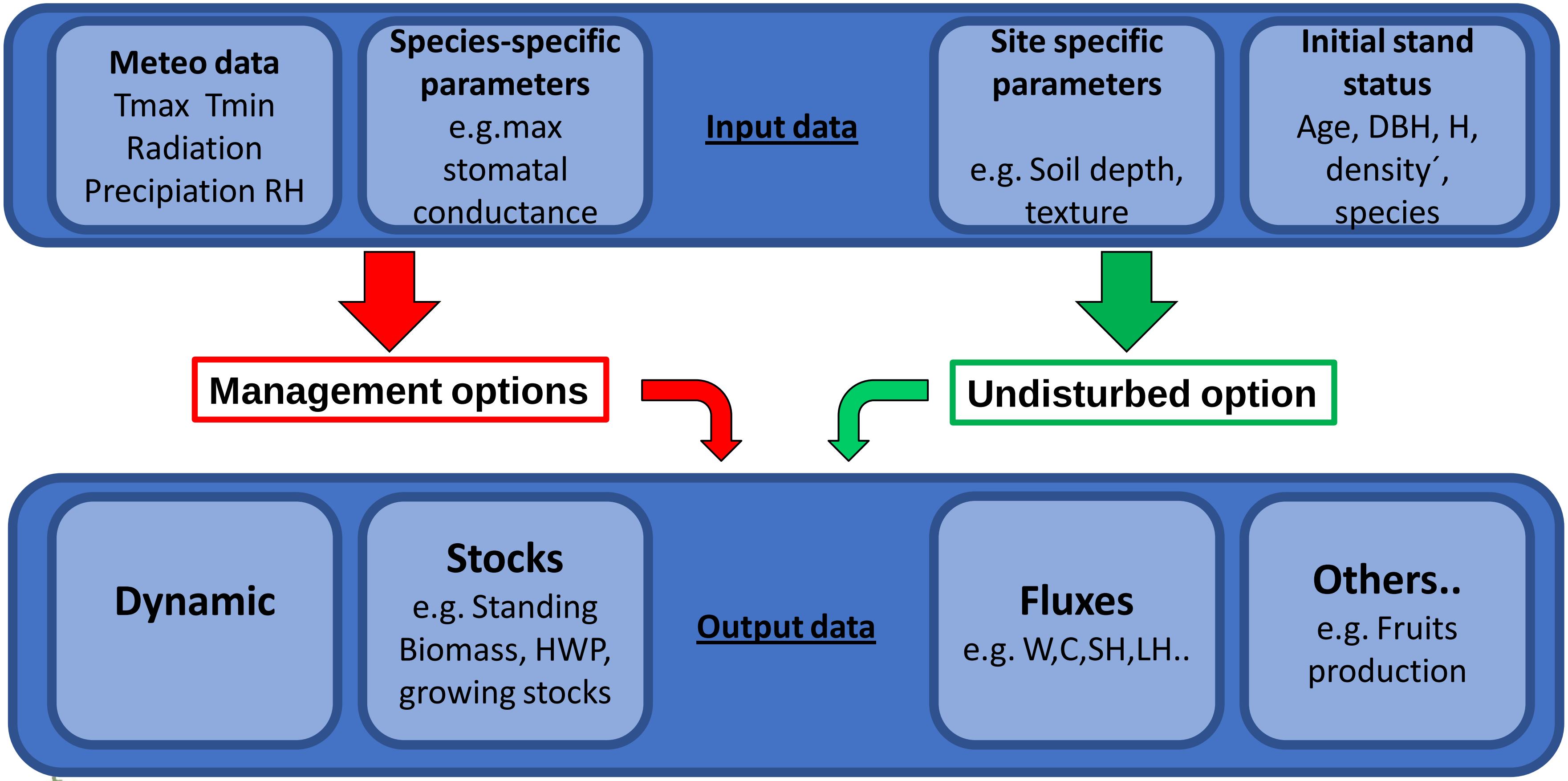
# 3D-CMCC-FEM Model core logic-structure



# Input/output model data and simulation options

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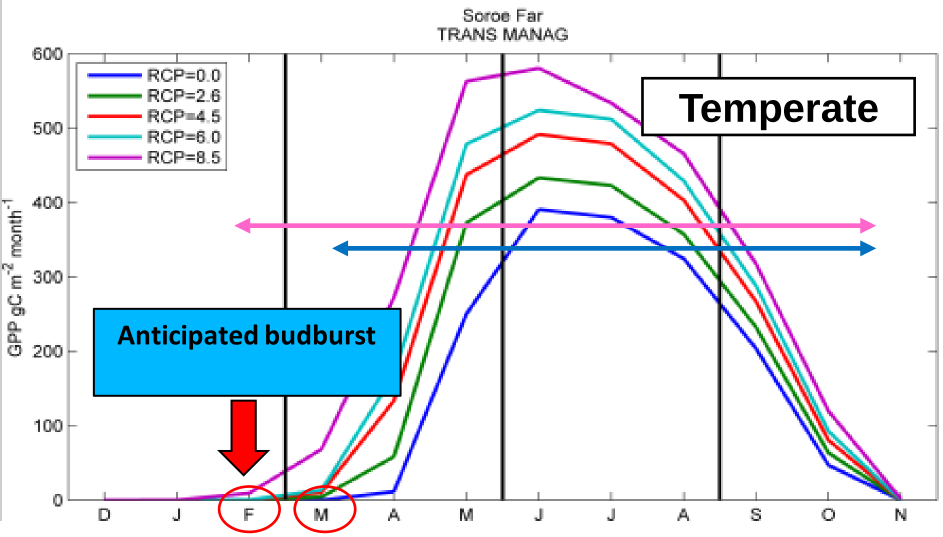
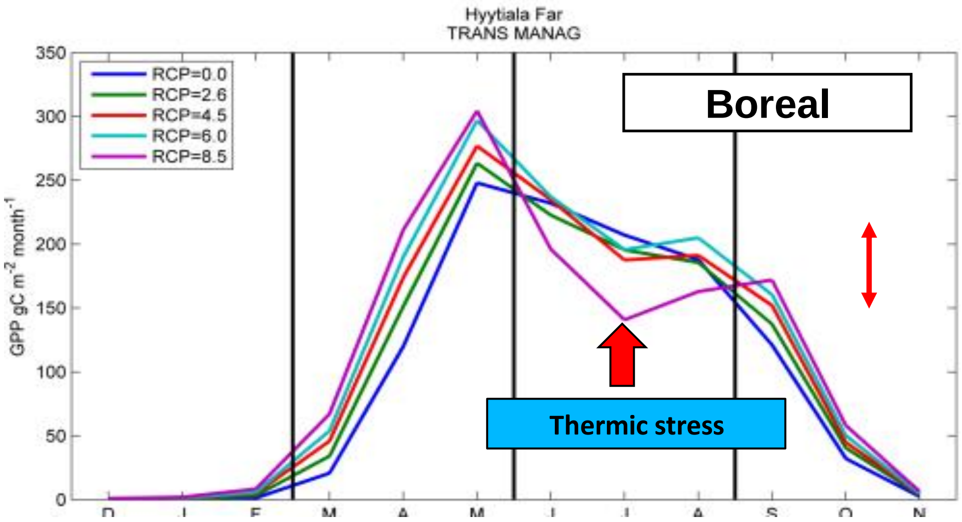
# Process-Based Model (PBMs) – Make predictions on climate change

Changes in **phenology** under different **climate forcing scenarios** from 2000 to 2100




Soroe site (Denmark)
*Fagus sylvatica*




Hyytiala site (Finland)
*Pinus sylvestris*

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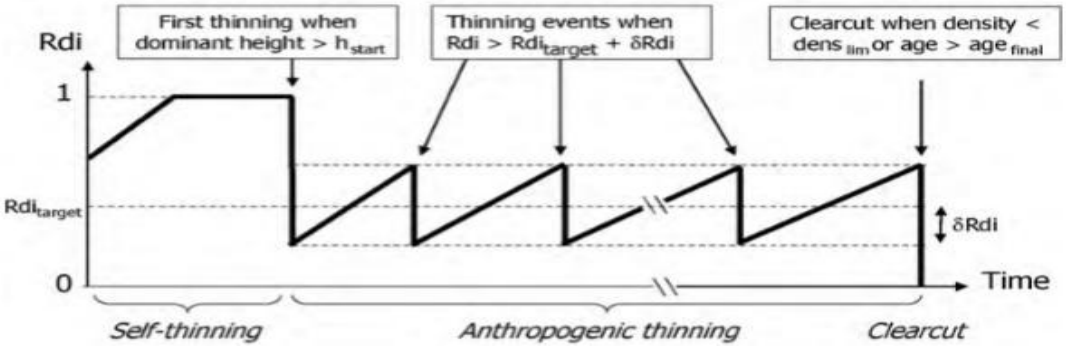
*Collalti et al. (2018), James*

# Process-Based Model (PBMs) – Make predictions on forest management

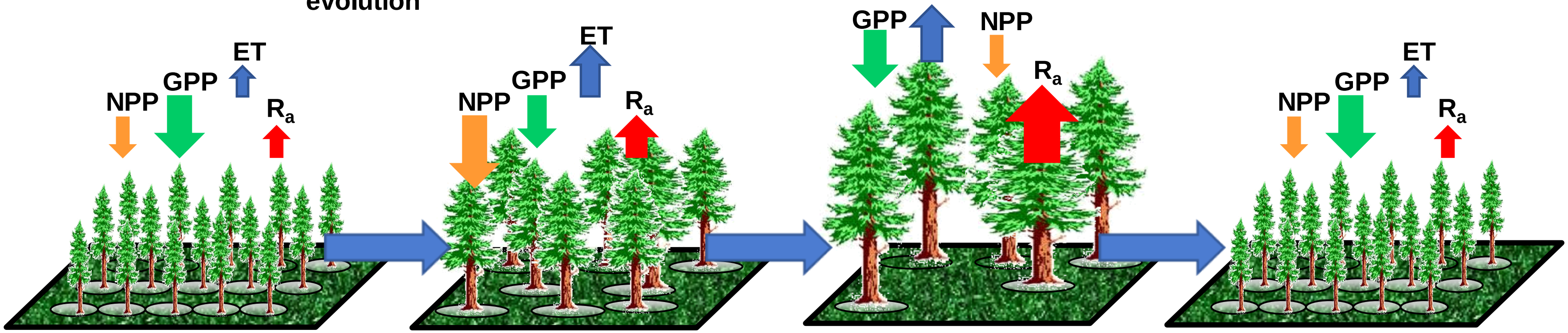
## What happens if we manage forests?




(Bellassen *et al*. 2010)

Natural evolution

Managing forests

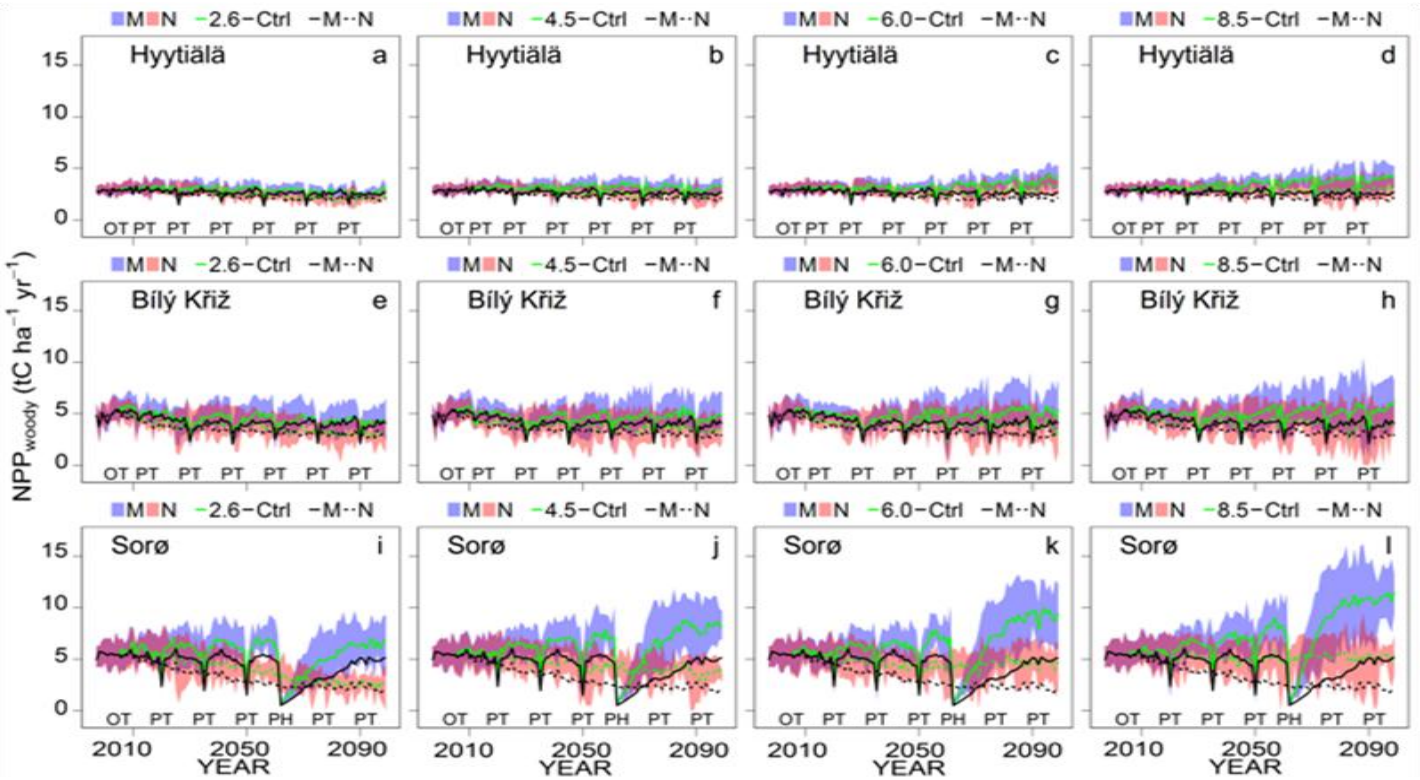



Initial state (real case) Thinning Thinning Clearcut and replanting

**Initial state** → **Final state**

# Testing Management Vs. No Management Under Climate Change

## Net Primary Productivity




UnManaged

Managed

**OT = observed thinning, PT = prescribed thinning, PH = prescribed harvesting**

(Collalti *et al.*, 2018)

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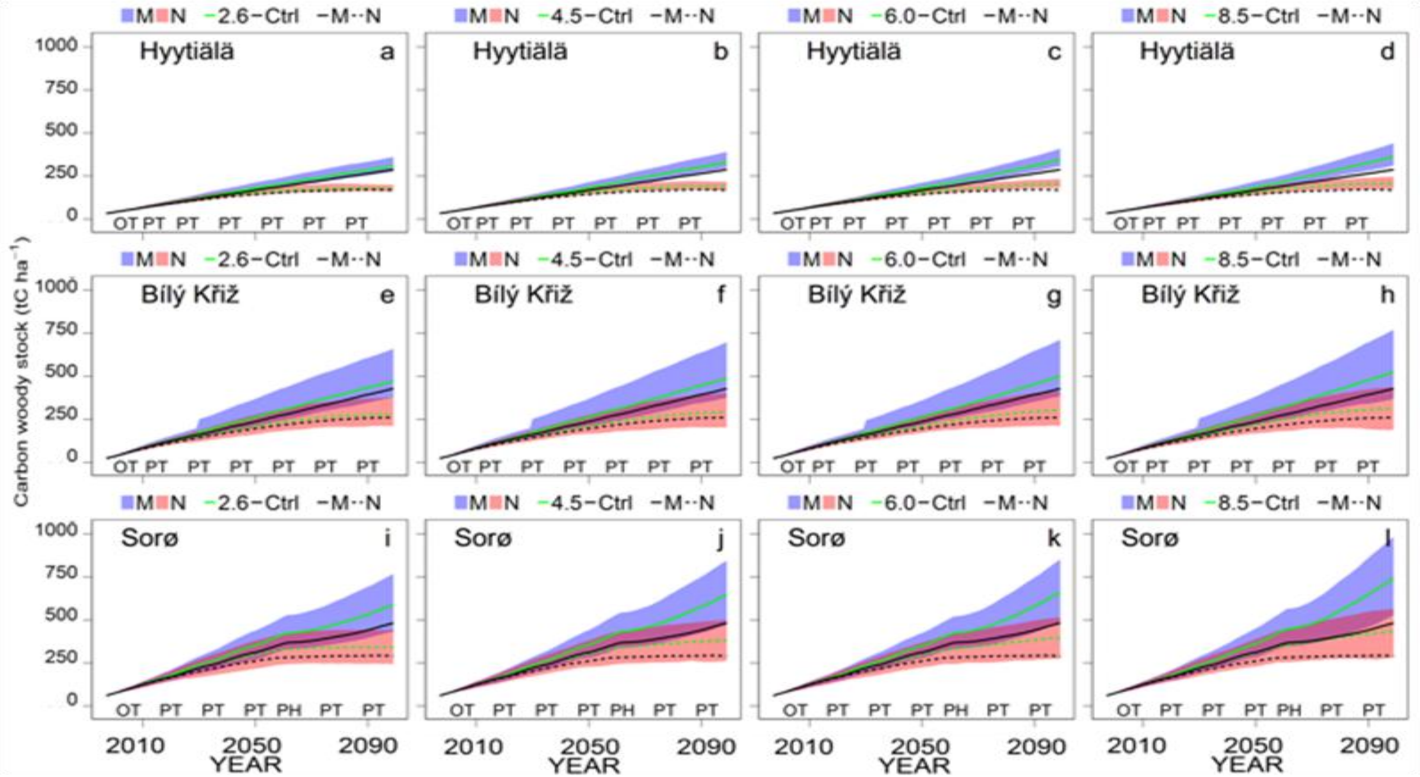
# Testing Management Vs. No Management Under Climate Change

## Carbon Woody Stocks



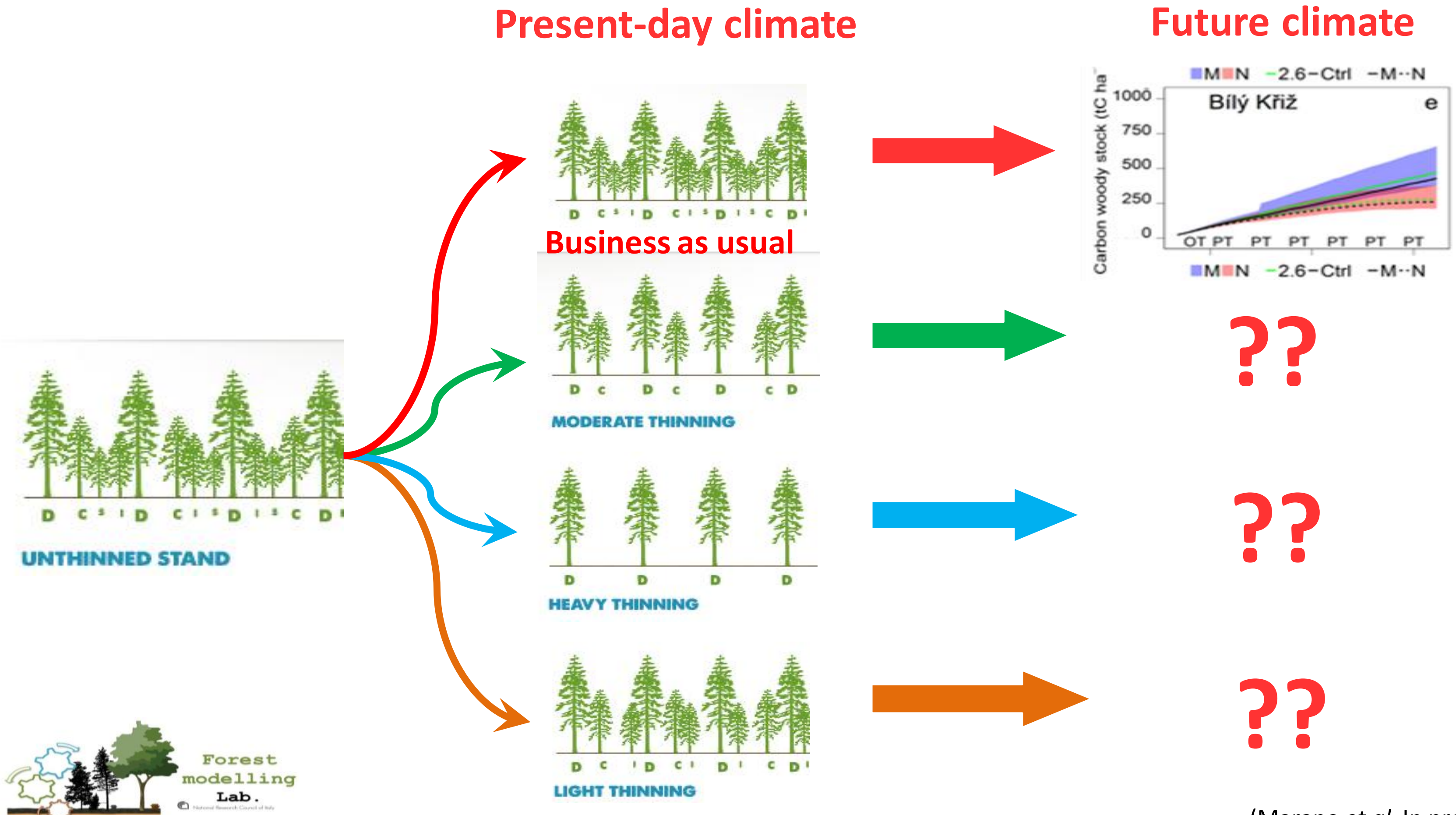

UnManaged

Managed

**OT = observed thinning, PT = prescribed thinning, PH = prescribed harvesting**

(Collalti *et al.*, 2018)

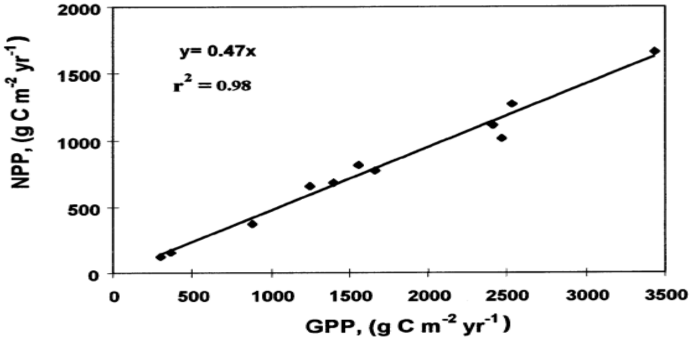
# What about future forest management?



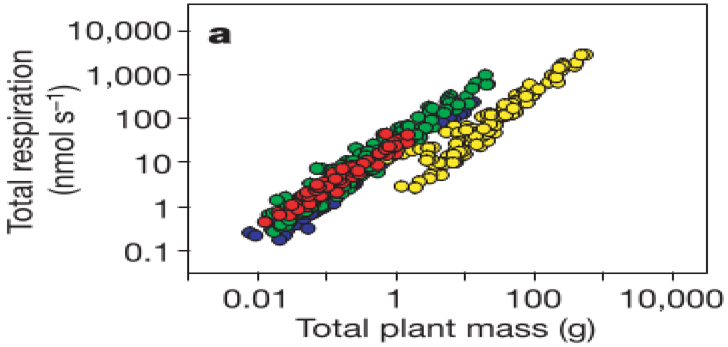

(Marano *et al*. In prep.)

# Process-Based Model (PBMs) – Testing long-lasting ecological theories

**Question:** Plant respiration is controlled by photosynthesis or biomass?




(*Waring et al. 1998, Tree Physiology*)




(*Reich et al. 2006, Nature*)

$H_1$: "Respiration is controlled by **photosynthesis"**

$H_2$: "Respiration is controlled by (total) **biomass"**

**Results:** none of these two hypotheses are actually correct!

(but how we found out that?)

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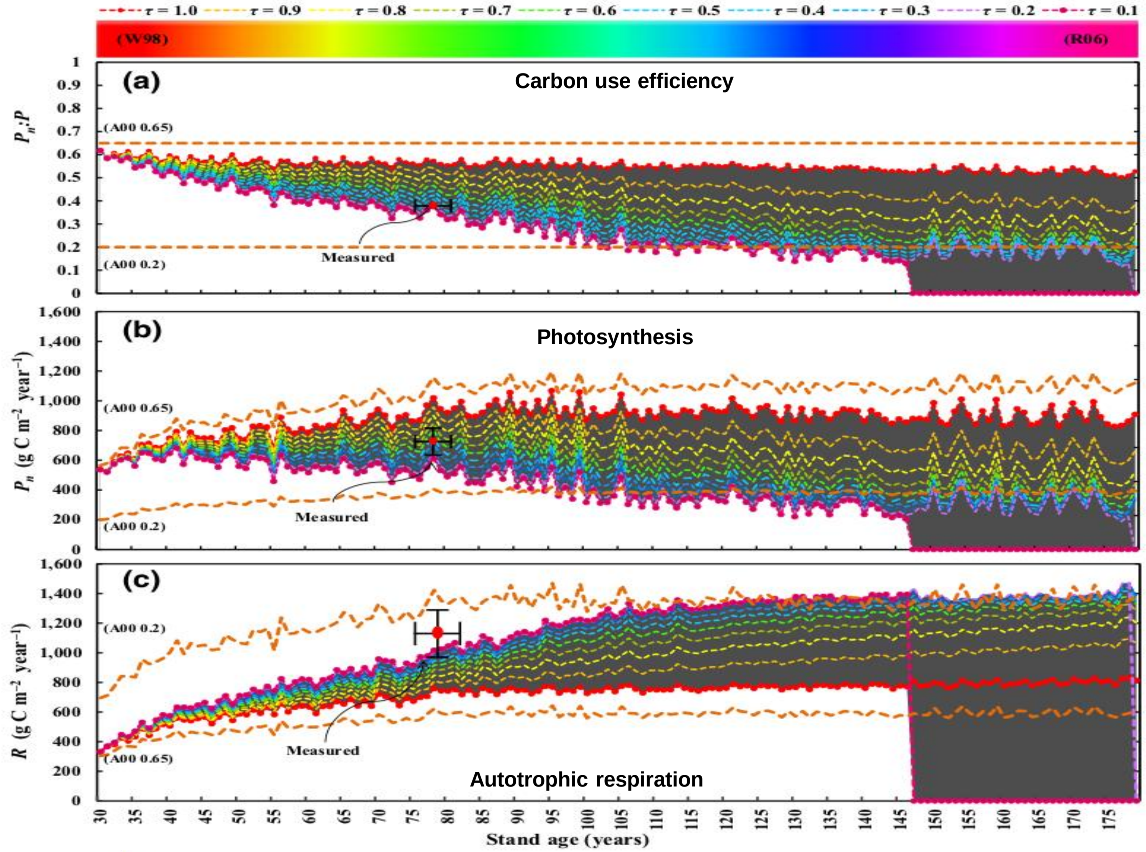
# Process-Based Model (PBMs) – Testing long-lasting ecological theories




If respiration would be controlled only by photosynthesis in winter, when photosynthesis is stopped, all live cells would die. However, there have been found many live cells older than year

H$_1$: Respiration controlled by **photosynthesis**

REJECTED

If respiration would be controlled only by biomass at increasing forest age respiration would became too high, consuming too much carbon, and trees would completely die when mature

H$_2$: Respiration controlled by (total) **biomass**

REJECTED

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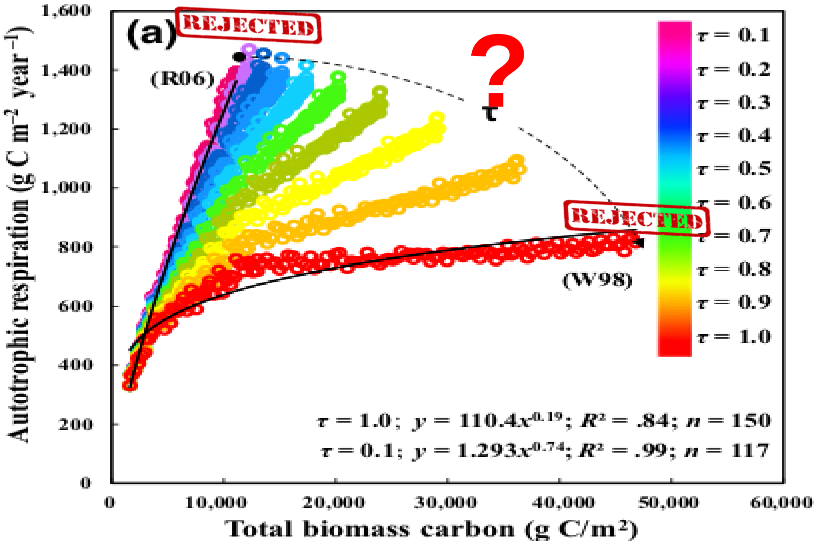
*Collalti et al. (2020), GCB*

# Process-Based Model (PBMs) – Testing long-lasting ecological theories

**<u>Conclusion</u>:** Respiration is controlled by **both photosynthesis** and **biomass** at a variable extent, which we do not currently know, but somewhere in between the two hypotheses (both excluded)




Collalti et al. (2020), GCB

# **Conclusions:** Strengths and present limitations of forest models (some)

## **Some present strengths**:

- Possibility to simulate **effects of climate change** ($CO_2$ fertilization effects, Temperature acclimation, ...)
- Simulate **eco-physiological processes** of heterogeneous forests with complex structure
- Consider **forest structure** evolution (i.e. vertical and horizontal heterogeneity)
- Simulate and quantify light and water **competition**
- Possibility to be spatially upgraded from **local** scale to **regional** scale reducing the amount of the needed initialization data

## **Some present limitations**:

- Relatively high request of **input data** and **parameters**
- High computationally **demanding**
- Still, to some extent, **uncertain**

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# Thanks!

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National Research Council of Italy

Consiglio Nazionale Ricerche
ISAFOM



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