Project Number 282910

ÉCLAIRE

Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems

Seventh Framework Programme

Theme: Environment

D14.8 - Impacts of historic and future changes (period 1900-2050) in climate and air quality

Due date of deliverable:**30/05/2015**

Actual submission date: **30/09/2015**

Start Date of Project: **01/10/2011**

Duration: **48 months**

Organisation name of lead contractor for this deliverable:
Alterra, Joint Research Centre

Project co-funded by the European Commission within the Seventh Framework P		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission	☐
RE	Restricted to a group specified by the consortium (including the	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

In ECLAIRE work package 14, several land surface and dynamic global vegetation models are used to simulate the impacts on ecosystems of various scenarios of climate change, air quality (exposure to O_3 and CO_2) and deposition of nutrients on plant productivity and nutrient cycling. This includes results for all ecosystems (forests, short vegetation's and agricultural land) using major plant functional types. All these models, however, do not include impacts of non-N nutrient availability and the effects of soil acidity on the availability of N and other nutrients. This is a clear drawback since the availability of key plant nutrients, not only including nitrogen, but also phosphorus, potassium and magnesium might be important determinants of the amount of carbon sequestration in forest (trees and soils) at the global scale.

In contrast, a simple empirical model has thus been developed that includes interacting effects of air quality and climate change on forest carbon sequestration, by further elaborating an empirical tree growth model EUgrow, combined with a process-based soil model VSD+ to evaluate the combined effects of past and expected future changes in climatic variables (precipitation and temperature), CO_2 concentrations, N deposition and ozone exposure on C sequestration in trees and soils of European forest ecosystems, with a special focus on the period 1900 to 2050.. We also evaluated the forest carbon sequestration response by accounting for soil acidification and the possible limitation of forests growth by other major nutrients, i.e. calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P), in addition to the impacts of both climate and air quality change.

2. Objectives

The objective of Deliverable 14.8 was an assessment of impact of historic and future changes on carbon sequestration. Such an assessment of carbon sequestration can be focussed on several different ecosystems. In this deliverable we have focussed on impacts of past and expected future changes in climatic variables (precipitation and temperature), CO_2 concentrations, N deposition, ozone exposure and nutrient (Ca, Mg, K and P) availability on C sequestration in trees and soils of European forest ecosystems. This is due to the fact that, carbon sequestration is most important in those ecosystems. Similarly, we covered substantial time window, going back to 1900 and projecting forward to 2050. Originally, the end-date scenario had been expected to focus on 2100, but this was amended to 2050 as this allowed a more consistent treatment through this period, since several of the input terms in the period 2050 to 2100 become increasingly uncertain. By focusing on the period up to 2050 we are able to give more confidence in the approach taken.

The objective of this task was to assess the impacts of the various drivers both single and in interaction using an empirical model, especially accounting for the uncertainty in empirical dose response functions for N deposition and ozone exposure.

3. Activities:

Modeling

The empirical model EUgrow model was developed to simulate the change in carbon sequestration in the above-ground woody tree biomass of forests, by modifying a known growth rate in a reference year (the year 2005) with the impact of all major drivers, including temperature, availability of water, CO_2, N, other nutrients (P, Ca, Mg, K) and exposure to toxicants, i.e. O_3 and N at extremely high inputs. This approach is comparable to Felzer et al. [2004] who derived GPP as a multiplication of the maximum rate of C assimilation with factors related to photosynthetically-active radiation (PAR), leaf area, monthly air temperature, atmospheric CO_2 concentration, relative canopy conductance, ozone concentration and the feedback of N availability on C assimilation. The reference growth rate was derived from known forest growth data for 250 regions and 20 tree species in the EFISCEN model data base (Schelhaas et al., 2007) for the (reference) year 2005. In assessing the impacts on the various tree species, a distinction was made in Norway spruce, Scots pine, oak, beech, birch, other conifers and other broadleaves. To gain insight into the interacting impact of drivers, we used various assumptions in this study with respect to interactions, including a model with: (i) plausible interactions (reference model) and (ii) 'no interactions' in which the impact of each driver is cumulative and the combined effect is the product of individual effects (multiplicative model). In the reference model, a distinction was made between assumed interactive factors affecting photosynthesis (temperature, water, light, CO_2 and nutrients, distinguishing N from other nutrients) and assumed non interactive modifying factors due to O_3 exposure. Values for the drivers in 2005 and during the whole period 1900-2050 were based on databases and models, as given below.

Input data assessment

The spatial information describing land cover, soils, and forest growth, was derived by overlaying and combining maps and databases of: (i) land cover, using a harmonised land cover map for Europe (Slootweg et al., 2005), (ii) soils, using the European Soil Database v2 map at scale 1:1 M (JRC, 2006) and (iii) about 250 forest regions with growth data for a variety of species and age classes from the European Forest Institute (Schelhaas et al., 1999).

Climate data for the period 1960-2050 were bias-corrected data from the ECHAM5 A1B-r3 RCA3 simulation (ref) and cover the period 1960-2050. Bias correction was available for daily temperature and precipitation. To run the EUgrow-VSD+ model from 1901 onwards, climate data were generated for the period 1901- 1960 by random draws out of the climate data of 1961-1970. In the simulations 10-year averages were taken centred around 1900, 1910, …, 2050 (1900 is the average of 1901–1905; 1910 of 1906–1915 etc.) to smooth the climate pattern. Trends in atmospheric CO_2 concentration between 1900 and 2005 were taken from Etheridge et al. (1996) for the period 1900-1960, based on measured CO_2 concentrations from air in Antarctic ice and firn, and from Keeling and Whorf (2006) for the period 1960-2005, based on measurements at Mouna Loa. Predictions for the year 2050 were based on the IPCC SRES A1B scenario that assumes a concentration of 573 ppm in 2050. The depositions of S as well as oxidised and reduced N were calculated with the EMEP model (Simpson et al., 2012). Also the phytotoxic ozone dose (POD) was calculated by the EMEP model, incorporating the DO3SE deposition module, which parameterises ozone uptake as functions of phenology, light, temperature, humidity, and soil moisture (Simpson et al., 2003). Historic S, NO_x, NH_3 and VOC emissions were taken from Lamarque et al. (2010). Predictions for the period 2005-2050 are based on GAINS emission scenarios.

Scenarios and assessment of individual driver impacts and their interactions

The scenarios used to study the impact of each driver on the sequestration of C in forests and forest soils is given in Table 1.

Table 1: Scenarios used to study the impact of each driver. 1901 implies that the driver was kept constant stayed at the 1901 level 1901-2050 implies that the driver changed during this period, based on historical data (1900-2005) and predicted data (2005-2050).

Scenario	1 Climate	2 CO_2	3 N deposition	4 Ozone
All drivers constant				
1 S0000	1901	1901	1901	1901
Three drivers constant (one driver variable)				
2 S1000	1901-2050	1901	1901	1901
3 S0100	1901	1901-2050	1901	1901
4 S0010	1901	1901	1901-2050	1901
5 S0001	1901	1901	1901	1901-2050
Two drivers constant (two drivers variable)				
6 S1100	1901-2050	1901-2050	1901	1901
7 S1010	1901-2050	1901	1901-2050	1901
8 S1001	1901-2050	1901	1901	1901-2050
9 S0110	1901	1901-2050	1901-2050	1901
10 S0101	1901	1901-2050	1901	1901-2050
11 S0011	1901	1901	1901-2050	1901-2050
One driver constant (three drivers variable)				
12 S1110	1901-2050	1901-2050	1901-2050	1901
13 S1101	1901-2050	1901-2050	1901	1901-2050
14 S1011	1901-2050	1901	1901-2050	1901-2050
15 S0111	1901	1901-2050	1901-2050	1901-2050
All drivers variable: Test individual effects of neglecting one driver				
16 S1111	1901-2050	1901-2050	1901-2050	1901-2050

A ‘scenario’ is any combination of the 4 drivers switched on or kept at their 1900-value; it is denoted S_{ijkl}, where i,j,k,l each take the value 1 (driver on) or 0 (driver constant), and i,j,k,l refer to Climate, CO_2, N_{dep} and O_3, respectively. Obviously, S0000 refers to constant model input for all 4 drivers (the ‘zero-line’) and S1111 is the full model run (all drivers with time dependent historical and future input). In the reference scenario (scenario 16; S1111), all drivers are assumed to change according to past estimates (period 1900-2005) and future predictions (period 2005-2050), using the IPCC A1b scenario. The impacts of the individual drivers is not additive in the EUgrow model and thus depends on the status of the other drivers. The impact of a particular driver was calculated by subtracting a scenario B from a scenario A that differ only in that driver being on or off. For every driver there are 8 such possibilities, as listed in Table 2.

Table 2: The eight possible subtractions of scenarios that were used to study the impact of each driver in interaction to the other drivers.

Nr	Influence of single effect			
	Climate	CO_2 conc.	N deposition	O_3 exposure
1	S**1**000–S**0**000	S0**1**00–S0**0**00	S00**1**0–S00**0**0	S000**1**–S000**0**
2	S**1**100–S**0**100	S1**1**00–S1**0**00	S10**1**0–S10**0**0	S100**1**–S100**0**
3	S**1**010–S**0**010	S0**1**10–S0**0**10	S01**1**0–S01**0**0	S010**1**–S010**0**
4	S**1**001–S**0**001	S0**1**01–S0**0**01	S00**1**1–S00**0**1	S001**1**–S001**0**
5	S**1**110–S**0**110	S1**1**10–S1**0**10	S11**1**0–S11**0**0	S110**1**–S110**0**
6	S**1**101–S**0**101	S1**1**01–S1**0**01	S10**1**1–S10**0**1	S101**1**–S101**0**
7	S**1**011–S**0**011	S0**1**11–S0**0**11	S01**1**1–S01**0**1	S011**1**–S011**0**
8	S**1**111–S**0**111	S1**1**11–S1**0**11	S11**1**1–S11**0**1	S111**1**–S111**0**

The impact of each driver is assessed using the linear-N model total biomass O_3 response model. In addition the multiplicative model, assuming no interaction between drivers was run for the S0 scenario to gain insight in the impact of interactions.

4. Results:

4.1 Trends in overall tree and soil carbon sequestration

Calculated temporal changes in the European average carbon sequestration in trees and in soil in response to changes in climate, CO_2 concentration, N deposition and O_3 exposure are shown in Figure 1. Both the calculate tree and soil carbon sequestration is averaged over 10 year periods. Results show a rather strong impact of the use of the empirically based growth responses to N deposition (linear or non-linear) and an even larger impact of the two empirical O_3 exposure functions, considering either total biomass or net annual increment.

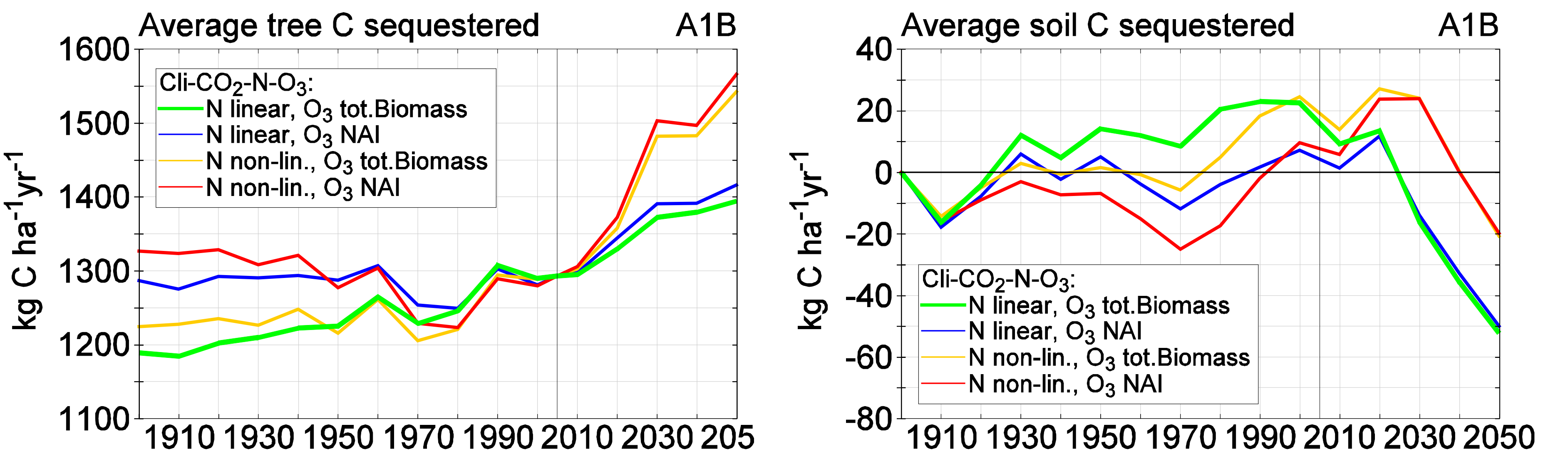

Figure 1: Temporal development of European average carbon sequestration in trees (left) and in soil (B) in response to changes in climate, CO_2 concentration, N deposition and O_3 exposure for two growth responses to N deposition (linear and non-linear) and O_3 exposure (total biomass and net annual increment, NAI).

The calculated carbon sequestration in trees increases almost continually over time in the period 1900-2005 when using the linear N deposition response and the O_3 exposure function for total biomass and the same holds for the coming period up to 2050. Instead a non-linear N deposition function does not significantly affect tree growth up to 1970, while it starts to increase from that period onwards (in response to the increased N deposition), and even more after 2005, which is mainly due to climate and CO_2 change, since N deposition decreases in that period. Apparently, the decrease in N deposition has a much smaller (reducing) effect on forest growth, as compared to the linear N deposition function. When using the O_3 exposure function for net annual increment, the calculated tree carbon sequestration stays either nearly constant in the last 100 years or even decreases in time, depending on the N response function used. Unlike N, the impact of O_3 response is much smaller in future predictions. This is most likely mainly due to the estimated smaller change in POD as compared to N deposition. The soil C pool changes reflect on average the changes in tree C pools as this affects the C input by litterfall. However, unlike tree C sequestration, the changes can be negative since soil respiration can be higher than litter C input. The decrease in the period after 2005 to negative values in 2050 for all scenarios is most likely due to climate change, on average increasing soil respiration by an increased temperature. Compared to tree C sequestration, the changes in soil C pools are on average very limited and (between -20-20 kgC ha^{-1} yr^{-1}) being nearly negligible compared to the ongoing tree C sequestration above 1000 kgC ha^{-1} yr^{-1}.

4.2. Impacts of individual drivers on tree carbon sequestration

The impacts of individual drivers on tree carbon sequestration assuming the linear nitrogen deposition function and an ozone exposure function based on total biomass is given in Figure 2

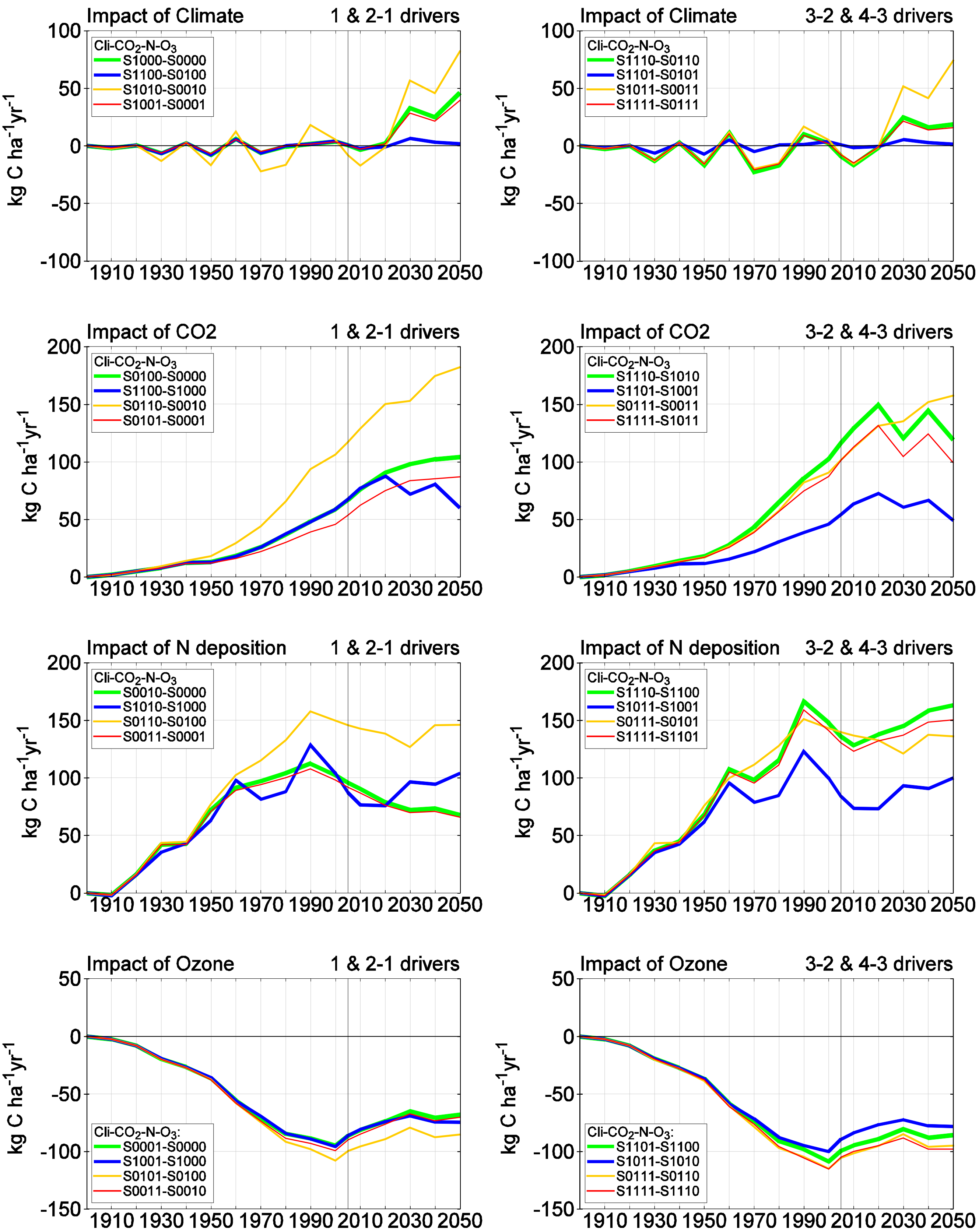

Figure 2: Influence of the single drivers computed according to Table 2, using the linear N model and the total biomass O3 response model.

In figure 2, the impact of each particular driver was calculated by subtracting two scenarios that differ only in that driver being on or off, including the eight possibilities listed before in Table 2. The impact of each driver is only assessed using the linear N and total biomass O_3 response model, which appears to produce the most plausible results. In general, effects of adding or removing a driver are expected to be highest for the situation where the other drivers enhance growth, because impacts of drivers are included in EUgrow as a fraction of the growth rate. The highest effect of CO_2 is thus expected for the situation where it is compared as an additional effect compared to climate +N, so Climate+ CO_2+N (1110)- Climate +N (1010), which is indeed found to be the case. Similarly, the highest effect of N availability is expected for the situation where it is compared as an additional effect compared to Climate + CO_2, so Climate+ CO_2+N (1110)- Climate + CO_2 (1100), which is also the case, although not deviating too much with the other scenarios. For climate, the highest effects are found for Climate+ N (1010)- N (0010) and for Climate+ N +O_3 (1011)- N +O_3 (0011), which is not trivial to explain. For ozone, there is hardly a difference between the various scenarios as the driver is assumed to act independently.

In summary, the model predicts that the fertilizing CO_2 effect is higher at elevated N, (which is the case in the N on scenario) than at low N (which is the case in the N off scenario, implying the use of 1900 N deposition data). Similarly, the model predicts that the fertilizing effect of elevated N availability (N deposition plus N fixation) is higher at elevated CO_2 than at low CO_2. In general, results are quite comparable for ozone since O_3 impacts are assumed to act independently. Climate impacts in relation to other drivers are highly site specific and results are thus not trivial to explain at a European wide scale.

4.3 Spatial patterns in tree carbon sequestration

Spatial patterns for the time averaged tree and soil carbon sequestration for the period 1900-1950, 1950- 2000 and 2000- 2050 are given in Figure 3, for the reference model, including interactions between drivers. Results show that the 50 year average carbon sequestration increases going from 1900-1950 < 1950-2000 < 2000-2050 in central Europe, but not in Northern and southern Europe (Fig 3). In these regions, the growth rate stays rather constant. Apparently, water availability limitations mainly offset the effects of CO_2 and temperature increase in Southern Europe, whereas limitations due to nitrogen availability and ozone exposure seem to offset those effects in Northern Europe.

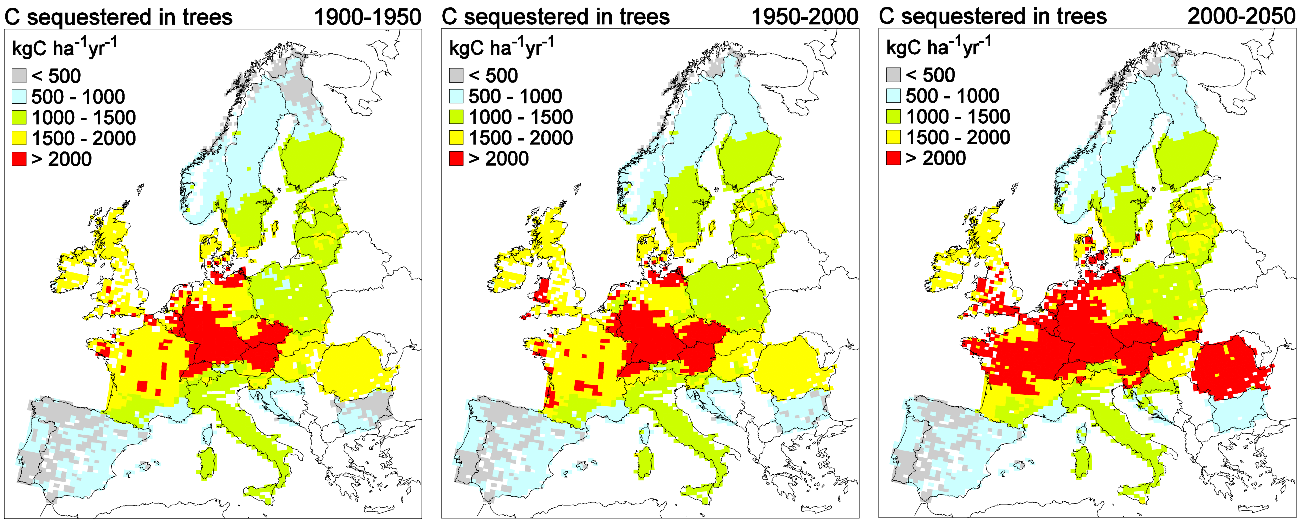

Figure 3: Spatial variation in calculated tree C sequestration over Europe in the period 1900-1950, 1950-2000 and 2000-2050, using the reference model with a linear N response model and a total biomass response to POD.

5. Milestones achieved:

No milestones were defined in relation to this deliverable

6. Deviations and reasons:

Delay in D14.8

Deliverable 14.8 was completed with a delay of about four months. The main reason was the inclusion of the most recent developments in empirical ozone response models and the interaction of climate, N and CO_2 impacts that appeared to be more demanding than originally foreseen.

7. Publications:

Bonten, L.T.C., G.J. Reinds and M. Posch, 2015. A simple model to calculate effects of atmospheric deposition on soil acidification, eutrophication and C-sequestration. Environmental Software & Modelling (submitted)

De Vries, W., M. Posch, D. Simpson, G. J. Reinds and L.T.C. Bonten, 2015. Modelling long term impacts of changes in climate, nitrogen deposition and ozone exposure on carbon sequestration of European forest ecosystems. Environmental Pollution (in prep).

8. Meetings:

ECLAIRE plenary meetings.

9. List of Documents/Annexes:

None.

REFERENCES

Felzer, B., D. Kicklighter, J. Melillo, C. Wang, Q. Zhuang, and R. Prinn (2004), Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model, Tellus, 56B(3), 230-248.

JRC (2006), The European Soil Data Base, distribution version v2.0, Joint Research Center, Ispra (Italy).

Lamarque, J.-F., et al. (2010), Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application, Atmos. Chem. Phys., 10(15), 7017-7039.

Schelhaas, M. J., S. Varis, A. Schuck, and G. J. Nabuurs (1999), EFISCEN's European Forest Resource Database, edited, European Forest Institute, Joensuu, Finland.

Schelhaas, M.J., Eggers, J., Lindner, M., Nabuurs, G.J., Pussinen, A., Päivinen, R., Schuck, A., Verkerk, P.J., van der Werf, D.C., Zudin, S., 2007. Model documentation for the European Forest Information Scenario Model (EFISCEN 3.1.3). Alterra, Wageningen, p. 118.

Slootweg, J., J.-P. Hettelingh, W. Tamis, and M. van 't Zelfde (2005), Harmonizing European land cover maps, in European Critical Loads and Dynamic Modelling: CCE Report 2005, edited by M. Posch, J. Slootweg and J.-P. Hettelingh, pp. 47-62.