The 3D-CMCC-CNR Forest Ecosystem Model, Climate Change and Management scenarios

(***Functional responses to climate change and management scenarios***)

Collalti A.

on behalf of the 3D-CMCC-CNR Model working group

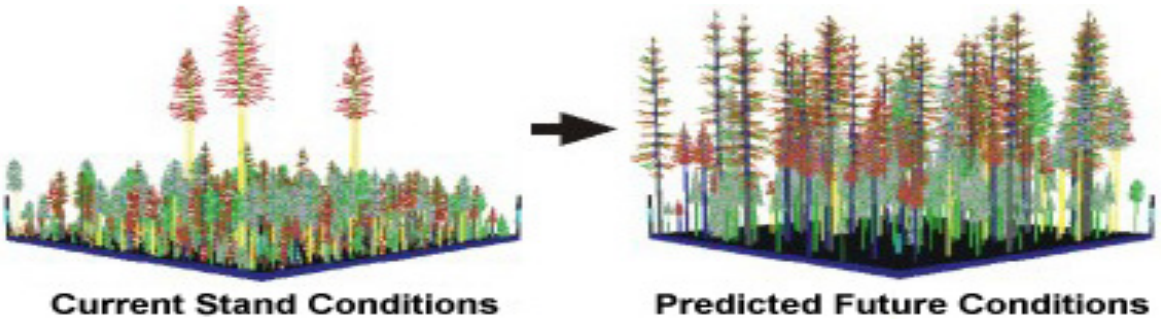
CNR-ISAFOM Institute for Agriculture and Forestry Systems in the Mediterranean –Rende (CS) Italy

Foundation Euro-Mediterranean Center on Climate Change IAFES division – Viterbo Italy

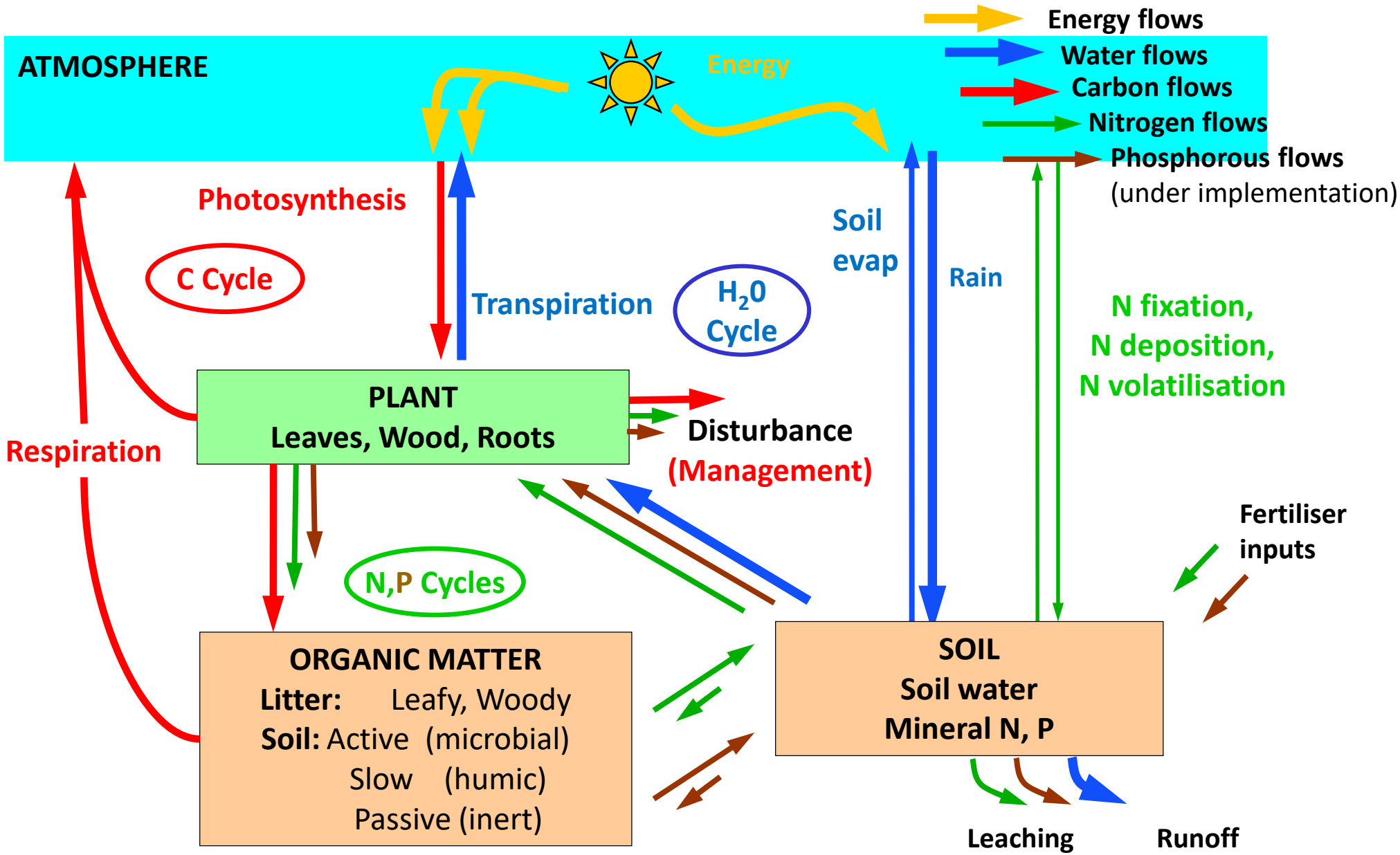
3D-CMCC-CNR (FEM/BGC) main **characteristics** and **applicability**

- **Bio-geochemical, Bio-physical, Process-Based Model**
- Couple the **Process-Based** models' **robustness** with a layer and cohort model
- Consider the canopy horizontal cell coverage trough algorithms that take into account the **forest density** (trees/ha)
- Can simulates a **mixed** forest composed by different cohorts, species, diameter and **height classes** as simultaneously composed by evergreen/deciduous species
- Compute and quantify the effects of this **heterogeneity** also into the daily soil water balance (i.e. evapotranspiration, soil evaporation or rain interception)
- Variable **temporal** scale(daily to monthly to annual)
- Variable **spatial** scale (1ha to *x* Km^2)
- Capability to simulate different **management** schemes under **current** and **future climate change** scenarios

It is a tool to predict forest responses to climate change

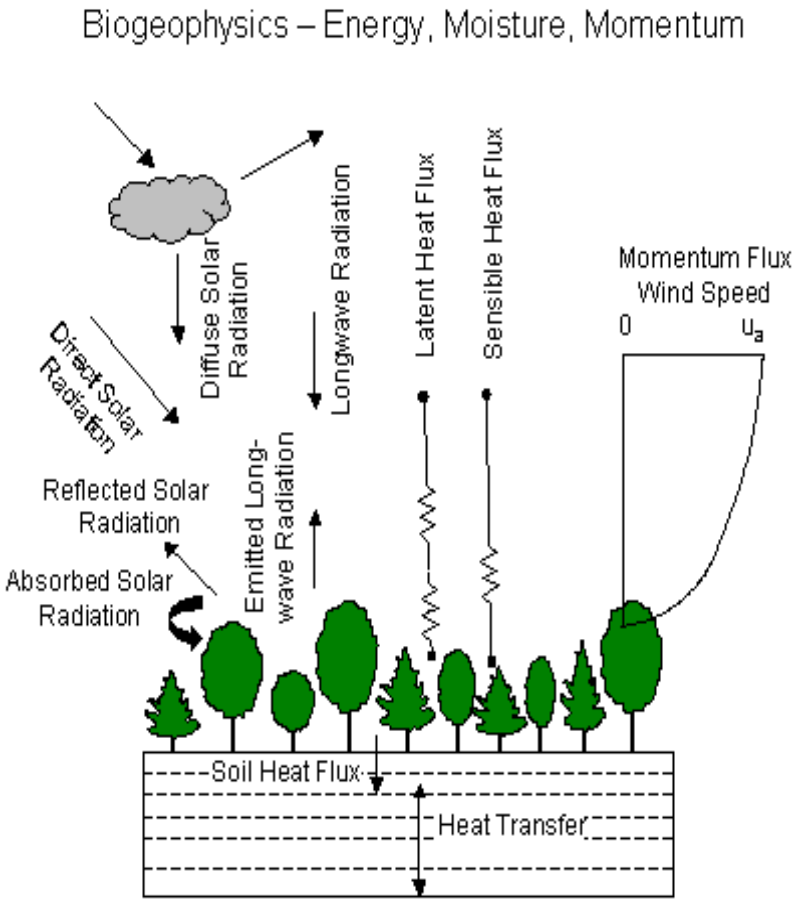


3D-CMCC-CNR FEM/BGC *main eco-physiological processes*



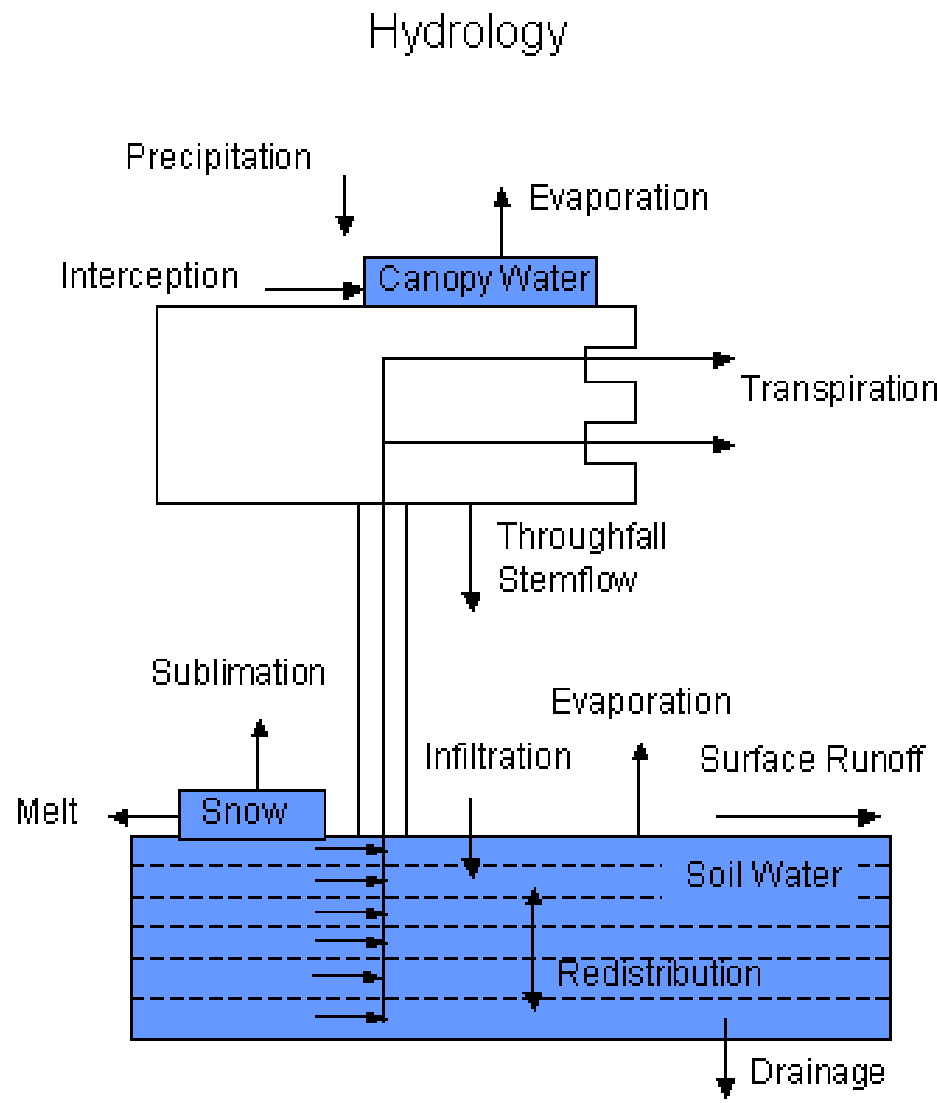
3D-CMCC-CNR FEM/BGC *Biophysical processes*:

- SURFACE ALBEDOS
- RADIATIVE TRANSFER
- LATENT HEAT FLUXES
- SOIL AND SNOW TEMPERATURE



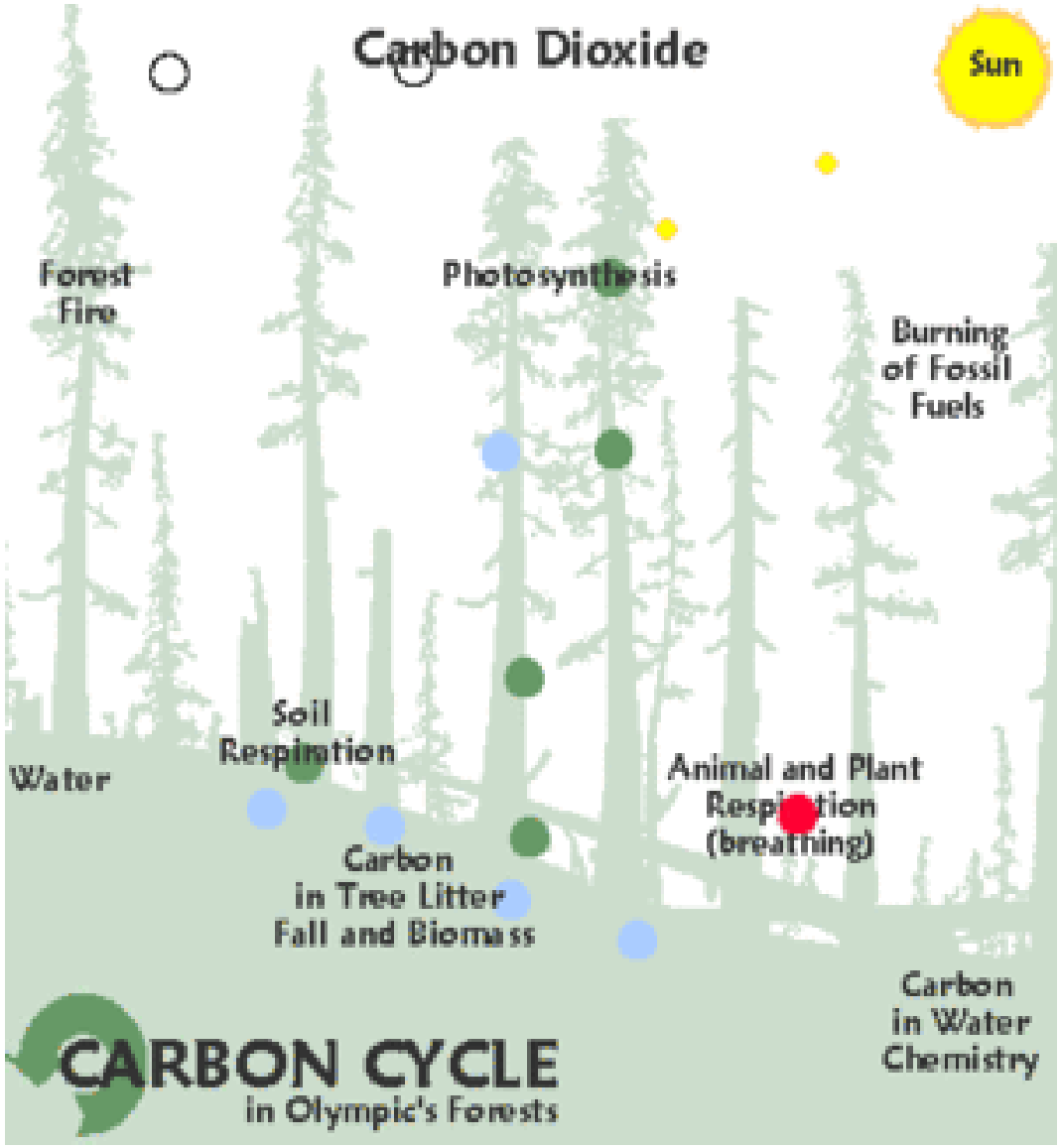
3D-CMCC-CNR FEM/BGC *Hydrological processes*:

- CANOPY TRANSPIRATION
- CANOPY INTERCEPTION
- (CANOPY EVAPOTRANSPIRATION)
- SOIL EVAPORATION
- SNOW MELT AND SUBLIMATION
- SURFACE RUNOFF AND INFILTRATION
- SOIL WATER CONTENT



3D-CMCC-CNR FEM/BGC *Biochemical processes*:

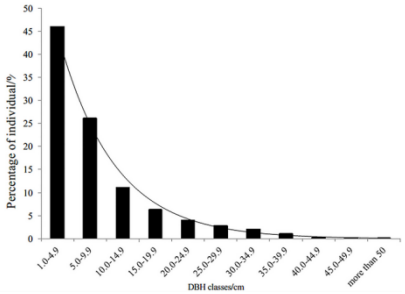
- CANOPY PHOTOSYNTHESIS
- AUTOTROPHIC RESPIRATION
- HETEROTROPHIC RESPIRATION
- C-N-P ALLOCATION
- PHENOLOGY
- VEGETATION STRUCTURE
- LITTERFALL
- "CARBON CYCLE"
- "NITROGEN CYCLE"
- "PHOSPHOROUS CYLE" *(under implementation)*



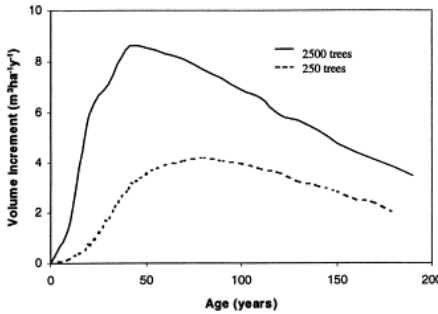
Main variables (classes) controlling forest dynamic and productivity

- **HEIGHT** → It defines **vertically** tree position into the forest structure, and its light availability

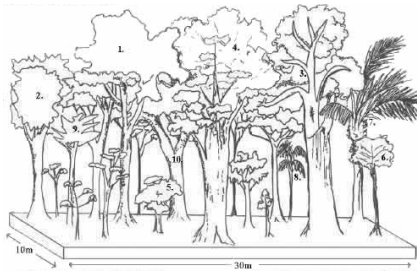
- **DBH** → It defines **horizontal** arrangement of crowns into the forest structure



- **AGE** → It determines the tree **age related decline** in forest productivity

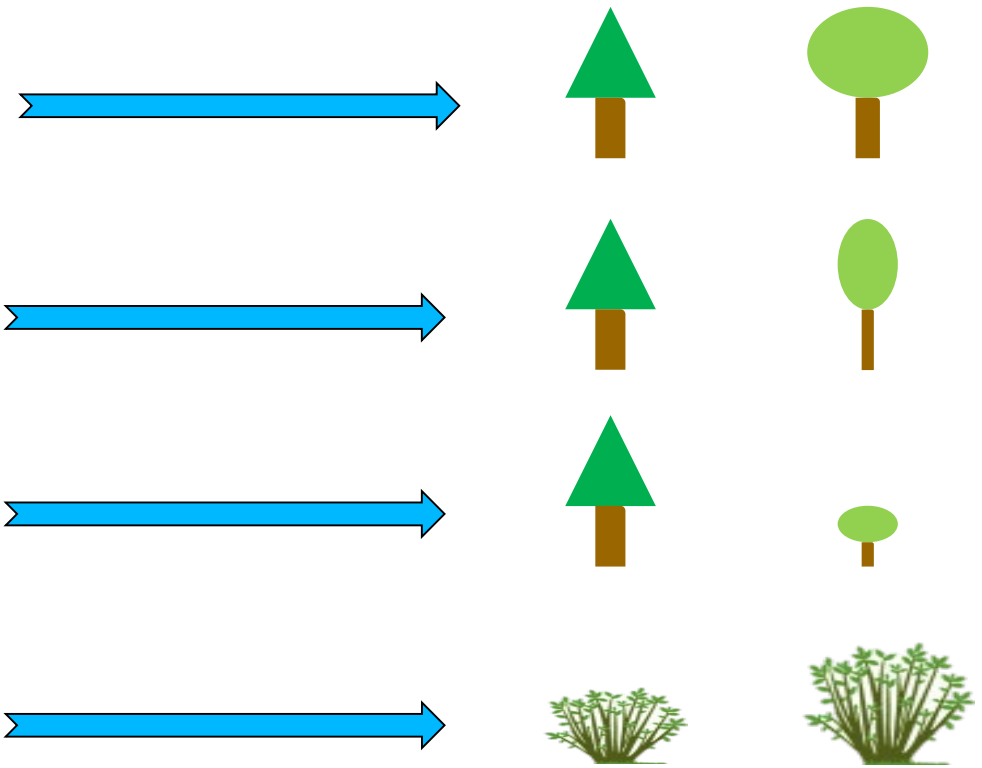


- **SPECIES** → It reflects the different **auto-ecology** among species and their differences to **adapt** to changing climate



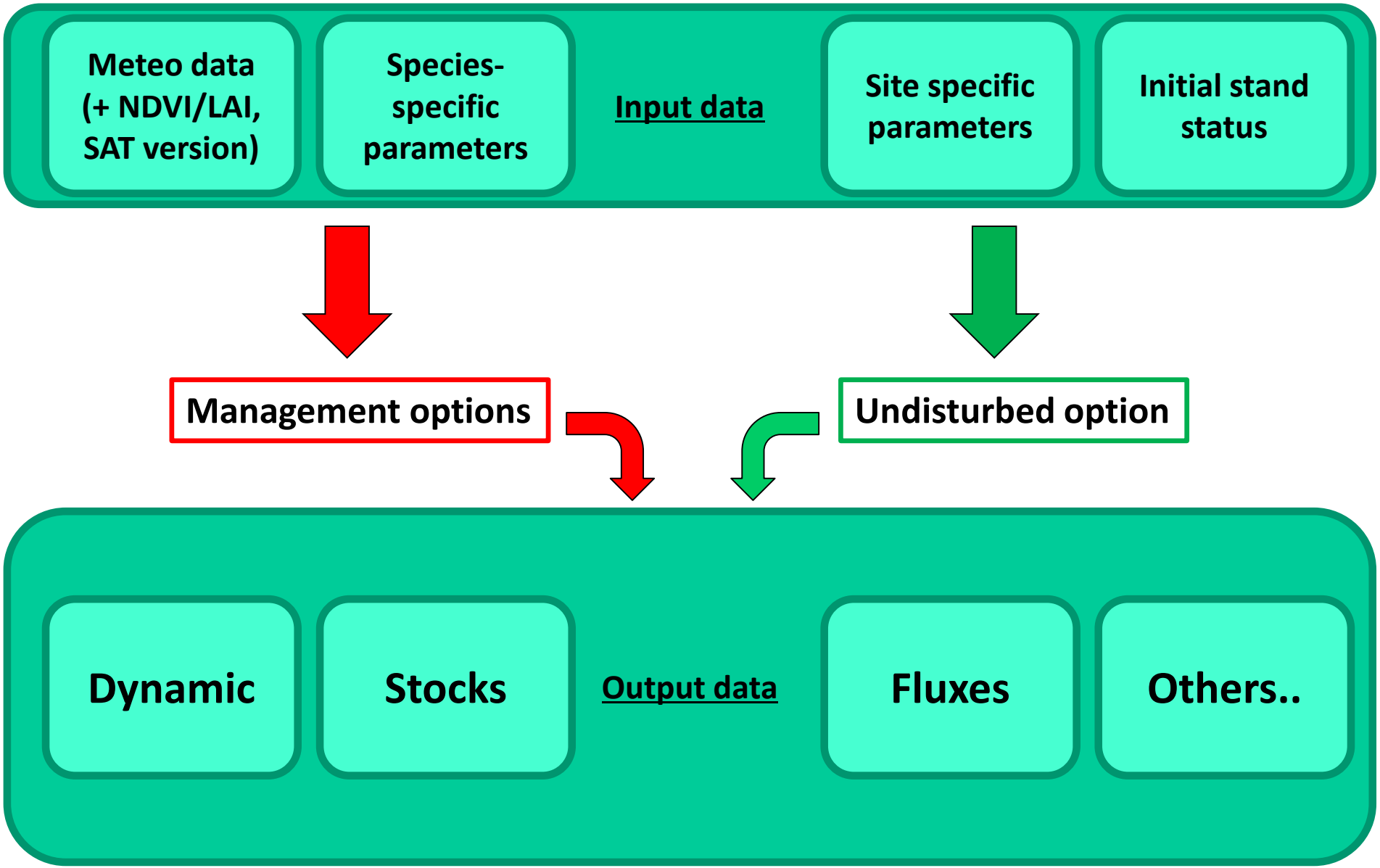
The aims:

- develop a model able to simulate **different** forest **typologies (mixed stands):**
  - **Multi-species**
  - **Uneven-aged**
  - **Multi-layered**
  - **Managed**

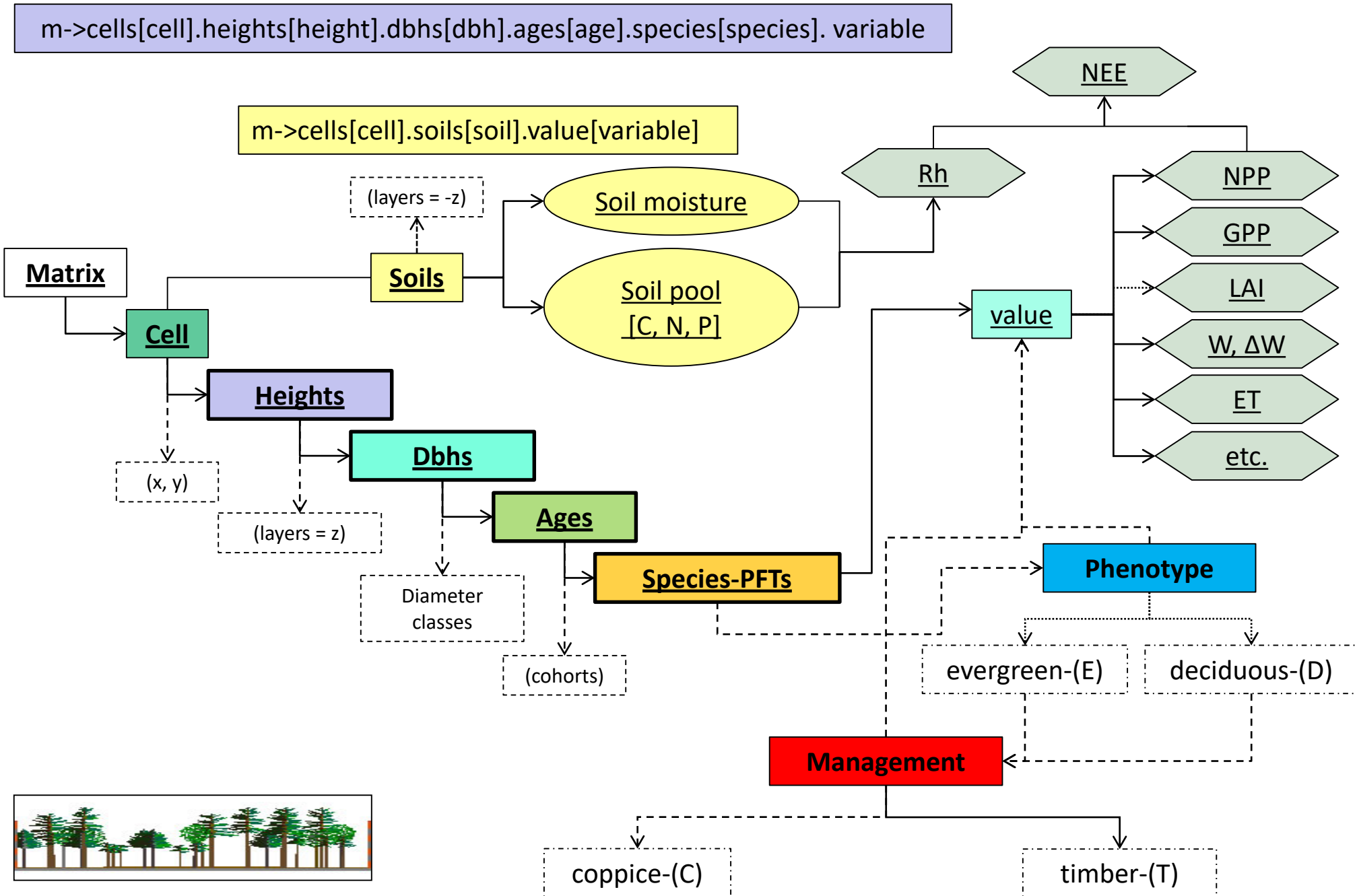


produce information about their **dynamics**, **growth** and **yield** at forest ecosystem- and class-level

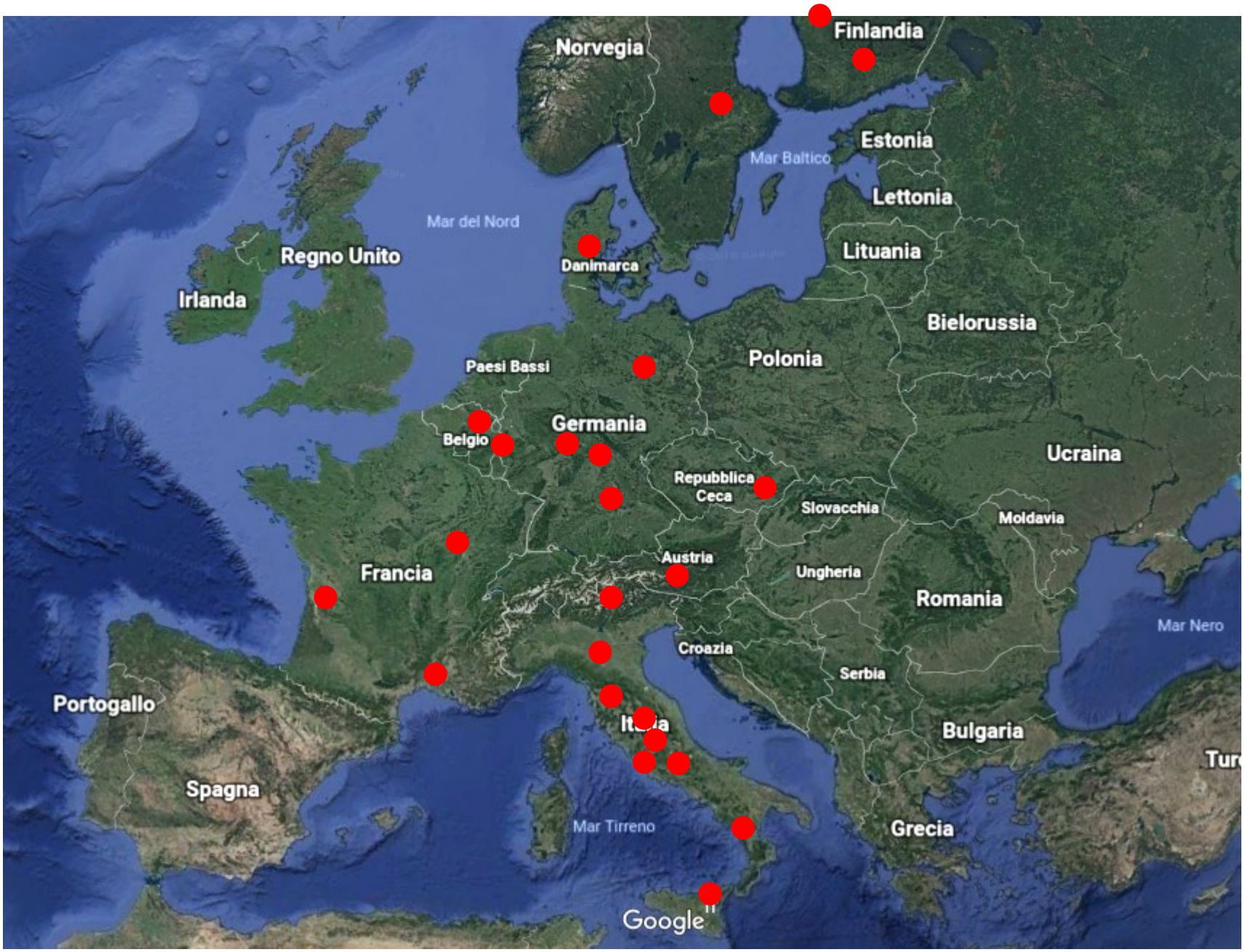
Input/output model data and simulation options



Model's C core logic structure (versions 5.x-6.x)



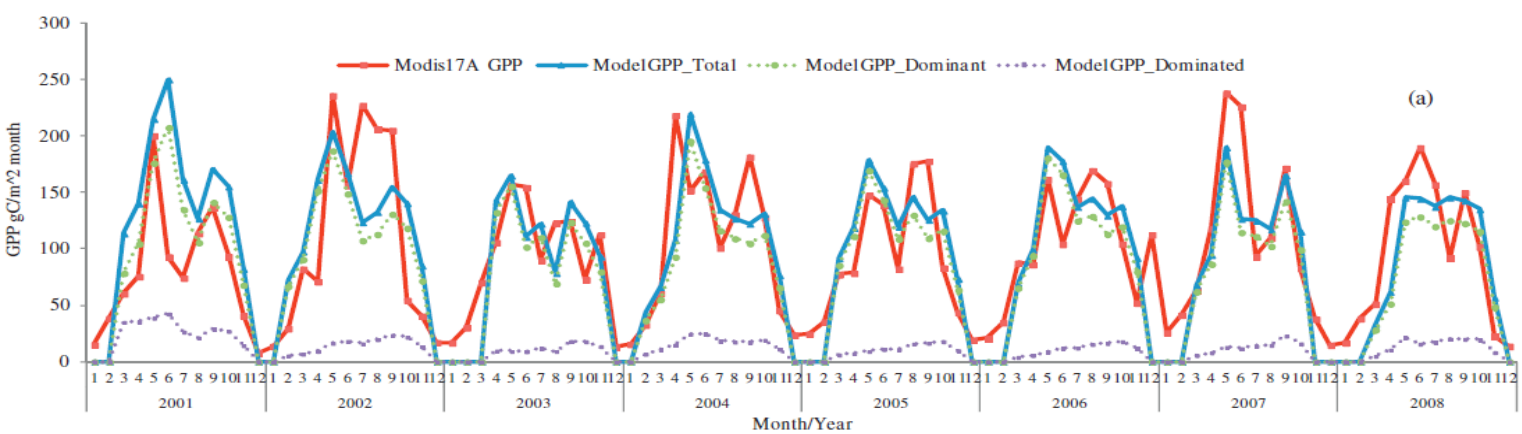
Model applications (and validations) over almost ten years..

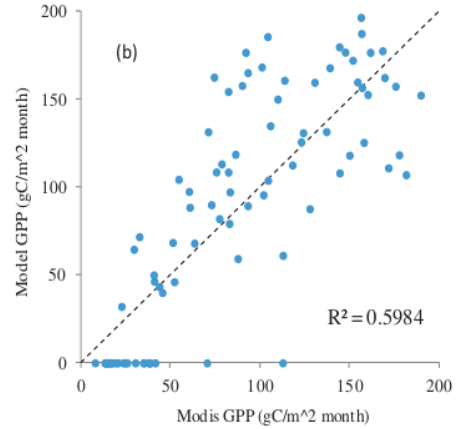


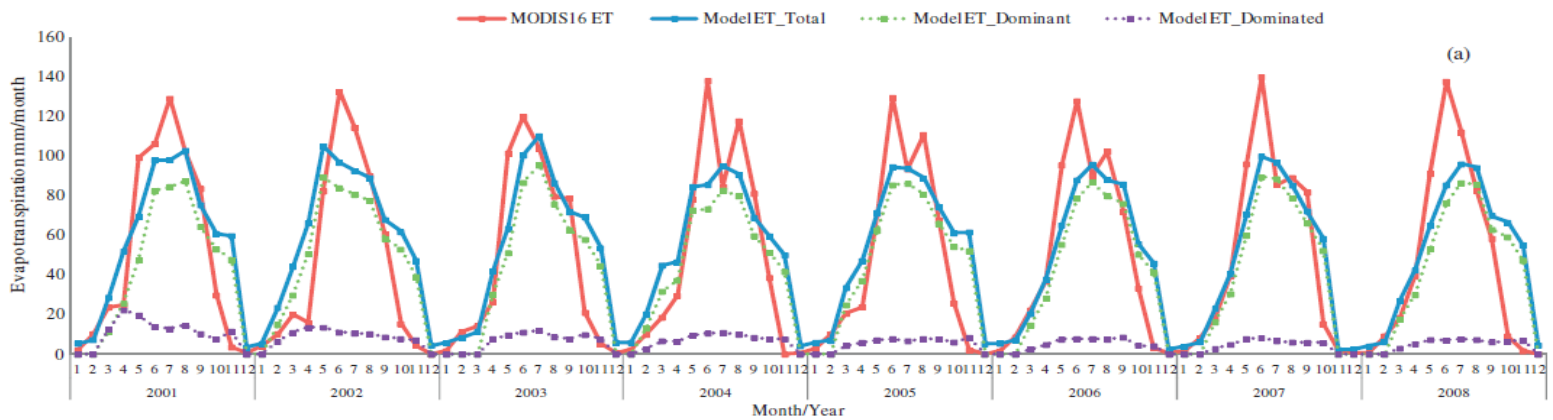
Some examples of model applications (under <u>current climate</u>)…

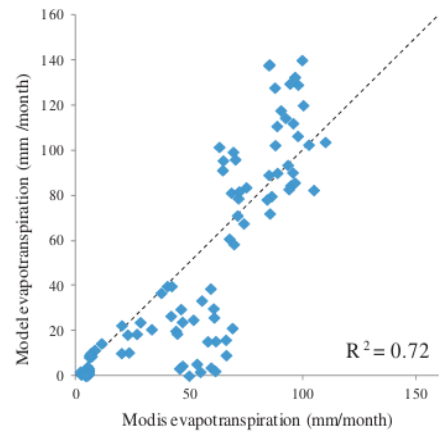
Model validation (v.4.0 + v. sat) Annual GPP-NPP-MAI-CAI

"A process-based model to simulate growth in forests with complex structure: Evaluation and use of 3D-CMCC Forest Ecosystem Model in a deciduous forest in Central Italy". **(*Collalti et al., 2014*)**









ELSEVIER

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

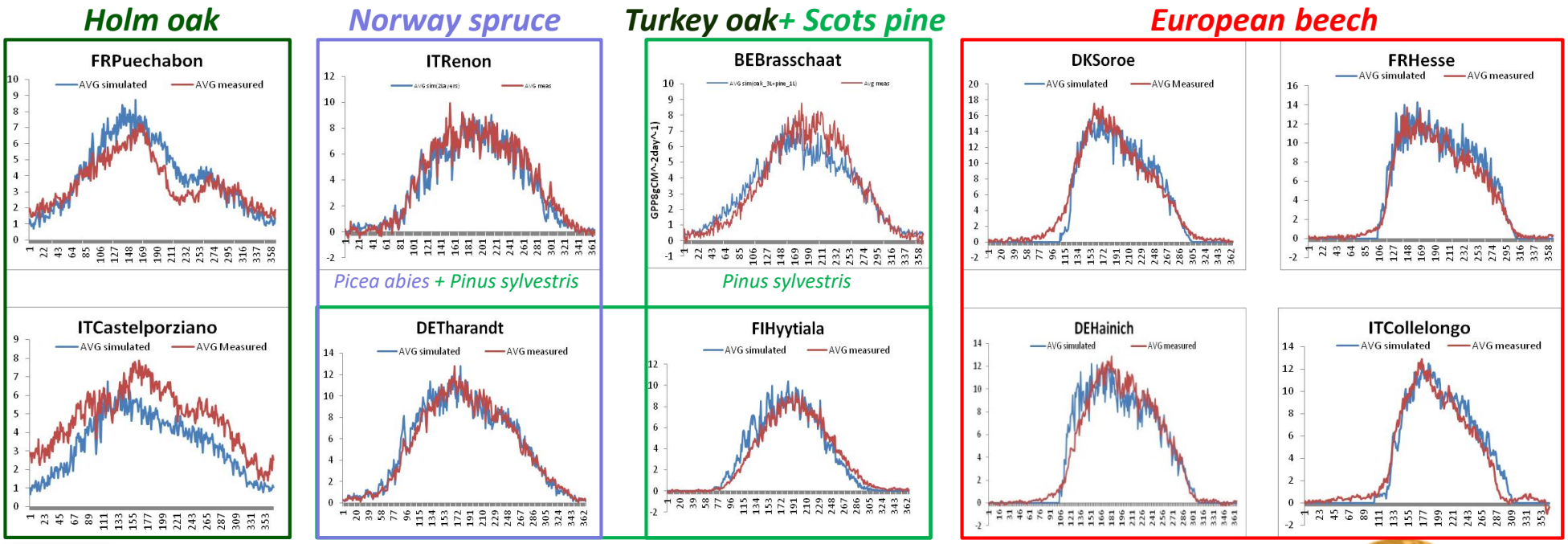
A process-based model to simulate growth in forests with complex structure: Evaluation and use of 3D-CMCC Forest Ecosystem Model in a deciduous forest in Central Italy

CrossMark

Alessio Collalti [a,b,*], Lucia Perugini [b], Monia Santini [a], Tommaso Chiti [b], Angelo Nolè [c], Giorgio Matteucci [d,e], Riccardo Valentini [a,b]

Model validation (v.5.1) - Seasonal GPP trends

"Validation of 3D-CMCC Forest Ecosystem Model (v.5.1) against eddy covariance data for ten European forest sites."
(Collalti et al., 2016)



Geoscientific Model Development
An interactive open-access journal of the European Geosciences Union

Geosci. Model Dev., 9, 479-504, 2016
http://www.geosci-model-dev.net/9/479/2016/
doi:10.5194/gmd-9-479-2016

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Volume 9, issue 2

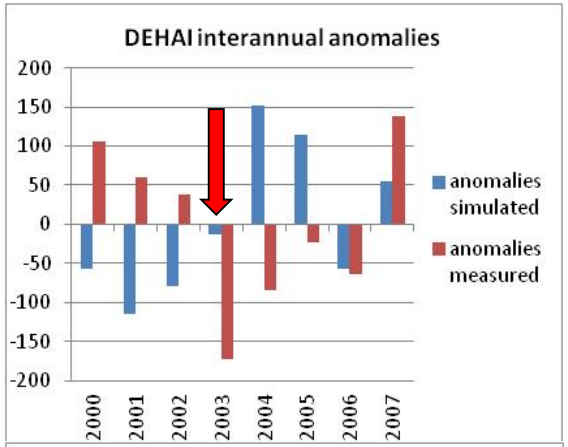
Development and technical paper

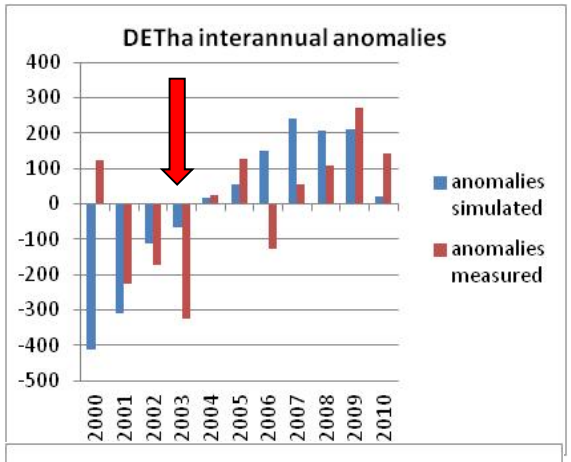
08 Feb 2016

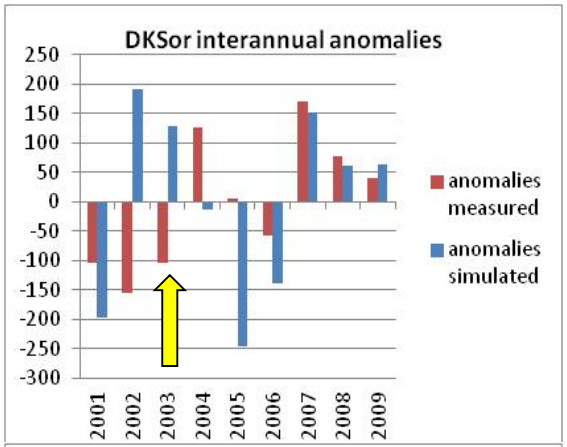
Validation of 3D-CMCC Forest Ecosystem Model (v.5.1) against eddy covariance data for 10 European forest sites

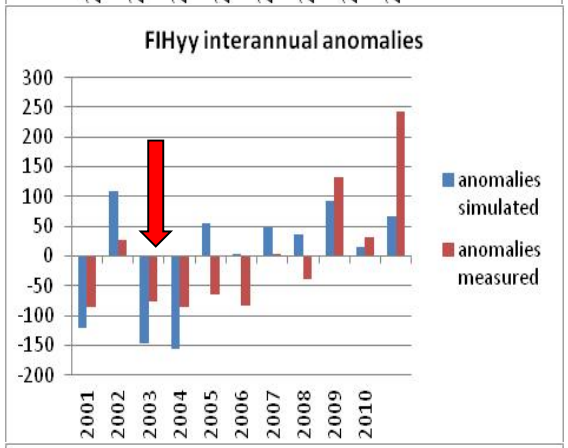
A. Collalti[1,2], S. Marconi[1,2], A. Ibrom[3], C. Trotta[2], A. Anav[4], E. D'Andrea[5], G. Matteucci[5,6], L. Montagnani[7], B. Gielen[8], I. Mammarella[9], T. Grünwald[10], A. Knohl[11], F. Berninger[12], Y. Zhao[13], R. Valentini[1,2], and M. Santini[1]

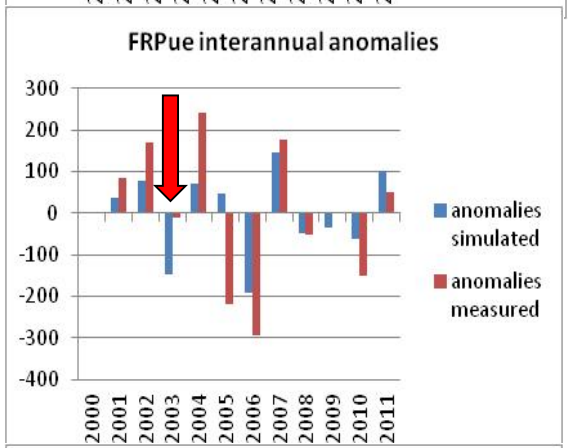
Model validation (v.5.1) – GPP Inter-annual variability and extremes (“*the acid test*”)

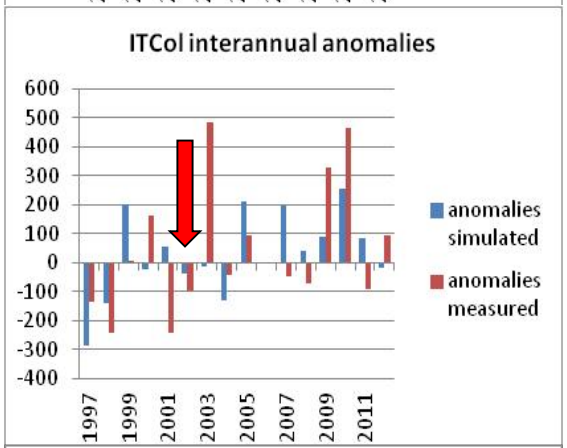


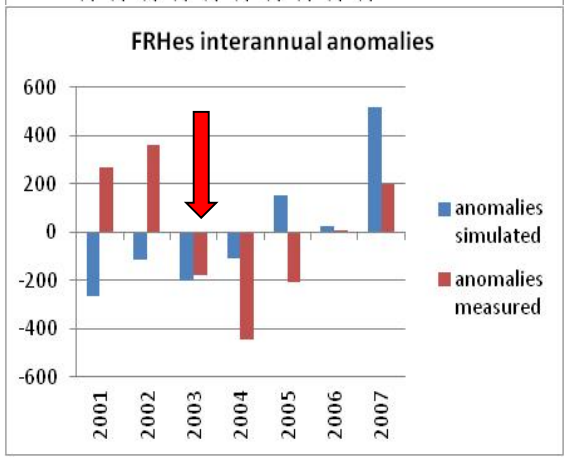


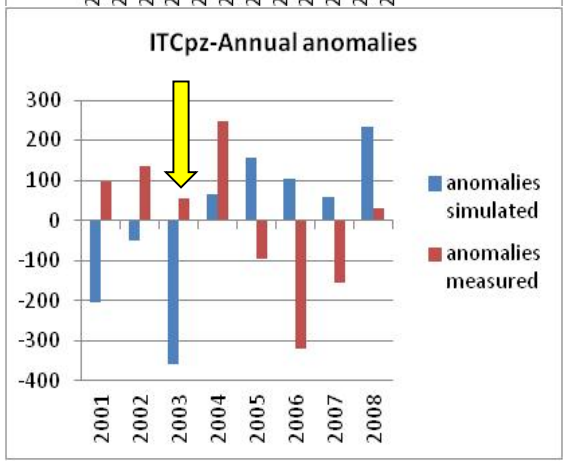


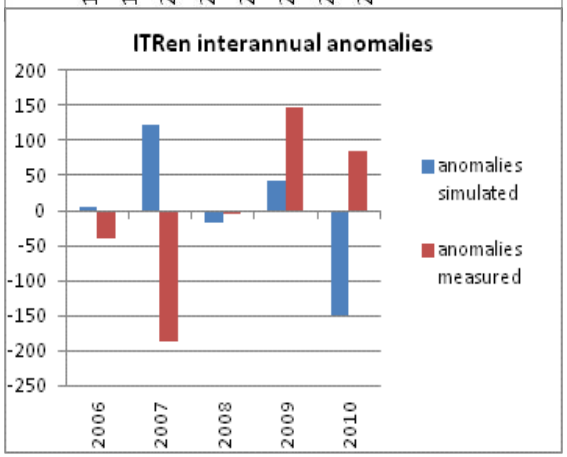












…but what about under different
climate change scenarios (and management)?

<u>Expected</u> physiological responses from trees and forests**:**

- increases in **photosynthesis** and **autotrophic respiration** because of warming
- increases in **photosynthesis** because of increasing atmospheric CO_2 (fertilization effect)
- Increase in **net primary productivity** because warming and CO_2 fertilization
- decrease in **leaf transpiration** per unit of carbon synthesized because of increasing atmospheric CO_2
- Increases in **water use efficiency** (e.g. photosynthesis / leaf transpiration)

<u>Uncertain</u> physiological responses from trees and forests**:**

- increases in **respiration** higher than in **photosynthesis** (reduced Carbon Use Efficiency)
- **Carbon allocation** (Structural vs. Non-structural biomass)
- effects of **management**
- plants **adaptation** capacity
- **Nitrogen** and **Phosphorus** limitations

Model projections under climate changes (v.5.2 and following):

Goals:

- evaluate vegetation responses to **warming**
- evaluate vegetation responses to rising **atmospheric CO_2 concentration**
- evaluate vegetation responses to changes in **precipitation** and **regimes**
- effects of **management** under climate change scenarios
- effects under **alternative management** scenarios

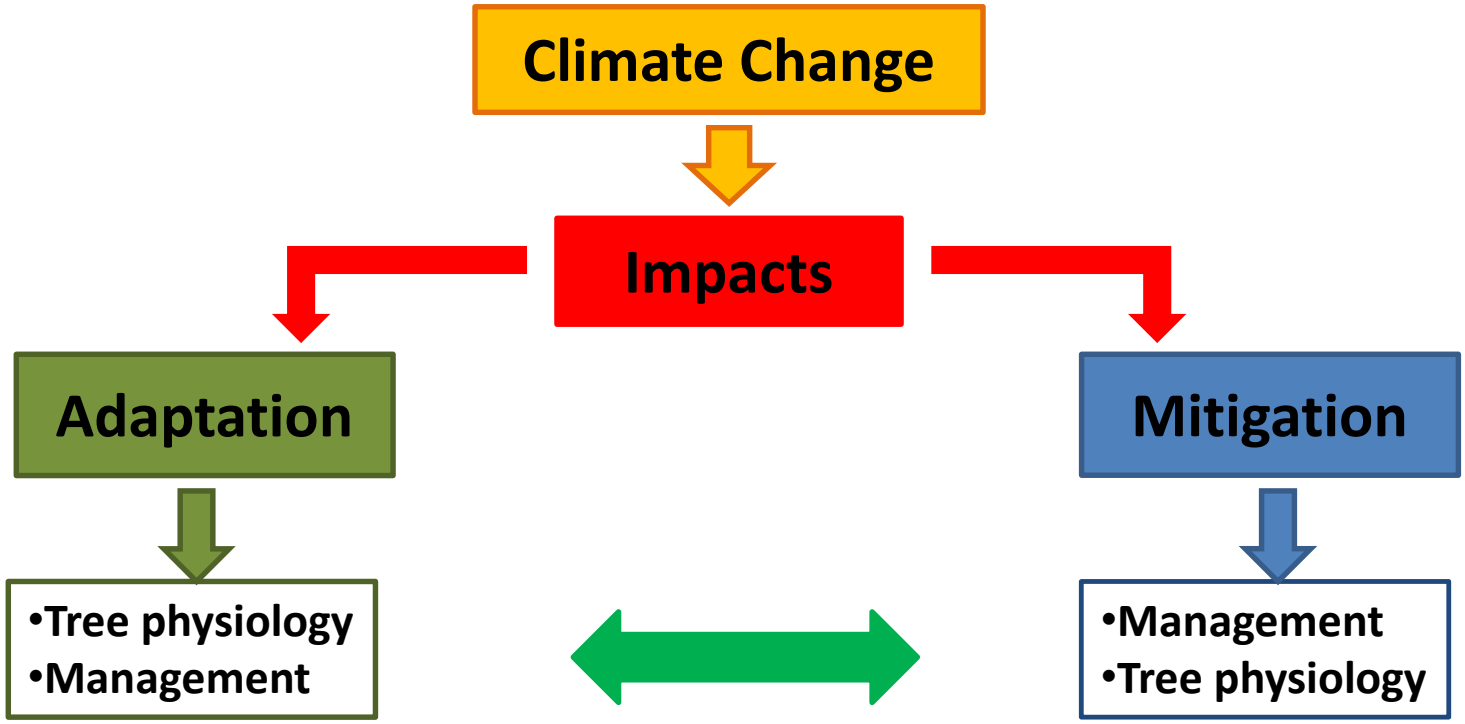
Adaptation & Mitigation

Problems:

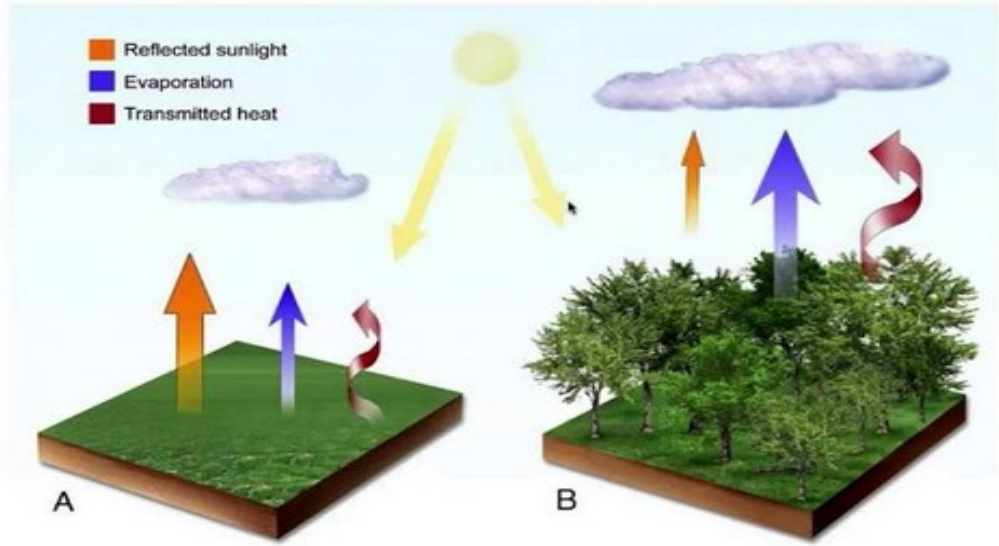
- uncertainty in **climate model** projections (both GCMs and ESMs)
- uncertainty in **LUC** projections
- uncertainty in model **assumptions**
- uncertainty in model **parameters**

Uncertainty

How can models simulate adaptation and mitigation in forests?



Forests serve to "protect" climate and make it more comfortable for people



Jackson *et al.*, 2008

Thus forest management…

However there's a long-lasting discussion about the forest role and their management….

FOREST MANAGEMENT

Europe's forest management did not mitigate climate warming

Kim Naudts [1*+] Yiying Chen [1+] Matthew J. McGrath [1] James Ryder [1] Aude Valade [2]
Juli

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NEWS FEATURE · 15 JANUARY 2019

How much can forests fight climate change?

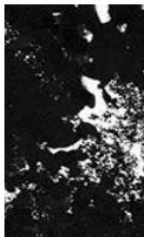
Trees are supposed to slow global warming, but growing evidence suggests they might not always be climate saviours.

Gabriel Popkin

LETTER

Corrected: Author Correction

https://doi.org/10.1038/s41586-018-0577-1



Trade-offs in using European forests to meet climate objectives

Sebastiaan Luyssaert[1,2]*, Guillaume Marie[1], Aude Valade[3,5], Yi-Ying Chen[2,6], Sylvestre Njakou Djomo[4], James Ryder[2,7], Juliane Otto[2,8], Kim Naudts[2,9], Anne Sofie Lansø[2], Josefine Ghattas[3] & Matthew J. McGrath[2]

The Paris Agreement promotes forest management as a pathway towards halting climate warming through the reduction of carbon dioxide (CO_2) emissions[1]. However, the climate benefits from

Despite being explicitly mentioned in both the Kyoto Protocol[12] and the Paris Agreement[1], little is known about the climate effects of forest management, including the effects of human-induced changes in tree

But….

Silva Fennica 34(2) research articles

Managing forests in uncertain times

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2018MS001275

Thinning Can Reduce Losses in Carbon Use Efficiency and Carbon Stocks in Managed Forests Under Warmer Climate

Grassi *et al. Carbon Balance Manage* (2019) 14:8
https://doi.org/10.1186/s13021-019-0123-y

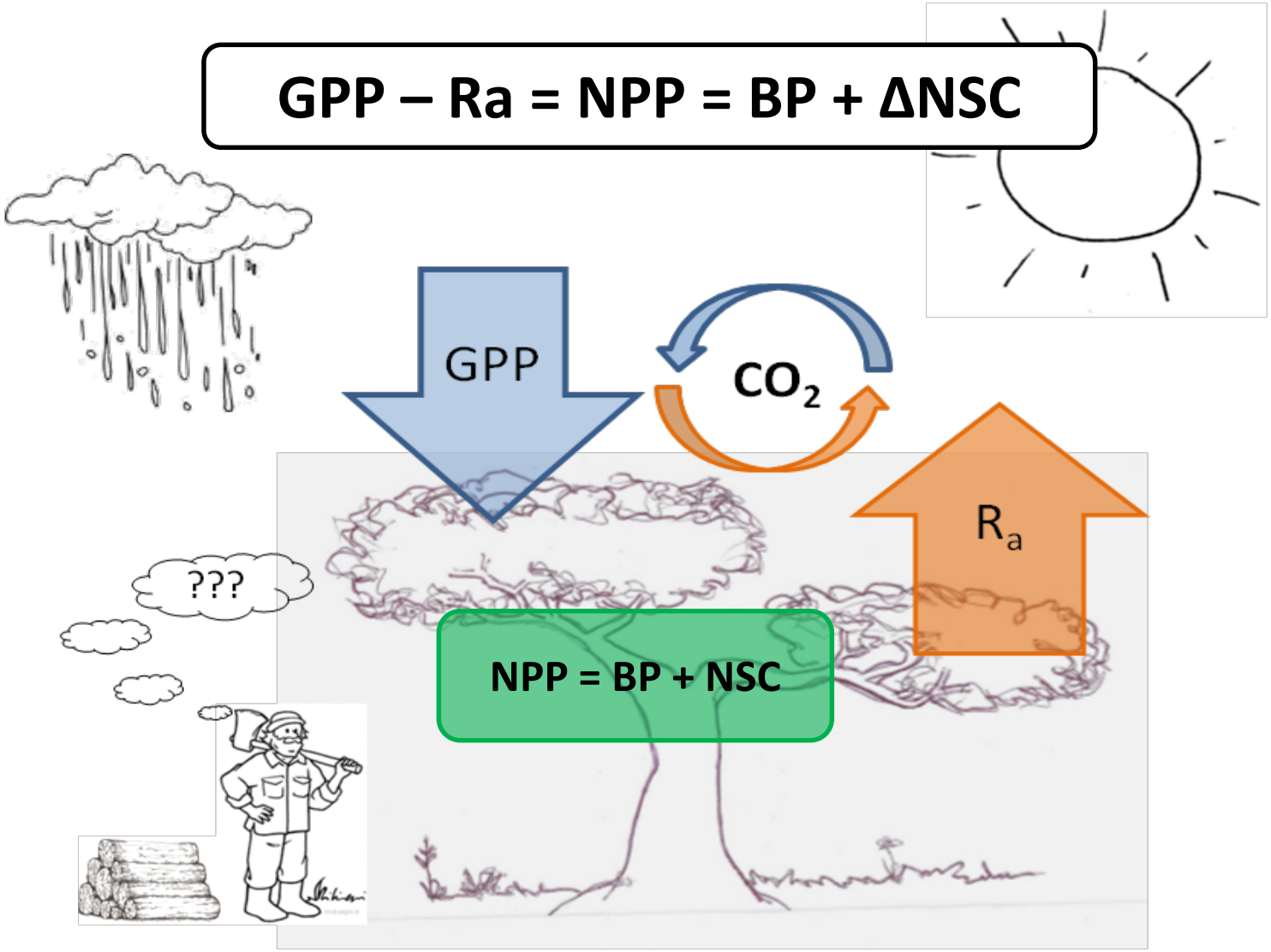
Carbon Balance and Management

COMMENTARY Open Access

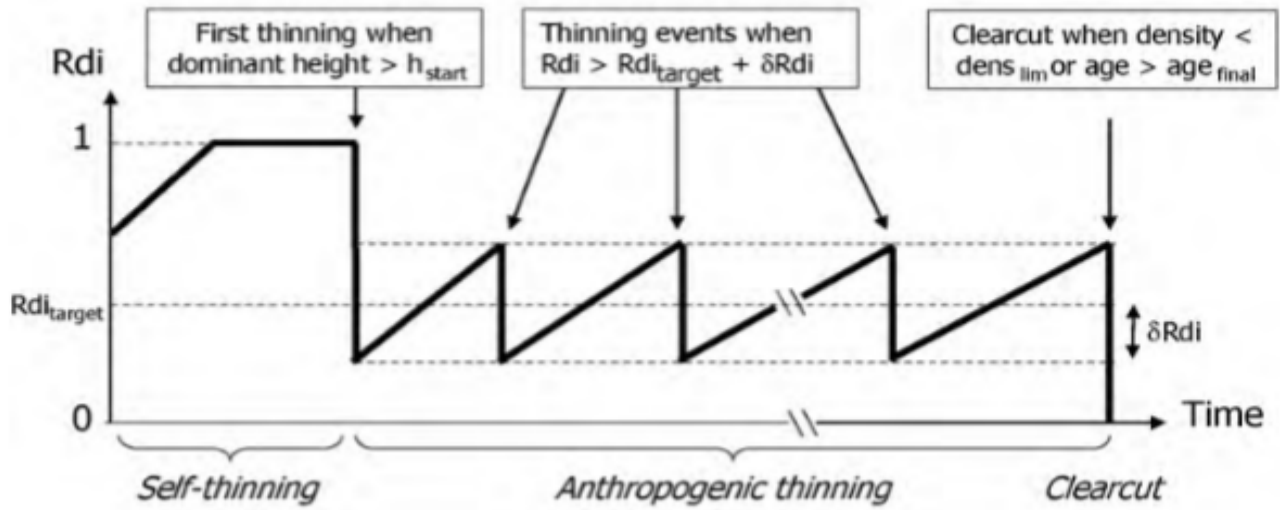
On the realistic contribution of European forests to reach climate objectives

Giacomo Grassi[1*], Alessandro Cescatti[1], Robert Matthews[2], Gregory Duveiller[1], Andrea Camia[1], Sandro Federici[3], Jo House[4], Nathalie de Noblet-Ducoudré[5], Roberto Pilli[1] and Matteo Vizzarri[1]

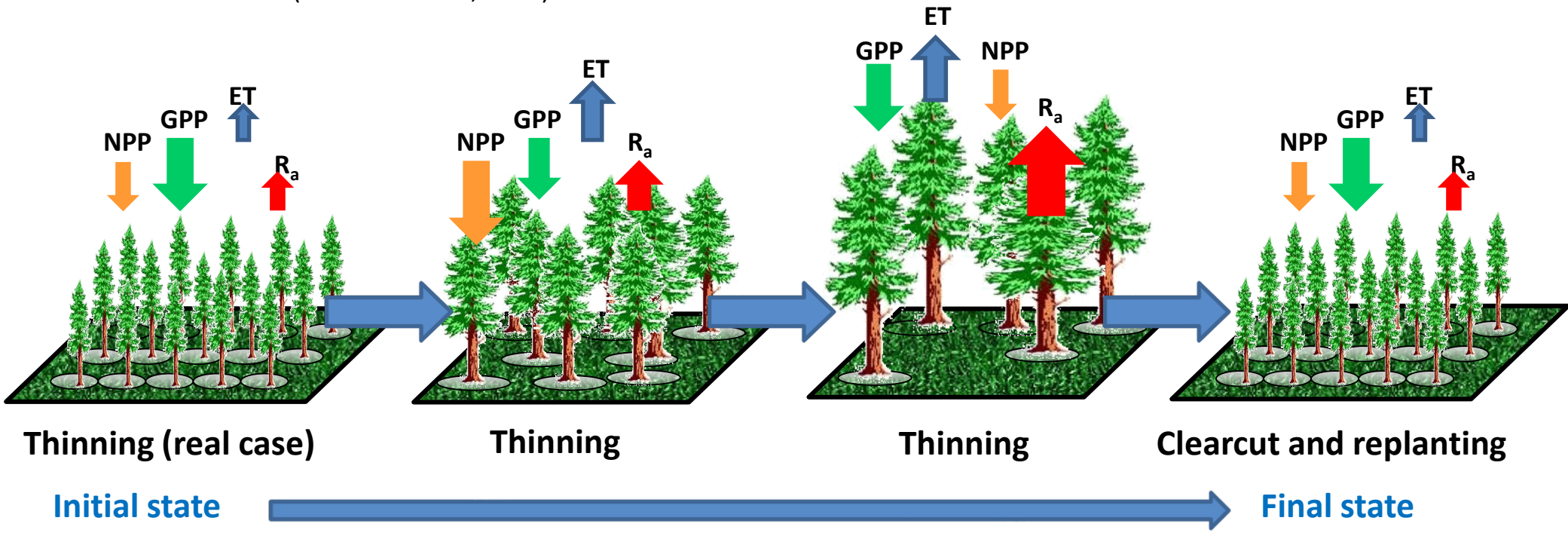
The general carbon balance and management… It is a rather delicate balance!!



Including management, the way 3D-CMCC-CNR model simulates "management"



(Bellassen *et al*., 2010)

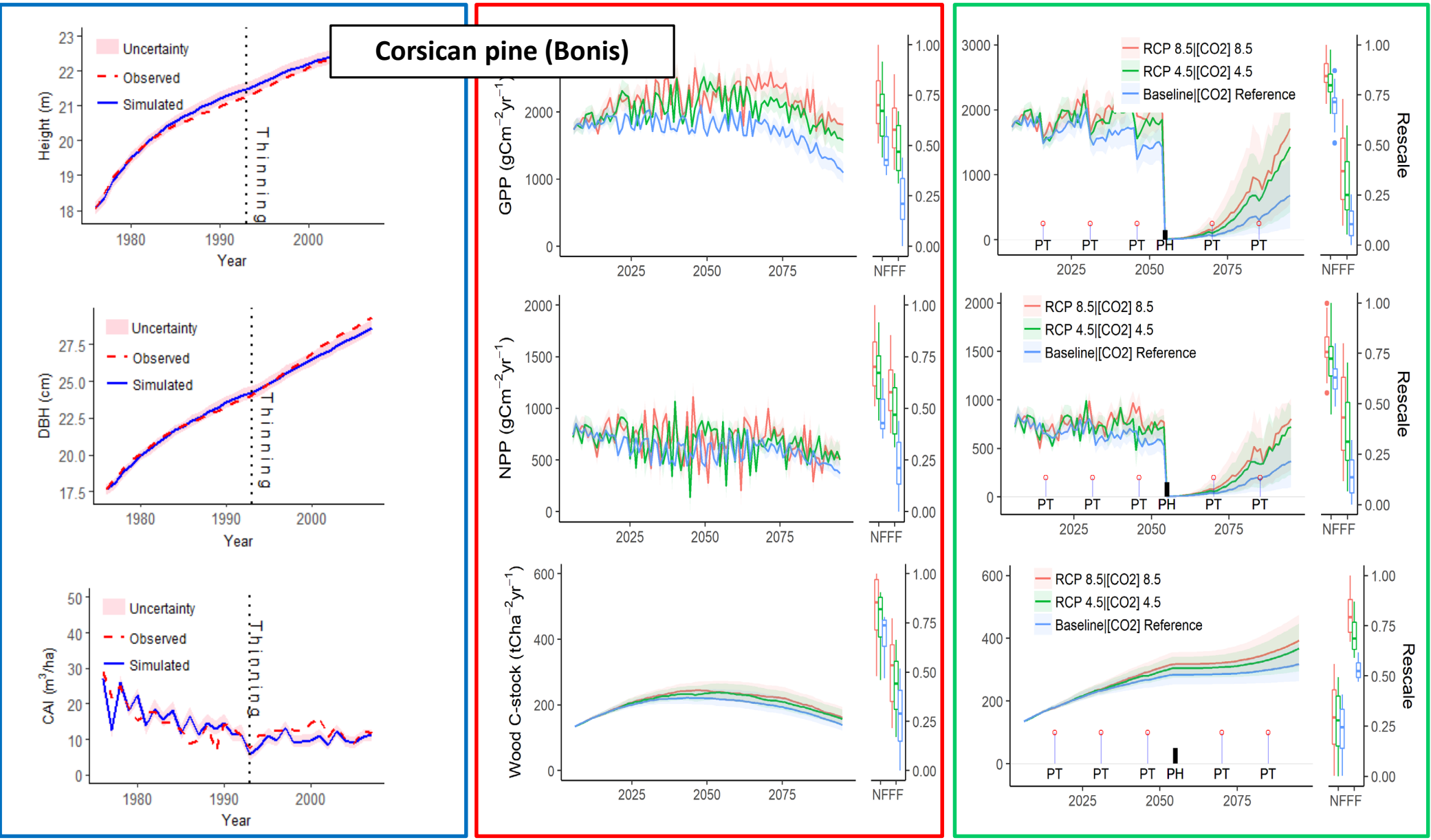


Model validation (v.5.2) - The PON "AlForLab" Project (*Collalti et al., 2017*):

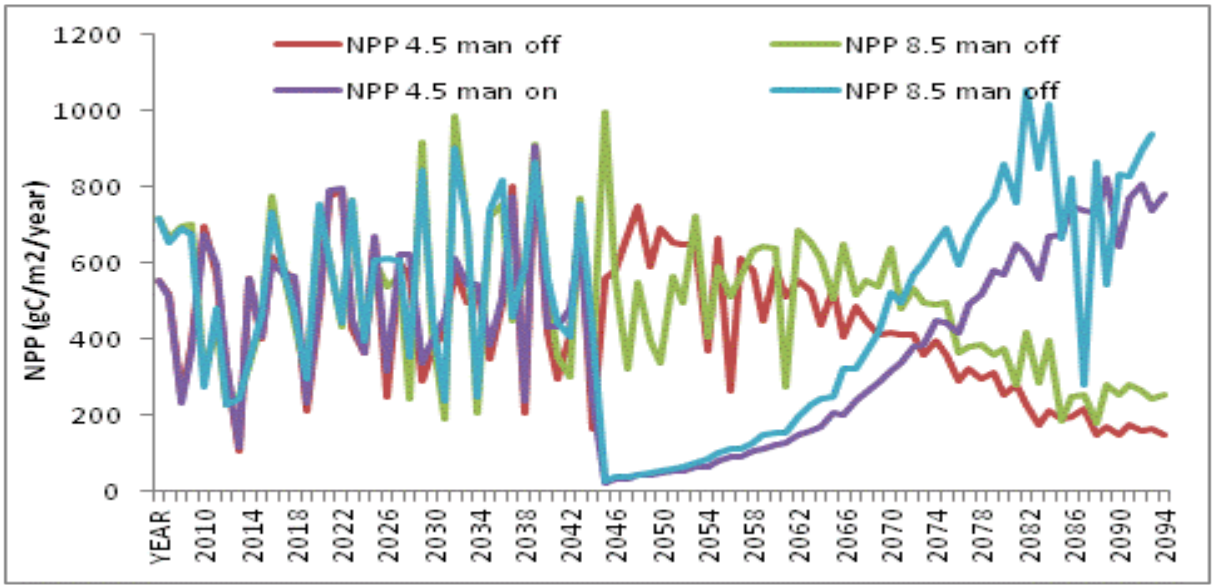
Validation

Climate change scenarios (unmanaged vs. managed)

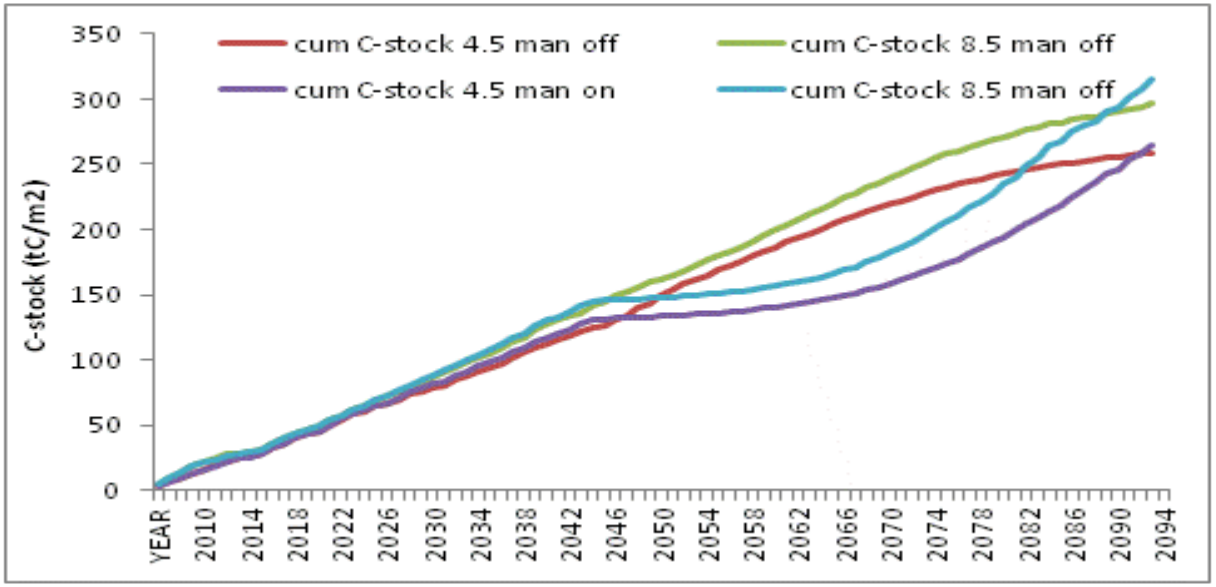
Corsican pine (Bonis)



3D-CMCC-CNR Bonis basin Calabria (preliminary results on C-Cycle) (Maesano *et al., in prep*)

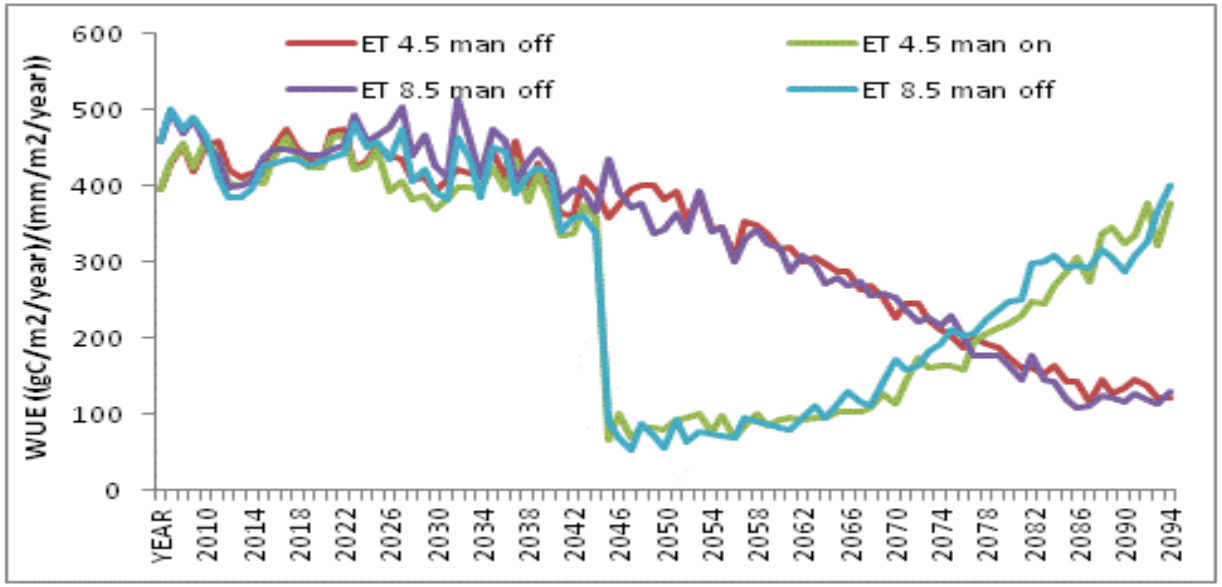


Productivity:
Productivity increases for the CO_2 enrichment but **only** if management is applied otherwise is contrasted by the **age-decline**

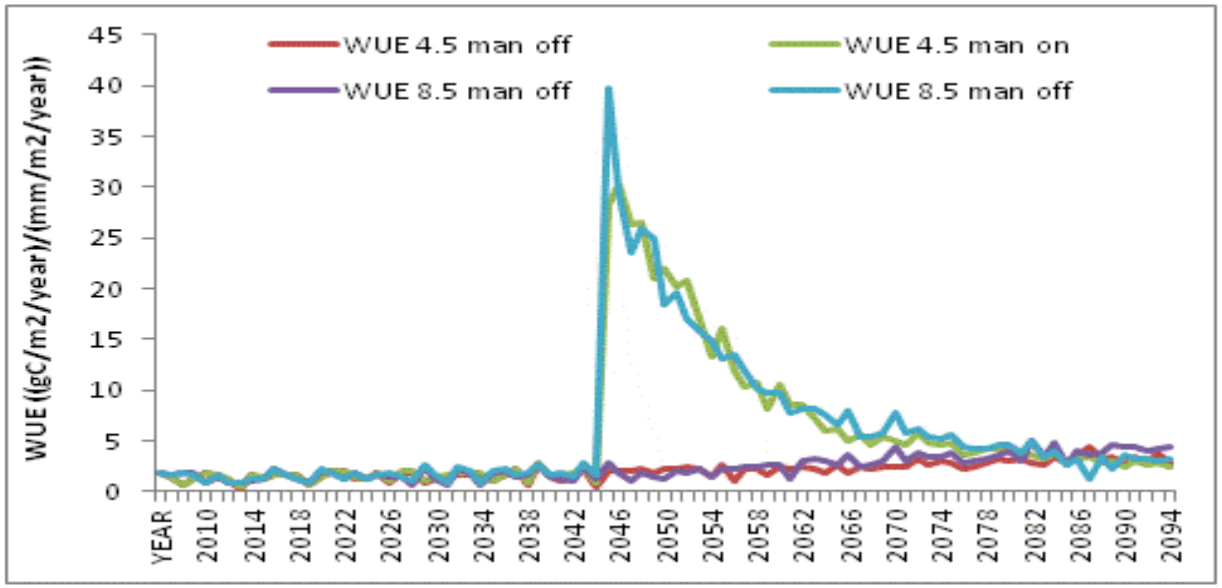


Mitigating effect:
Increased carbon stock capacity which increase even **more** when management is applied

3D-CMCC-CNR Bonis basin Calabria (preliminary results on H_20-Cycle) (Maesano *et al., in prep*)



Evapotranspiration:
Evapotranspiration participates to microclimate **cooling** but at the same time evapotranspiration decreases with forest ageing. Management helps in maintaining high rates of evapotranspiration



Mitigating effect:
High WUE means that plants can **fix** more carbon per unit of water transpired. Management helps in maintaining high rates of WUE

The ISIMIP projects:

climate projections
RCP scenarios from CMIP & CORDEX archives

Socio-economic input
SSP scenarios

Impact models global & regional

agriculture	water
biomes	Forests
coastal infrastructure	health
fisheries	energy
agro-economics	permafrost

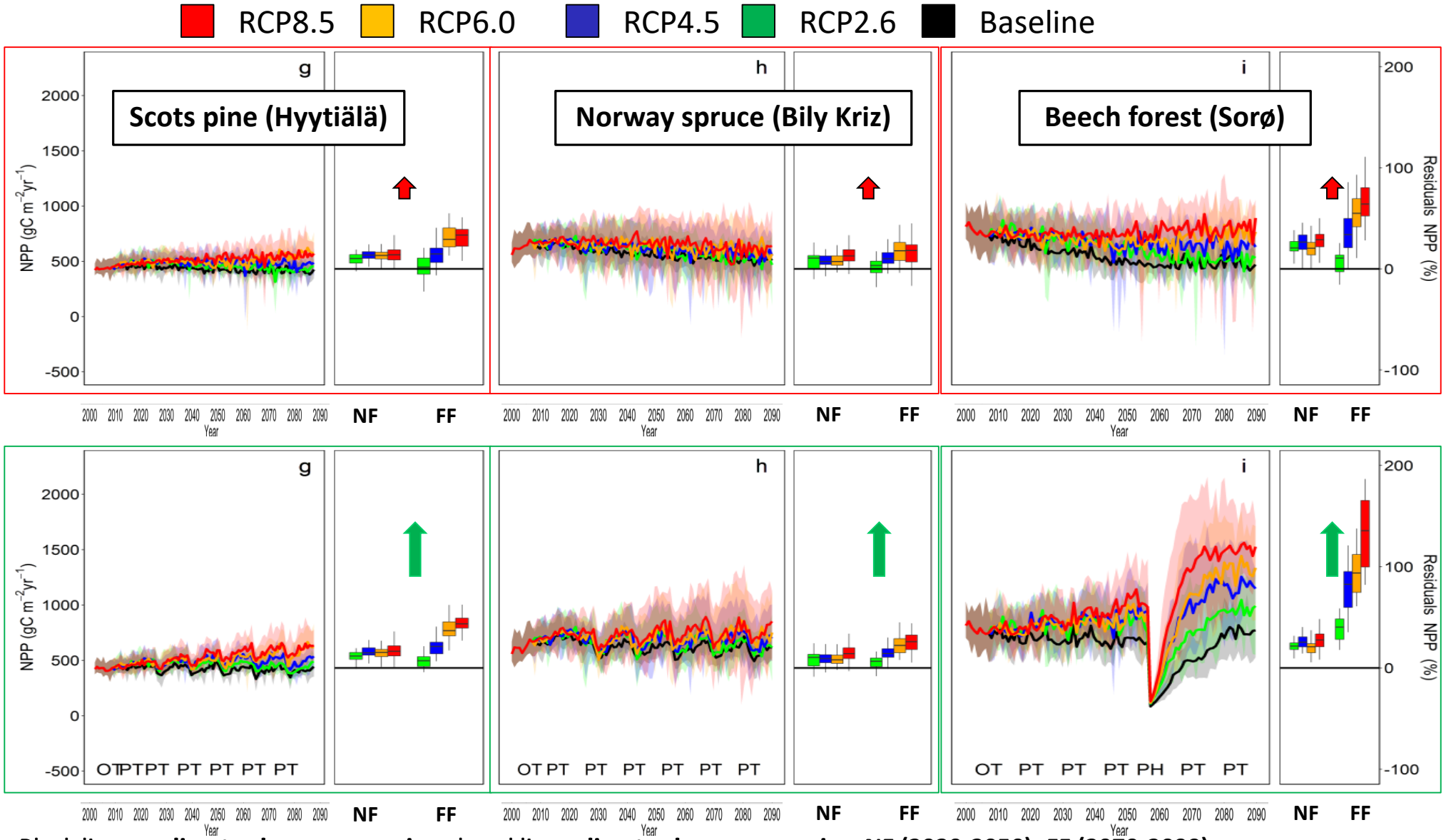
- Synthesis of impacts at different levels of global warming
- Quantification of uncertainties
- Model improvement
- Cross-sectoral interactions
- Cross-scale intercomparison
- Focus topics (e.g. extreme events, adaptation)

The **Inter-Sectoral Impact Model Intercomparison Project**:
•**9 sectors** from Agriculture to Water
•**5** Global Climate Models (**GCMs**) forcing data (downscaled)
•**4** Representative Concentration Pathways (**RCPs**)

Within the "**Forest Sector**":
•**9** European **forest** stands
•More than **12** Forest Process-Based Models (**PBMs**) involved

Model validation (v.5.2) - Functional responses under climate changes (*Collalti et al., 2018*)

Net Primary Productivity (1996-2099) (Unmanaged vs. Managed)

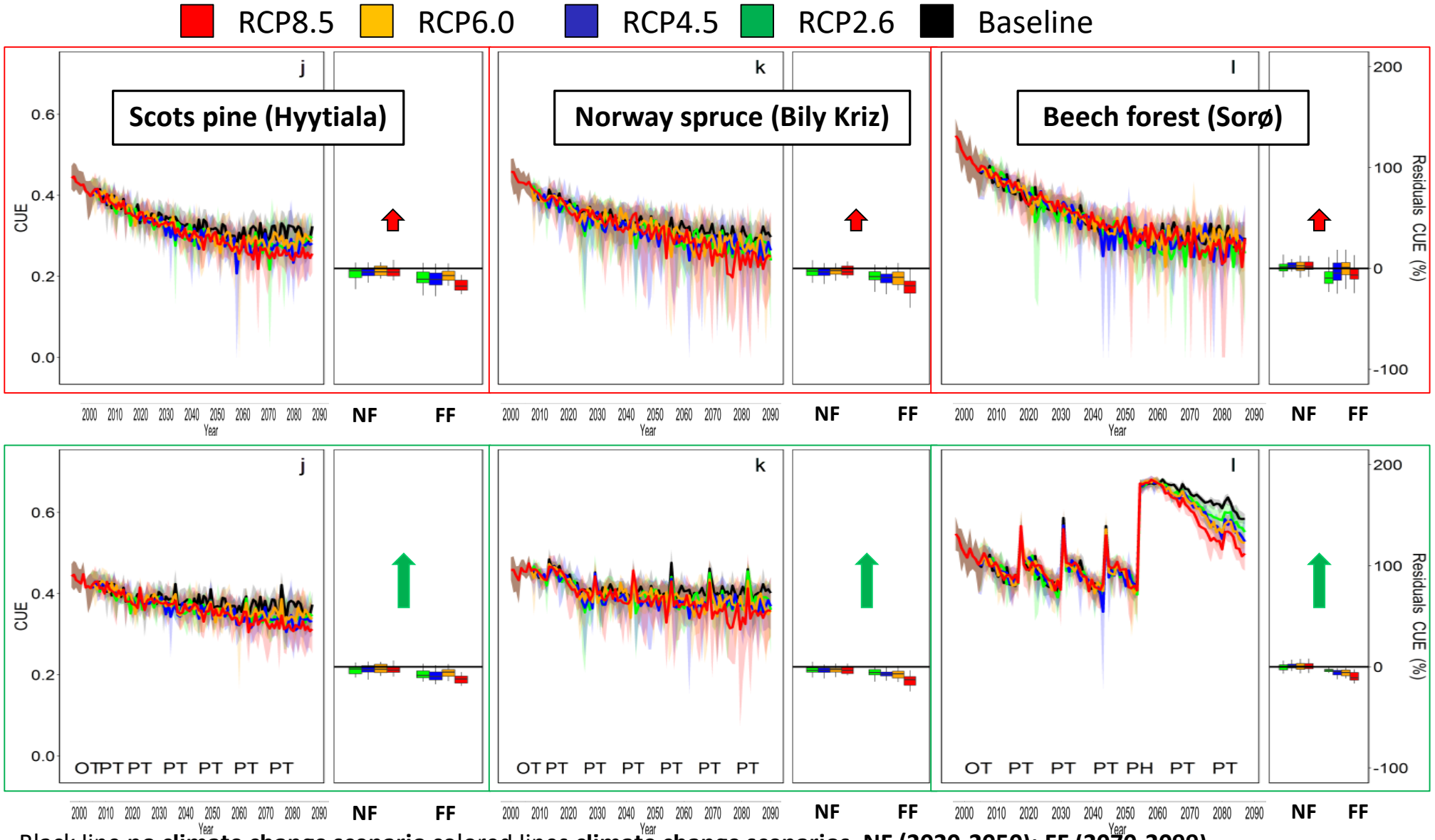


Black line **no climate change scenario** colored lines **climate change scenarios. NF (2020-2050); FF (2070-2099)**

CLIMATE CHANGE INCREASES **NPP** -> MANAGEMENT INCREASES "INCREASES"

Model validation (v.5.2) - Functional responses under climate changes (*Collalti et al., 2018*)

Carbon Use Efficiency (1996-2099) (Unmanaged vs. Managed)

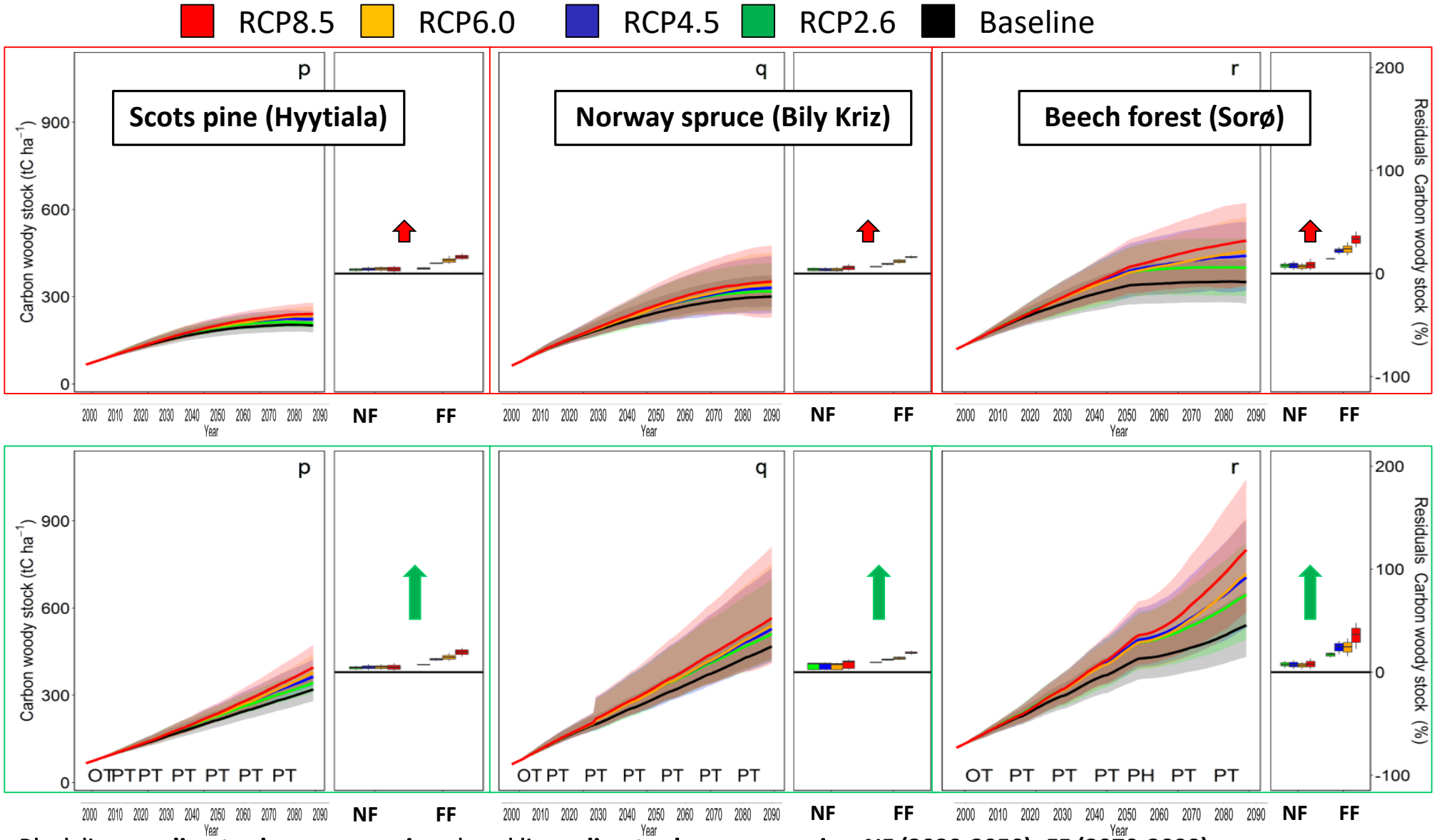


Black line **no climate change scenario** colored lines **climate change scenarios. NF (2020-2050); FF (2070-2099)**

CLIMATE CHANGE REDUCES **CARBON USE EFFICIENCY** -> MANAGEMENT REDUCES "DECREASES"

Model validation (v.5.2) - Functional responses under climate change (*Collalti et al., 2018*)

Carbon woody stock (1996-2099) (Unmanaged vs. Managed)



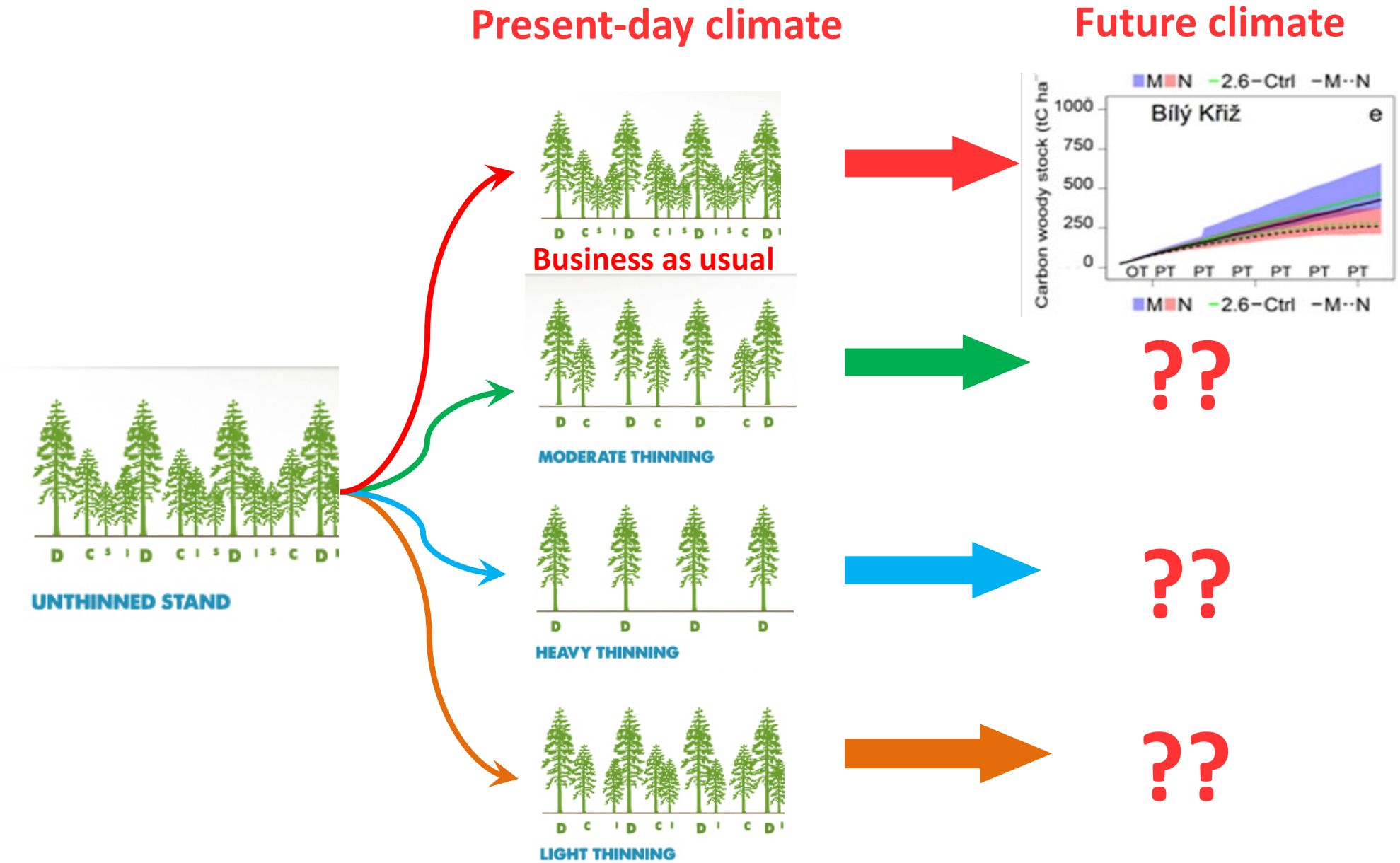
Black line **no climate change scenario** colored lines **climate change scenarios. NF (2020-2050); FF (2070-2099)**

CLIMATE CHANGE + AGEING REDUCES **C-STOCK capability** -> MANAGEMENT REDUCES "DECREASES"

How and to what extent **different forest management** practices may modify the processes that control **carbon dynamics** during **undisturbed** stand development? and in response to **climate change**?

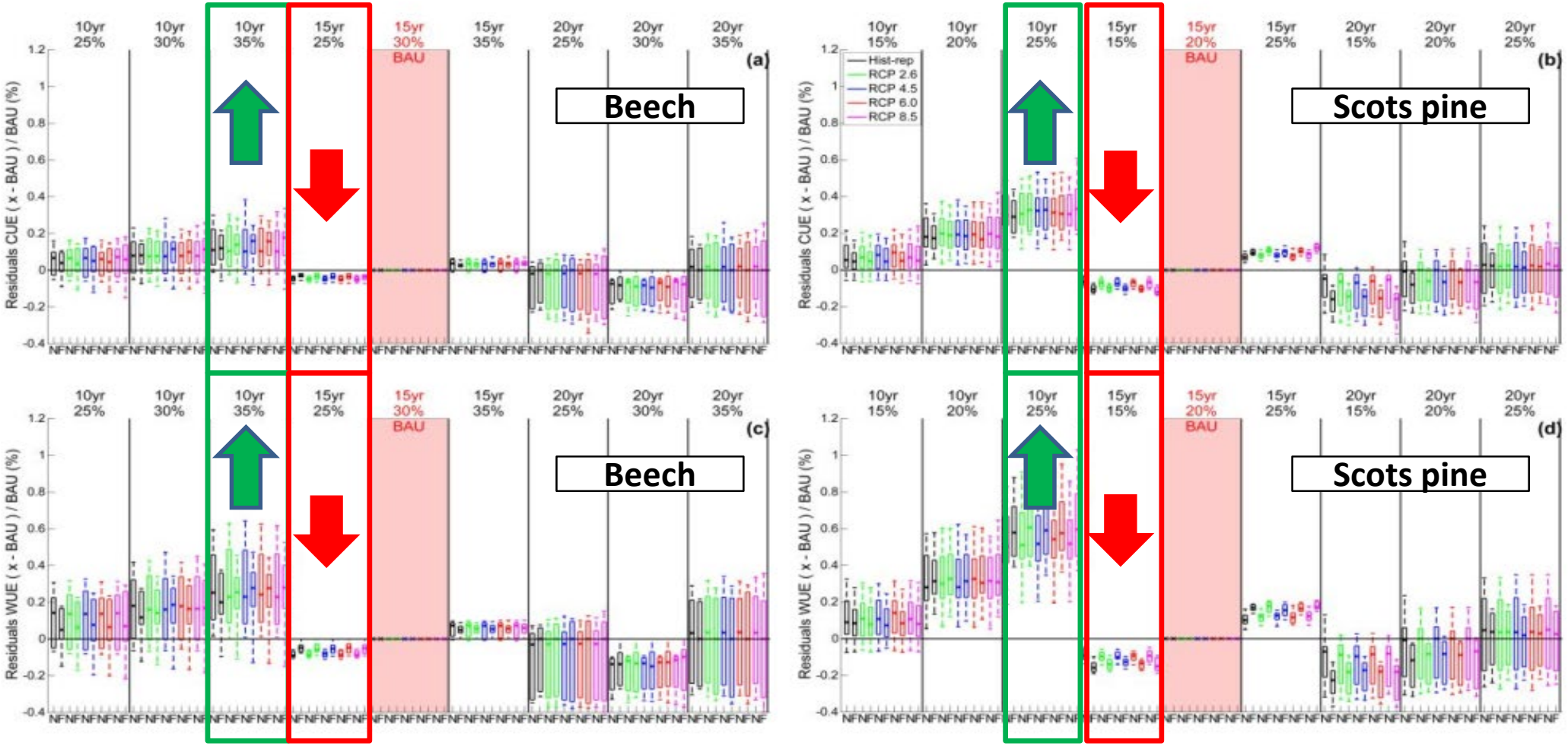
The **current** management practices, under climate change, are still the **best option**?

How can we deal with these questions? (Collalti *et al. in prep.*)



Functional responses under climate changes (Collalti *et al. in prep.*)

Management and scenarios of adaptive management under climate change

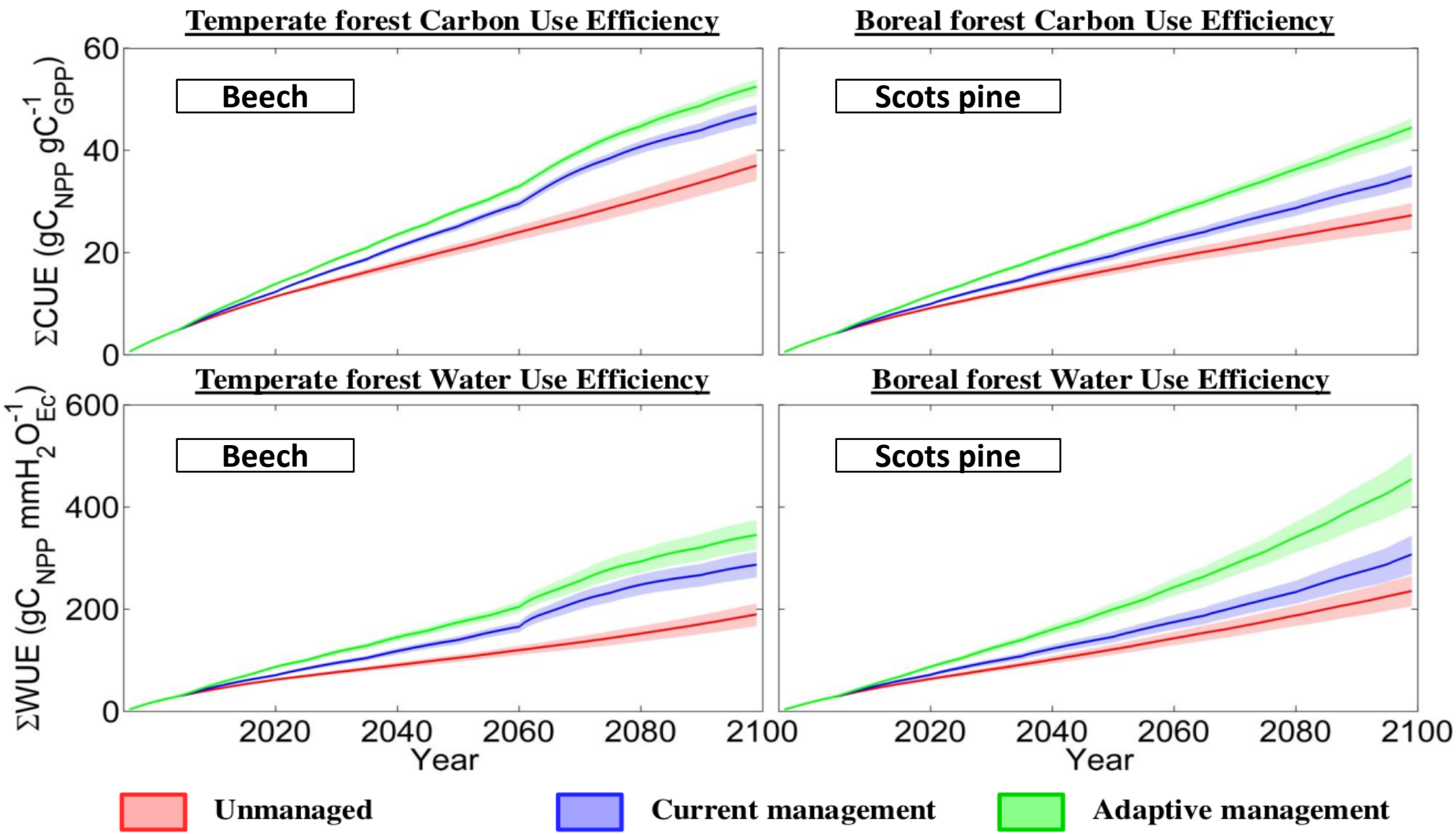


Best management practice = **10 years interval thinning, 35% standing basal area removed**

Worst management practice = **15 years interval thinning, 25% standing basal area removed**

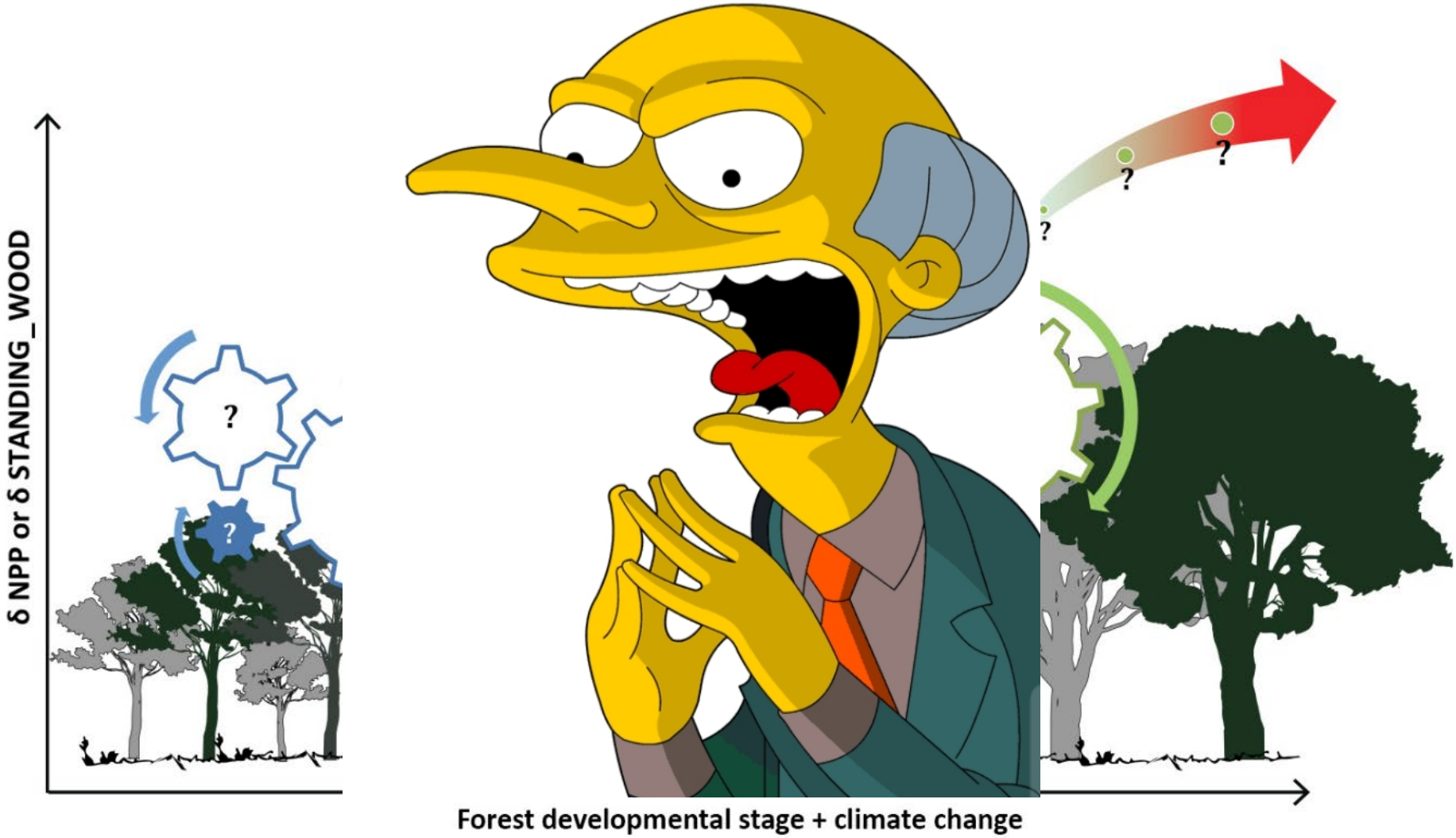
Functional responses under climate changes (Collalti *et al. in prep.*)

Management and scenarios of adaptive management under climate change

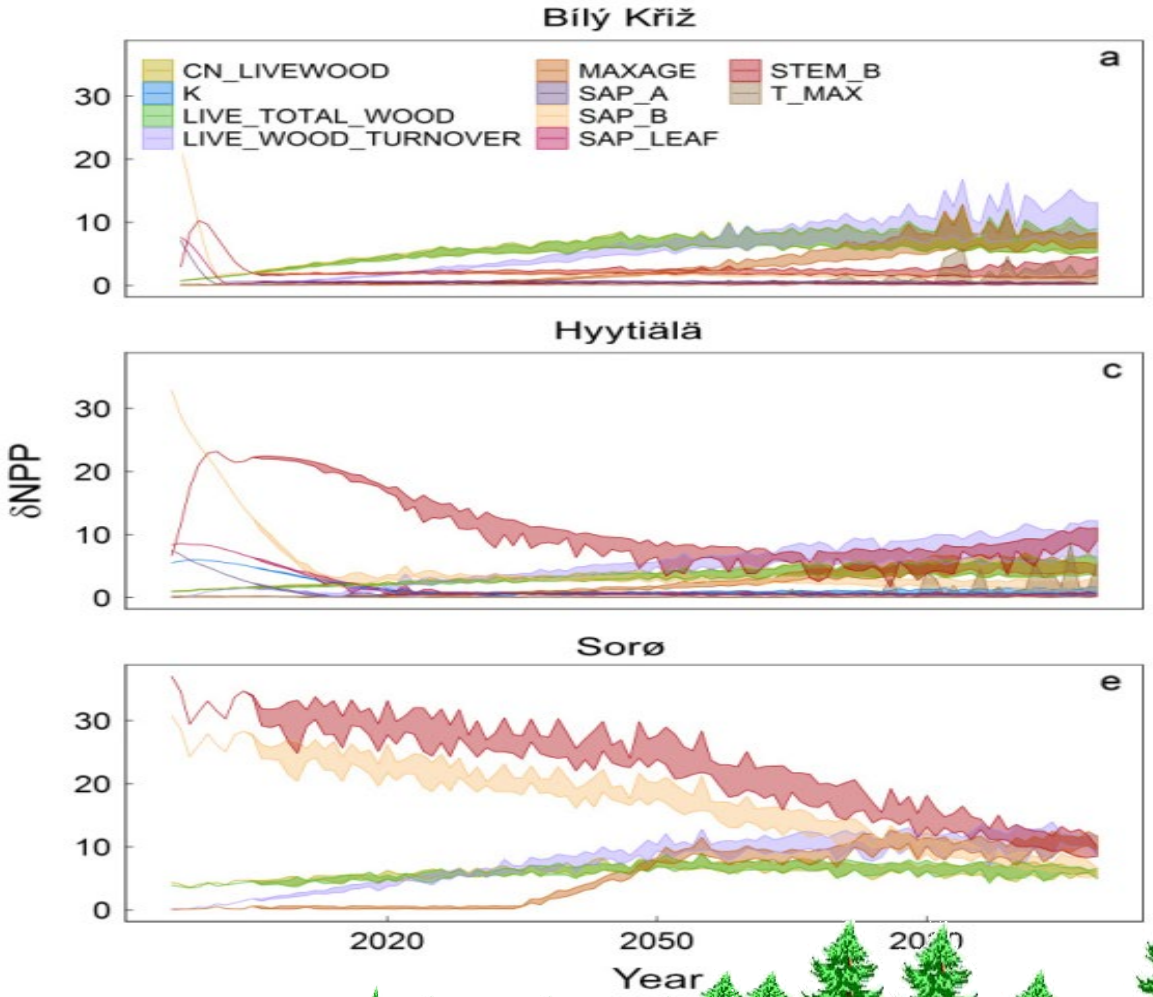


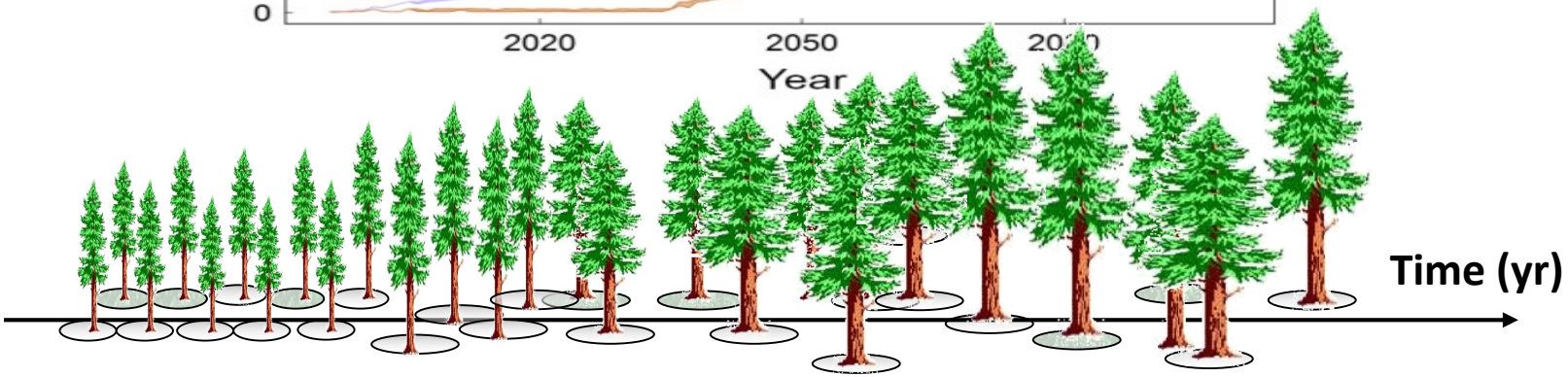
However…. The uncertaintiy…

"Uncertainty in model simulations is the quantitative measure of systematic and random variation from the "true" value of a simulated entity (Aubinet et al. 2012)."



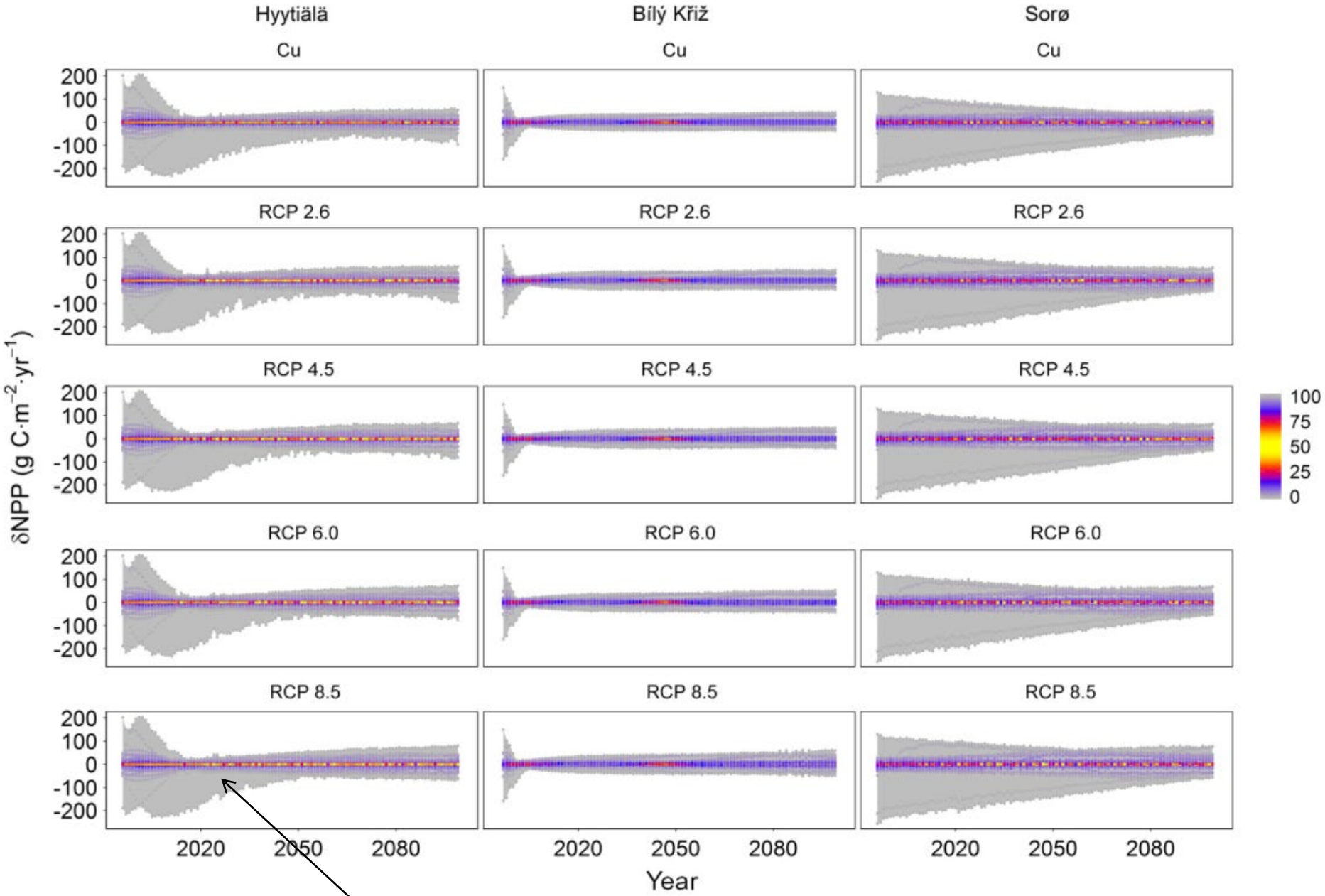
Uncertainties along successional stages (Collalti *et al.*, 2019)





Young | Mature | Early old growth | Mid old growth | Late old growth

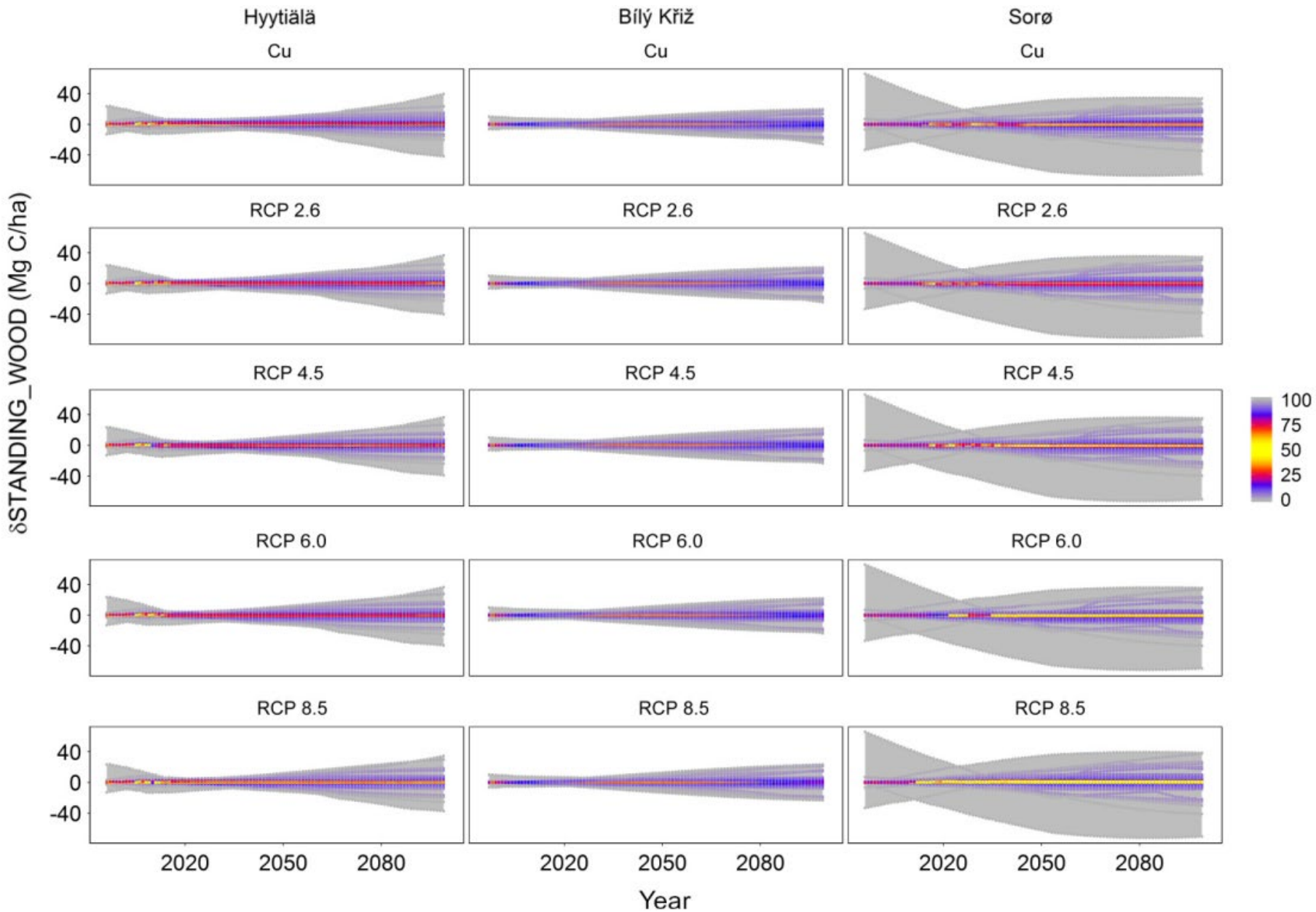
Model sensitivity and uncertainty analysis *(Collalti et al., 2019)* - Net Primary Productivity



Good news! Only few parameters are really uncertain!

(*Collalti et al., 2019*)

Model sensitivity and uncertainty analysis *(Collalti et al., 2019)* – Standing Wood



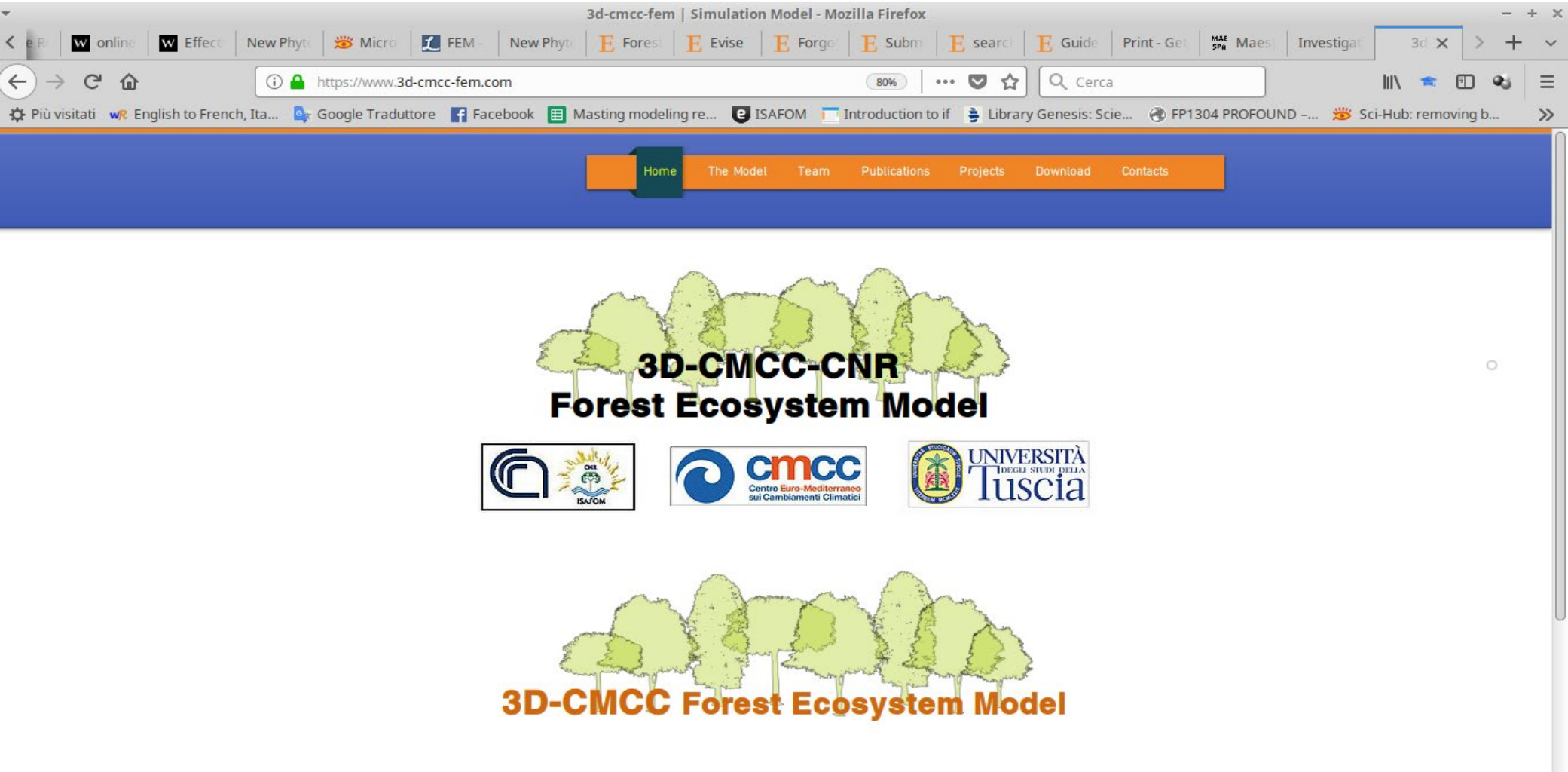
Strengths and present limitations for 3D-CMCC-CNR forest model

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

Present limitations:

- Inability to simulate **naturally changes** in species composition (cells do not interact themselves)
- Relatively high request species/PFTs **parameters**
- High computationally **demand**
- Inability to simulate **different management options** (different than thinning and clear-felling)
- **(Relatively) high uncertainty**

That's all Falks!

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or contact us at**: 3d-cmcc-fem@cmcc.it**