Modelling impacts of changes in climate, N deposition, CO_2 and O_3 exposure on carbon sequestration in European forests

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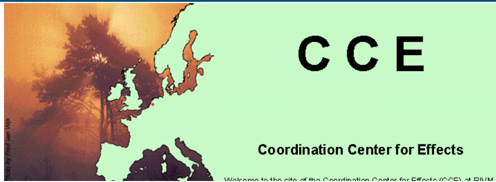

Impacts of air quality and climate change

Forest growth/carbon sequestration is affected by

- Air quality effects and interactions
  - CO_2 fertilization.
  - N and S deposition: N availability/limitation; soil acidity.
  - Phosphate and base cation availability/limitation.
  - Ozone exposure.
- Climate change
  - Water availability
  - Temperature

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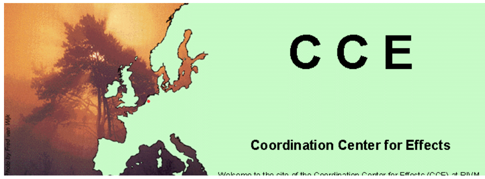
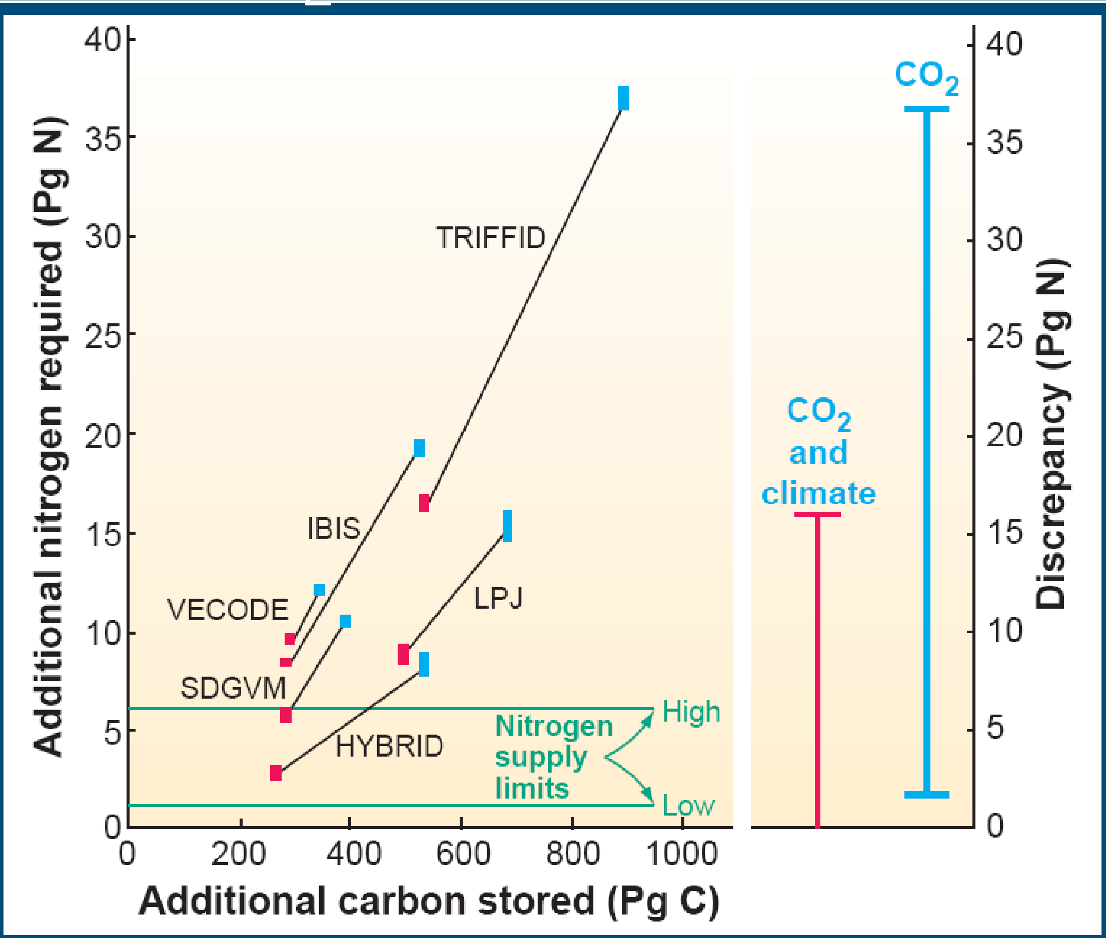


Interactions of air quality and climate change

- Evidence for interaction between those drivers of carbon sequestration, such as:
  - Elevated temperature lead to stomatal opening, increasing the effect of CO_2 and O_3.
  - Increased water stress and CO_2 levels lead to stomatal closure, limiting the CO_2 fertilization effect and damaging effects of O_3.
  - CO_2 increases N uptake by an increase in fine root biomass.
  - Nutrient limitations inhibit the CO_2 fertilization effect

N, climate and CO_2 interactions on C sequestration



Modelling studies which don't incorporate N-limitation may overestimate growth due to CO_2 stimulation and climate

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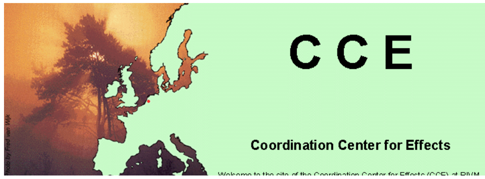
Source: Hungate et al., Science (2003)



Modelling approach

- Environmental effects on tree growth, *G*, is calculated for the period 1900- 2050 as a function of a reference growth, G_{ref}, and modifying factors:

- $G = G_{ref} * f_{drivers}/f_{drivers,ref}$

i.e. modifying factors are all scaled to a factor 1 in 2005, being the year at which the reference growth is assessed

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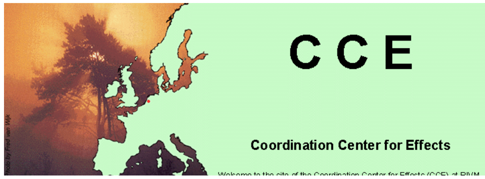

Modelling approach

- Interactions of effects of drivers on tree growth for the period 1900- 2050 are included in various combinations:

- $f_{drivers} = \min\{f_{CO2} * f_{Temp}, f_{water}\} * f_{Nnut} * f_{Ntoxic} * fO_3$ (1)
- $f_{drivers} = \min\{f_{CO2} * f_{Temp}, f_{Nnut}\} * f_{water} * f_{Ntoxic} * fO_3$ (2)
- $f_{drivers} = \min\{f_{CO2} * f_{Temp}, f_{water}, f_{Nnut}\} * f_{Ntoxic} * fO_3$ (3)
- $f_{drivers} = f_{CO2} * f_{Temp} * f_{water} * f_{Nnut} * f_{Ntoxic} * fO_3$ (4)
- $f_{drivers} = \min\{f_{CO2} * f_{Temp} * f_{water} * f_{Nnut} * f_{Ntoxic} * fO_3\}$ (5)

- In this study, we excluded limitation of Ca, Mg, K, P

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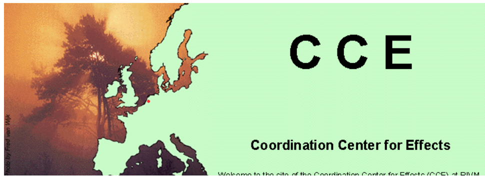

Modelling approach

- Reference growth was based on the EFI database, which contains growth data for approximately 20 tree species and 10 age classes in about 250 regions in Europe (EU27 minus Greece plus Switzerland, Norway and Croatia).
- EFI growth was related to the average air quality and climate in the year 2005 (Most current data in EFI data base)
- We back-calculated the growth using air quality and climate history in the past (1900-2000) and for the “future” (2000-2050) for four scenarios (CLE and SLE for N deposition and IPCC-SRES A1 and B2 for climate and CO_2)

Climate change and N modifying factors

- Temperature factor: includes influence of temperature on CO2 exchange: taken from the C-Fix model by Veroustraete et al. (2002).

- Water stress factor: included as the ratio actual/potential evapotranspiration: an increase in evapotranspiration increases growth

- N deposition: a trapezoidal shape function based on a study with approximately 350 stands of ICP Forests by Solberg et al (2008). N limitation included as the ratio N demand/ N availability.

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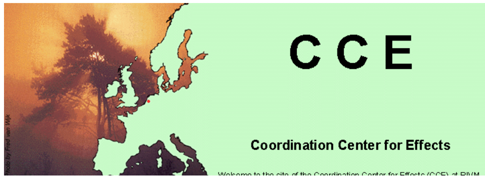

CO_2 modifying factor

Based on scaling factor for CO_2 according to Gifford (1980):

$$gCO_2 = 1 + \beta \cdot \ln\left(\frac{C_a}{C_{a,0}}\right)$$

Rescaling this function to a value between 0 and 1 according to:

$$fCO_2 = gCO_2 / gCO_{2,max} = gCO_2 / \left[1 + \beta \cdot ln\left(\frac{C_{a,max}}{C_{a,0}}\right)\right]$$

C_a, $C_{a,0}$ and $C_{a,max}$ are the CO_2 concentrations at: (i) ambient level, (ii) reference level, set at 350 ppm and (iii) maximum level defined as three times the reference level (1050 pm)

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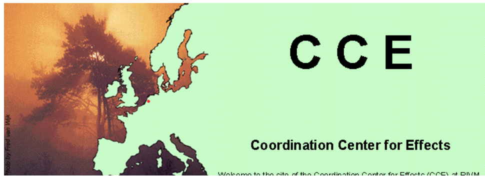

Ozone modifying factor

- The phytotoxic ozone dose (POD) is used as the metric for O3 exposure.
  - POD1 values for forests are calculated with the EMEP-DO3SE model
  - Model includes impact of photosynthetically active radiation (PAR), temperature, vapour pressure deficit (VPD) and soil water fraction on stomatal conductance
- Response to POD on growth is linear with a based on Harmens et al (2010):
  - $fO_3 = 1.0 - a^* \text{ POD1}$

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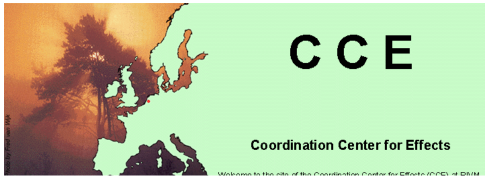
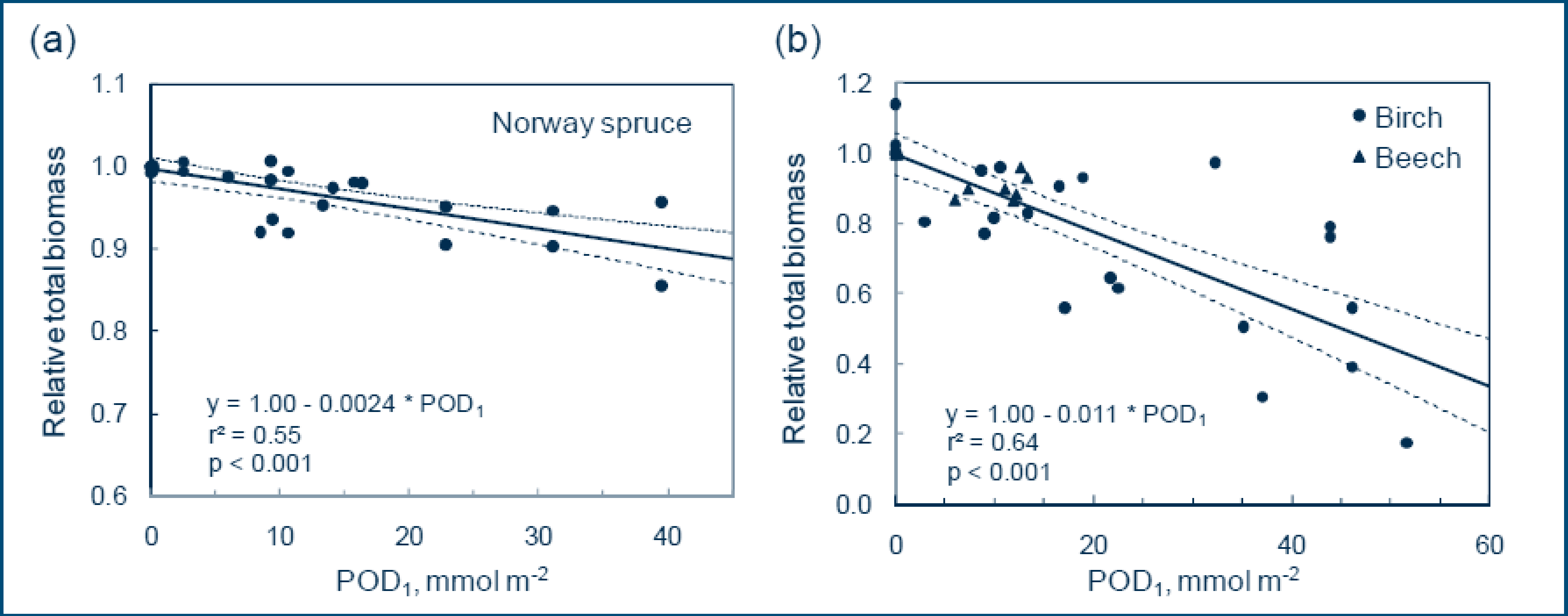


Ozone modifying factor



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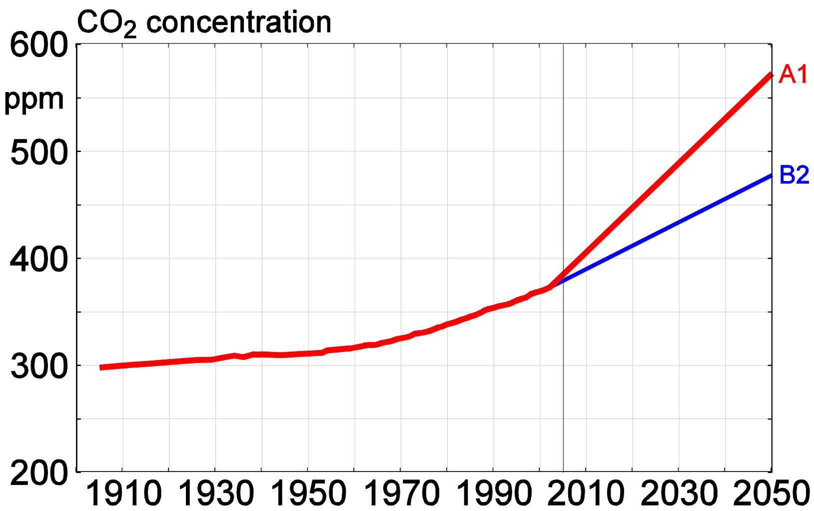
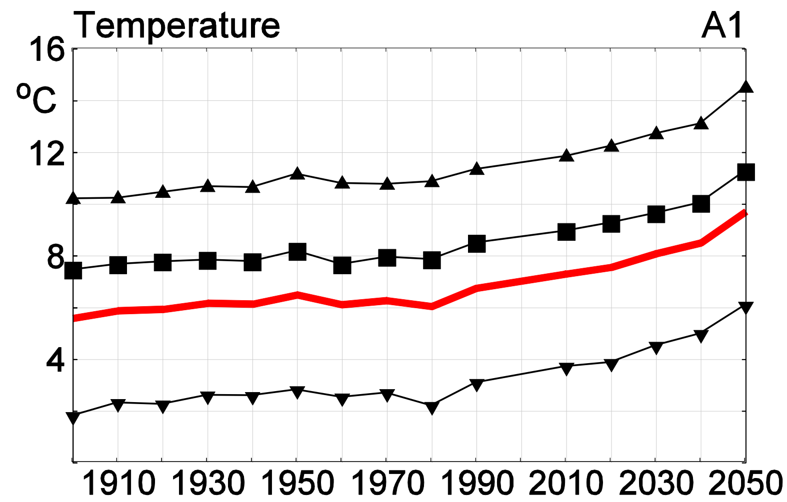
Changes CO_2 concentration and annual temperature





Temporal development of CO_2 (Etheridge et al 1996; Keeling and Whorf, 2006) and annual average temperature (Mitchel et al 2004). Overall average (red line) and averages in three European regions (▼: North; ■: Central, ▲: South).

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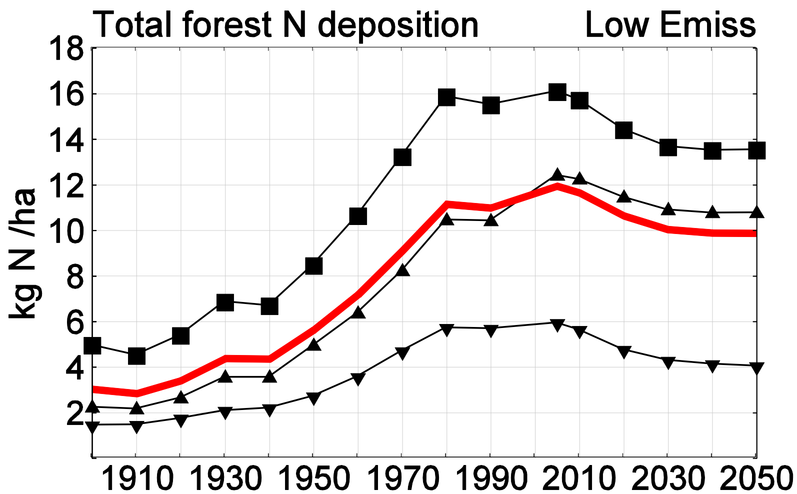
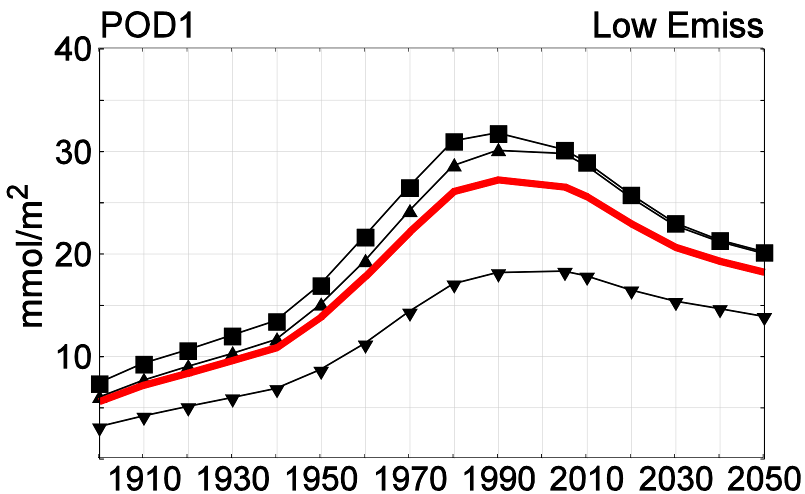
Changes N deposition and POD for SLE scenario





Temporal development of average N deposition and average POD1 in Europe (red line) and in three European regions (▼: North; ■: Central, ▲: South).

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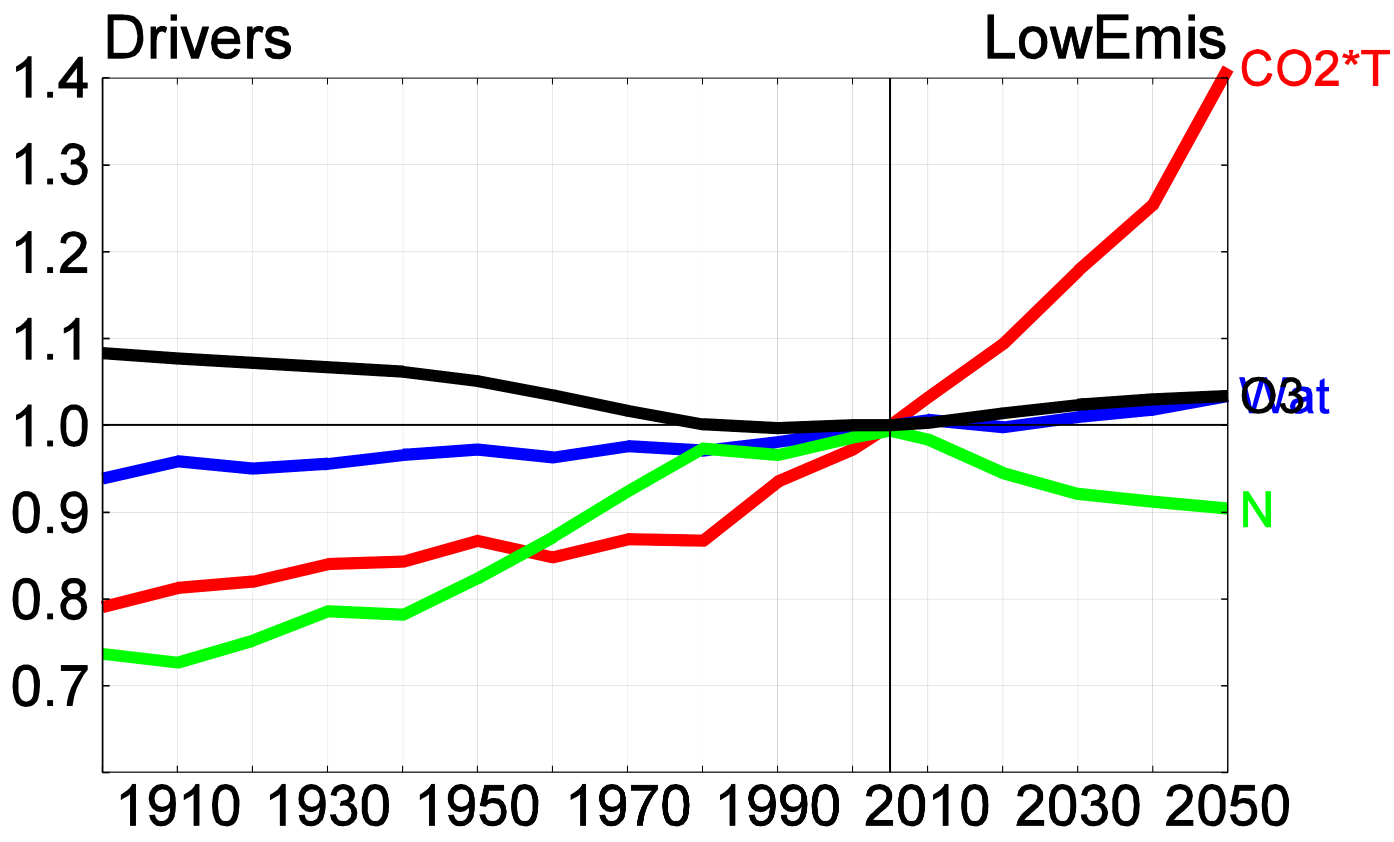
Trends in impacts of individual drivers



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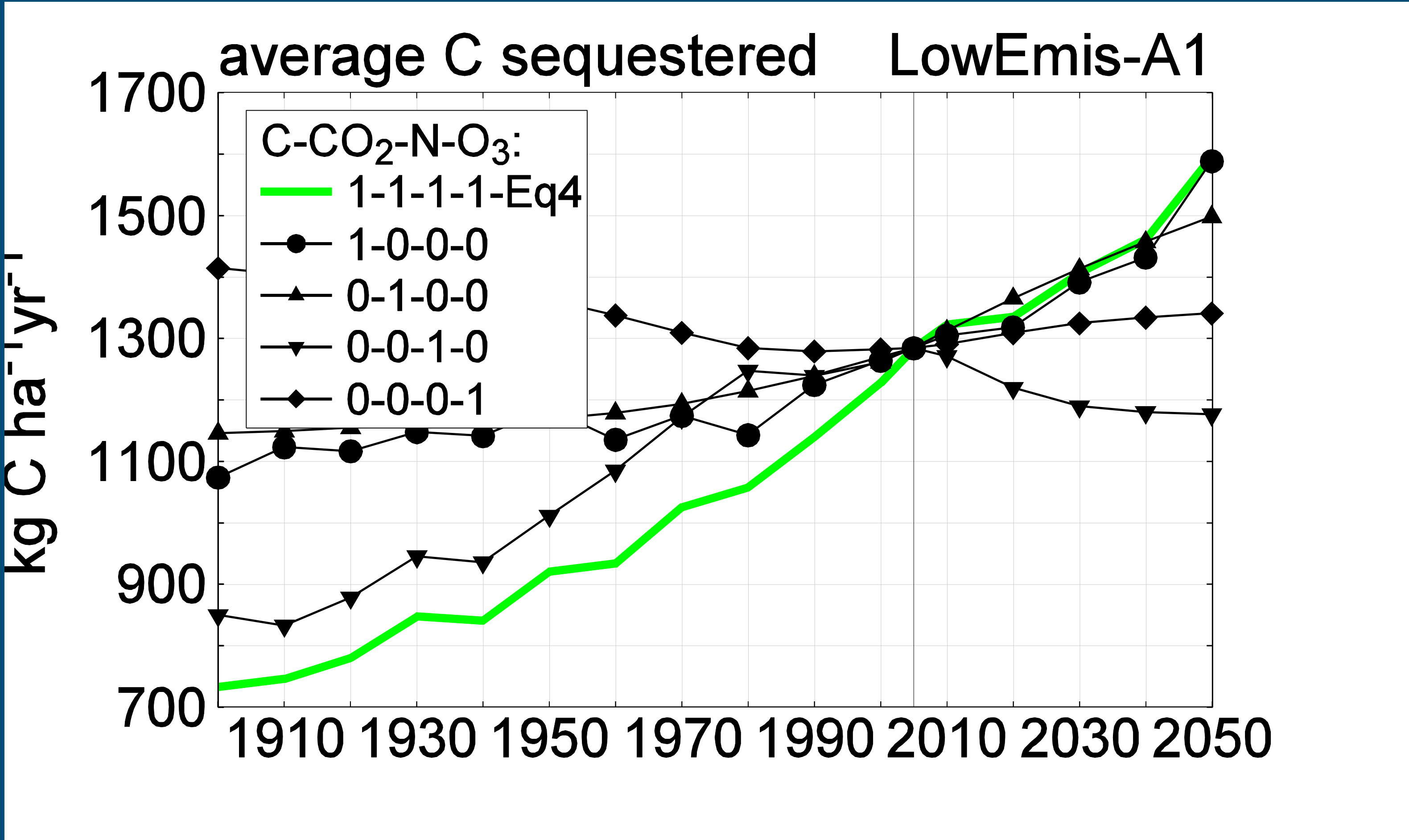
Impacts of drivers on tree C sequestration: Sensitivity to individual drivers by including one



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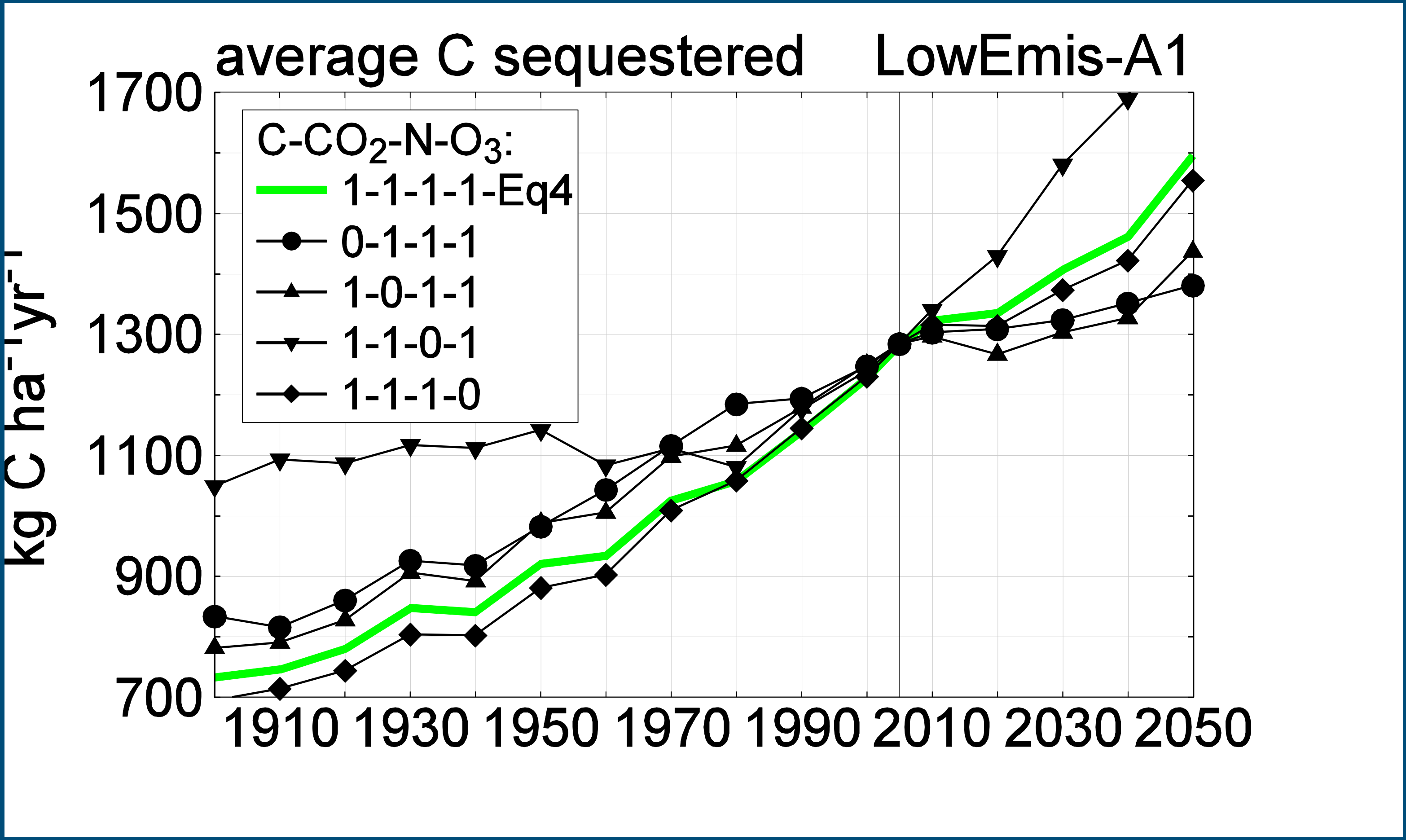
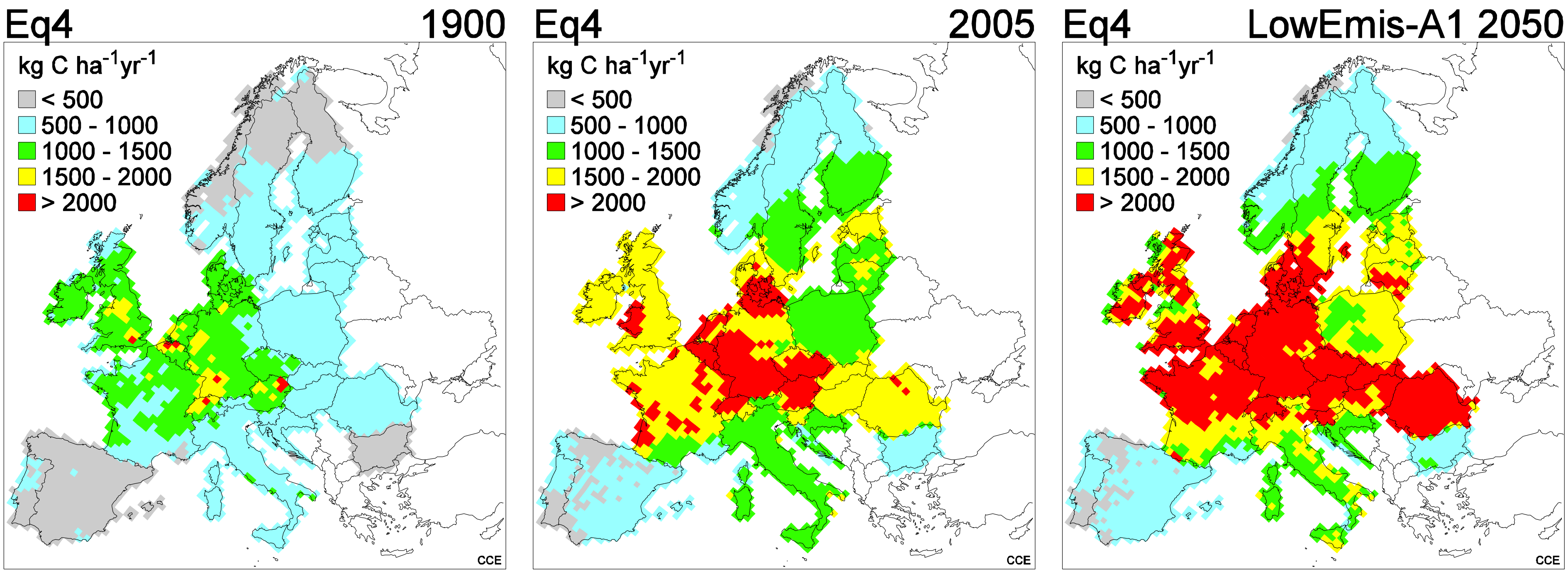


Maps of average C sequestration: multiplicative approach



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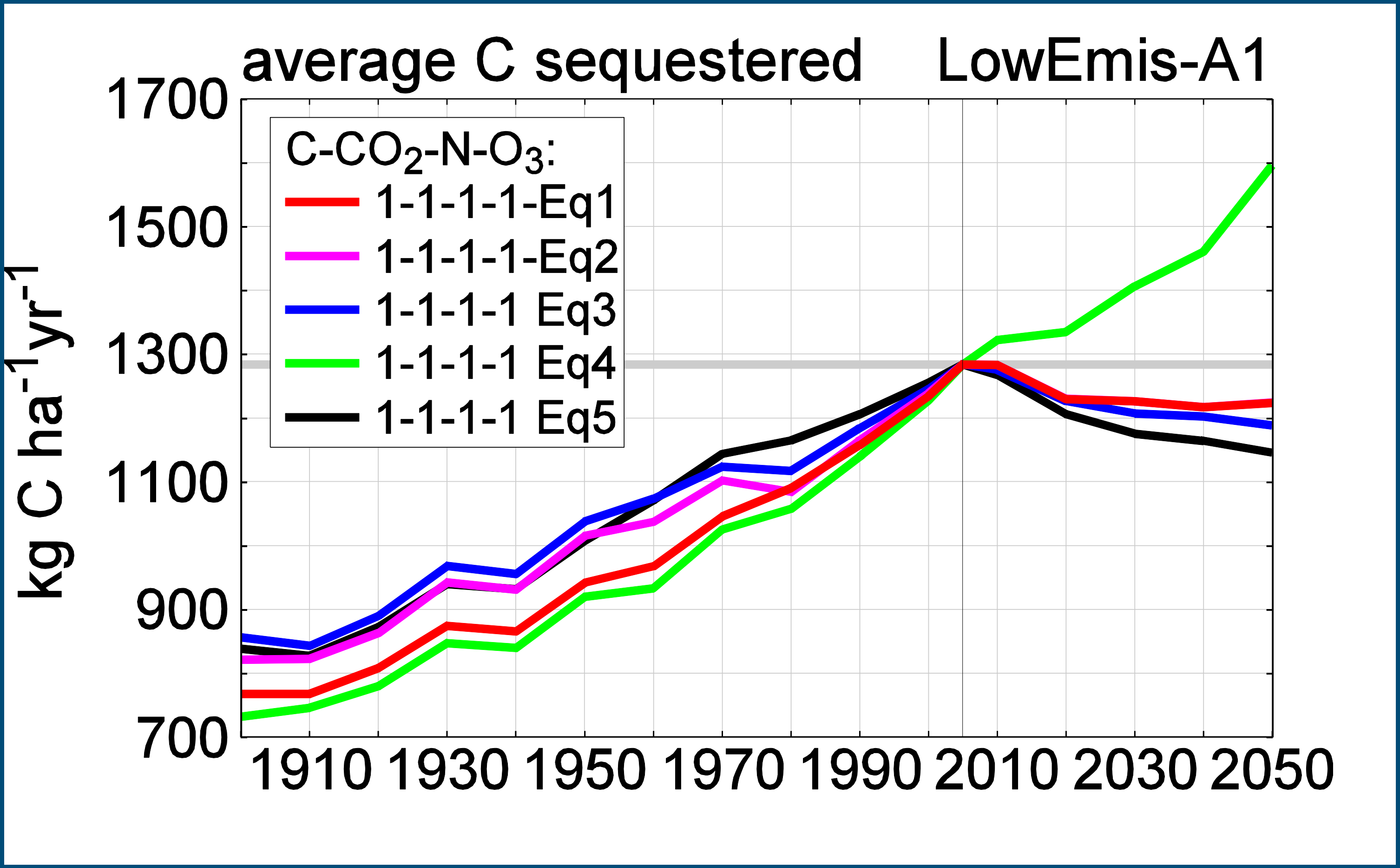
Impacts of drivers on tree C sequestration: Sensitivity to the interaction approach



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Conclusions

- Compared to growth in 2005, a multiplicative drivers impact (MDI) model shows a 44% growth increase in the period 1900-2000. This is due to an increase in CO_2 (11%), Temperature (16%), N (33%) and POD (-10%)
- For the future, the MDI model shows a 24% growth increase in the period 2005-2050. due to an increase in CO_2 (11%), Temperature (24%) and a decrease in N (-10%) and POD (3%)
- Approaches including interactions between drivers show less impacts of driver changes in the past and much less in the future. It even implies a decrease in C sequestration in all approaches. This is mainly due to N limitation effects!!. Inclusion of interaction is uncertain!!!

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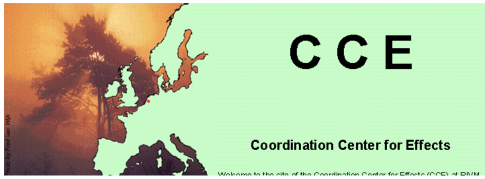

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