Project No. 282910

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

Seventh Framework Programme

Theme: Environment

Due date of deliverable: **01/11/2012**

Actual submission date: **18/01/2013**

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

Duration: **48 months**

Organisation name of lead contractor for this deliverable :
NERC

Deliverable Name: **ÉCLAIRE Key Messages for Policy Makers, Year 1.**

Project co-funded by the European Commission within the 7th Framework Programme		
Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including the Commission	☐
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ÉCLAIRE

Key Messages for Policy Makers

Outcomes after Year 1

Contents

Executive Summary

The central goal of ÉCLAIRE is to assess how future climate change may alter the extent to which air pollutants have adverse effects on terrestrial ecosystems.

Based on the emerging activities of the first year, it is now hypothesized that, that *climate change will worsen the threat of air pollutants on Europe's ecosystems*:

- Climate warming may cause an increase the emissions of many trace gases, such as biogenic volatile organic compounds (BVOCs), ammonia (NH_3) and the soil component of nitrogen oxides (NO_x) emissions. These effects are expected to increase ground-level concentrations of NH_3, NO_x and ozone (O_3), as well as atmospheric nitrogen deposition.
- Climate warming may increase the vulnerability of ecosystems towards air pollutant exposure or atmospheric deposition. Such effects may occur as a consequence of combined perturbation, as well as through specific interactions, such as between drought, O_3, N and aerosol exposure.

The emerging message from the first year of ÉCLAIRE is that the first of these interactions (climate-emission-concentration-deposition) is likely to be very significant. Unless decisive mitigation actions are taken, it is anticipated that ongoing climate warming will increase agricultural and other biogenic emissions, posing a challenge for national emissions ceilings and air quality objectives related to nitrogen and ozone pollution.

Further evidence from the measurement and modelling activities of ÉCLAIRE is needed before any clear statements can be made regarding the second of these interactions (climate-pollution-ecosystem vulnerability). Potentially, the two effects may combine, leading to a substantial worsening of the overall air pollution threat of air pollution under future climate scenarios.

The ongoing efforts of ÉCLAIRE focus on working to quantify these relationships more precisely for the different components. The findings highlights the priority for further concrete actions to mitigate air pollution emissions if a further worsening of the air pollution threat to Europe's ecosystems is to be avoided, including on the *Natura 2000* network.

1. Progress in answering the key questions

This report is the first in a series of annual policy briefings prepared annually from the ÉCLAIRE project. It covers in a synthetic way the progress towards meeting the Key Questions and Specific Objectives as described in ANNEX I and II. In addition, the progress of ÉCLAIRE in achieving advances beyond the state-of-the-art is summarized. The report finishes with a short policy briefing considering wider issues emerging from the ÉCLAIRE process.

In this section we answer the seven key questions of ÉCLAIRE based on present understanding.

Q1: What are the expected impacts on ecosystems due to changing ozone and N-deposition under a range of climate change scenarios, taking into consideration the associated changes in atmospheric CO_2, aerosol and acidification?

First modelling efforts highlight the following:

- There is a strong temperature sensitivity in rates of NH_3 volatilization from agricultural systems, of NO_x emissions from agricultural and other soils, and of Biogenic Volatile Organic Compounds (BVOC) from managed and unmanaged ecosytems.
- Based on available measurements, a first empirical estimate suggests that 5 ºC warming would increase global NH_3 emissions by 42% (28%-67%). Together with increased anthropogenic activity, total global NH_3 emissions may increase from 65(45-85) Tg N in 2008 to reach 132(89-179) Tg by 2100, if no actions are taken (Sutton et al., 2013).
- It is currently estimated that temperature increase from climate change may increase European soil NO_x emissions by 40% by 2100 (Butterbach Bahl, *unpublished results*), and isoprene emissions, an ozone precursor, between zero and 40% (Arneth *et al.* 2008; plus emerging results).
- The large uncertainty in isoprene emissions arises from the fact that climate change (esp. warmer temperatures) increase emissions, but increasing atmospheric CO_2 concentration has been shown to decrease emissions. The net effect of these two antagonistic processes is unknown. It is to be expected that changes in monoterpene emissions are of the same order of magnitude.
- These potential emission increases from climate change would counteract the air quality benefits of current efforts to reduce anthropogenic emissions in Europe. The ongoing work of ÉCLAIRE is developing the fundamental basis to improve this quantification.
- Based on anticipated climate-induced increases in emissions, an increase in adverse effects on ecosystems can be expected, pending the findings of how climate change alters the vulnerability of ecosystems to a given pollution dose. The potential interactions with CO_2 and acidification have yet to be assessed.

Q2: Which of these effects off-set and which aggravate each other, and how do the mitigation and adaptation measures recommended under climate change relate to those currently being recommended to meet air pollution effects targets?

The synergies and trade-offs lead to complex non-linear responses, for which process-based models are being developed. In the case of soil NO_x, measurements show that raising soil moisture and temperature increase emissions (new results, building on Schaufler *et al.*, 2010), whereas for NH_3, temperature-induced increases in volatilization are off-set by increases in water availability. The non-linearities are even more complex for ground level O_3, where the response of BVOC emissions varies by compound; available evidence indicates that climate warming will raise O_3 ozone exposure to terrestrial ecosystems.

A full quantitative analysis of the interactions between mitigation and adaptation measures has not yet been completed.

The current evidence shows that the warming effects of reactive nitrogen (N_r) air pollution (N_2O emission, O_3 concentrations and vegetation damage reducing C uptake) and are largely offset by the cooling effects (O_3 effect on CH_4 lifetime, increasing C storage by forests, and effect of N_r aerosol). However, cost-benefit analysis shows that the cooling components of N are associated with a very high societal cost on human health and ecosystems, strongly supporting further reduction of N emissions.

An emerging message is that measures related to N need to focus on improving *full chain nitrogen use efficiency*, which will lead to reduced emissions of all reactive nitrogen forms and associated pollution (including, N_2O, NH_3, NO_x and O_3), while providing economic opportunities resulting from saving N in agricultural and other uses.

In this regard the ÉCLAIRE community have been leading a Global Overview on Nutrient Management for UNEP, with the key messages brought to the Rio+20 Summit in May 2012. The report will be presented to the UNEP Governing Council in February 2012.

Q3: What are the relative effects of long-range global and continental atmospheric transport vs. regional and local transport on ecosystems in a changing climate?

First coordinated studies have been presented in the report of the Task Force *Hemispheric Transport Air Pollution* (HTAP) 2010 assessment report. This assessed impacts on crops by ozone, biodiversity changes due to nitrogen deposition, changes in land-carbon uptake due to regional and extra-regional emission reductions.

The pollution-impacts were assessed in a rather crude and ad-hoc way- without strong relationship to concrete emission scenarios. Impacts of 20% emissions reductions made in North America, East and South Asia, and Europe itself, on European crop losses due to ozone were compared. In relative terms, the European impact was 60-70% of the total, with the sum of the other continents contributions was 30-40%.

ÉCLAIRE gives support to and benefits from the 2nd phase of HTAP model experiments, by using the results from new HTAP global scale emission scenarios combining global scale models with regional models. New methods in developed in ÉCLAIRE will allow more quantitative impacts of the long-range impacts of vegetation-air pollution interactions. A first coupling of the regional EMEP model with ensemble results from HTAP is currently being implemented.

Q4: What are the appropriate metrics to assess ozone and nitrogen impacts on plants and soils, when considering state-of-the-art understanding of interactions with CO_2 and climate, and the different effects of wet vs. dry deposition on physiological responses?

At the moment, policy analyses for the *Thematic Strategy on Air Pollution* (TSAP) revision and the Convention on Long-range Transboundary Air Pollution employ critical levels (thresholds for air concentrations and ozone fluxes) and critical loads (for deposition) as the main indicators for ecosystems damage. Such critical levels and loads are established for current climatic conditions by national teams and compiled into European-wide databases.

However, the quantification of critical thresholds is critically influenced by climate change, and additional processes that are currently not considered could become relevant under a changed climate.

For **ozone**, ÉCLAIRE is developing the basis for extending the application of thresholds using flux based approaches rather than based on ozone concentrations. This will allow the effects of changes in drought under climate change to be directly factored-in to future scenarios. For **nitrogen**, experimental work and data-mining is ongoing to distinguish the effects of different nitrogen forms, including whether there is an interaction with ozone exposure. In addition, in a novel element of ÉCLAIRE an examination is being made of whether ambient atmospheric deposition of hydroscopic particles will alter plant water relations, providing the basis for a new chemical/physiological mechanism. Answers to this question will become clear as the project progresses.

Q5: What is the relative contribution of climate dependence in biogenic emissions and deposition vs. climate dependence of ecosystem thresholds and responses in determining the overall effect of climate change on air pollution impacts?

It will only be possible to answer this question at the end of the project. For now, the focus is on understanding and quantifying the different components, which will later be assembled into the bigger picture.

Q6: Which mitigation and/or adaptation measures are required to reduce the damage to "acceptable" levels to protect carbon stocks and ecosystem functioning? How do the costs associated with the emission abatement compare with the economic benefits of reduced damage?

These questions are being addressed by further development and application of the GAINS model within ÉCLAIRE. Work is ongoing to establish an improved costing basis for the benefits of reduced air pollution effects on ecosystems, and to integrate these with the effects on human health and materials.

Q7: How can effective and cost-efficient policies on emission abatement be devised in the future?

One of the expected outcomes of ÉCLAIRE will be to construct an improved knowledge chain that quantifies the impacts of climate change into the dose-response relationships for air pollution effects on ecosystems By factoring these issues into the integrated assessment modelling, and cost-benefit analysis, the toolbox will be developed for emission control policies that are cost-effective also under a changed climate.

2. Major advances in the state-of-the-art

2.1. Emissions and Exchange Processes

Measurement network

A flux measurement network has been initiated that will, over the next 15 months, greatly improve the availability of fluxes of soil NO, O_3, NH_3 and biogenic volatile organic compounds (BVOCs) with European ecosystems, which will be analysed to improve our process-based models to describe surface/atmosphere exchange.

An international, collaborative measurement campaign was conducted in June 2012 at the Bosco Fontana mixed oak forest near Mantova, Po Valley, Italy. The aims were to:

(i) investigate in detail the exchange of pollutants with semi-natural vegetation in this polluted European region,
(ii) study the role of in-canopy chemical conversions in modulating the flux with the vegetation,
(iii) provide ground validation data of satellite retrievals of pollution fields with emphasis on NH_3 and
(iv) provide an additional ground-site for the PEGASOS Po Valley chemical experiment. Measurements were very successful and the analysis is ongoing.

In addition, the experiment has allowed the establishment of a new long-term forest tower facility in the Po Valley, representing a combination of ecosystem and pollution climate that was until now not represented in European measurements.

Laboratory Experiments

Laboratory experiments of exchange processes have shown that for some ecosystems, decomposing leaf litter represents a larger source of ground level NO emissions than the soil itself, with important implications on the targeting of follow-up research with ÉCLAIRE and beyond and on representation of soil NO in emissions models to ensure correct response to climatic variables. ÉCLAIRE has also substantiated that significant NO concentrations can be produced within plants as a messenger within the response of vegetation to O_3 stress.

A study associated with ÉCLAIRE has shown that oxygenation products of BVOCs, which were previously thought to be formed in the atmosphere, can be emitted directly from vegetation. This has implications for the potential of plants to detoxify O_3 within the plant itself and calls for a reassessment of how these compounds need to be treated by exchange models.

Laboratory measurements have also investigated the emission of BVOCs as a function of heat and drought stress for boreal, temperate and Mediterranean species, with emphasis on the O_3 production potential of the emitted compounds: while BVOC emissions decrease under drought stress, their relative potential for O_3 production increases.

Process level exchange modelling

It is becoming increasingly apparent, that the biosphere/atmosphere exchange of the key compounds of interest to ÉCLAIRE (N_r, O_3, VOCs) is heavily modulated by chemical conversions below the height which can be resolved explicitly by chemical transport models. Empirical corrections of the effects, where they exist at all, are non-mechanistic and not suitable for the work within ÉCLAIRE.

Thus, a new multi-layer coupled transport/exchange/chemistry model (ESX) has been devised, which will developed as a community model to simulate biosphere/atmosphere exchange of gaseous pollutants and aerosols taking into account chemical conversion processes near and within plant canopies. This will be used as a common ÉCLAIRE framework to

(i) interpret and assimilate past and present field measurements,
(ii) quantify O_3 and N_r loads to vegetation and
(iii) will be implemented in a simplified form at least into the EMEP model. Both an internal ÉCLAIRE workshop and an international expert workshop (organised jointly with COST ES0804, ABBA) were organised to develop this as a state-of-the-art framework.

In parallel, an existing multiple-layer canopy exchange model implemented in a 1-D chemistry-climate model system (MLC-CHEM) has been coupled to the DGVM LPJ-GUESS to assess the relevance of O_3 deposition impacts on BVOC emissions feeding back on O_3 concentrations and deposition.

The treatment of stomatal conductance (g_{sto}) has been improved in the DO$_3$SE model, which now incorporates a module that allows leaf level g_{sto} to be estimated according to a photosynthetic-based method.

The DNDC biogeochemistry model is being improved to provide more realistic emissions of NO (and N_2O) and to enable application at the European scale. First applications have revealed that the agricultural management data currently used by the project is not fully consistent between countries, further informing future project priorities.

2.2. Emissions and exchange at local, EU and global scales

Upscaling emission modelling

A number of important model developments were achieved that seek to describe emissions of biogenic O_3 precursors (isoprene, NO) in response to climate change, change in CO_2 concentration and N-deposition. In cases of N-trace gases, temperature will lead to an increase in emission, exacerbated by enhanced N-deposition. Indirect effects of larger productivity of vegetation on nitrogen cycling, and N-emissions are unclear but presumably play a minor role. In case of isoprene the picture is more complex, as the stimulation of emissions through warmer temperature might be offset by inhibition of isoprene emissions by higher CO_2 levels. The net effects are difficult to predict, since these will also depend on how the climate/CO_2 interplay will affect total plant productivity.

Emission models are currently in the test-phase, but will aid to project changes into the future & contribute to investigate the role of biogenic emissions for air pollution and climate, either on European or global level. To achieve progress over the coming year, an initial protocol to link scenarios and surface models to chemistry transport models (CTMs) and global climate models (GCMs) was agreed on, and first set of bias-corrected climate drivers became available.

Messages from model intercomparisons

Two intercomparison projects that were completed for CTMs, one (in cooperation with EMEP Task Force on *Measurement & Modelling*, TFMM) across scales from 7 km to 56 km grids, investigating effects of climate change on ozone. The results of the scale-exercise have been presented for use within EU Thematic Strategy work, and at the EMEP Steering Body. The results are still being analysed, but one main message is that the grid size does not play a major role for air quality model calculations which are targeted on the determination of the background (non-urban) air quality, but (as expected) urban agglomerations were better resolved with decreasing grid size. Another finding is that one model differed from the other three in showing a very strong urban impact due to a special meteorological treatment in urban areas – something to be understood in the analysis phase. The EnsClim project suggested that ozone changes due to direct climate change effects were small relative to those expected from emission changes, but model response differed significantly, and highlighted differences in biogenic isoprene emissions as a likely reason for the differences.

2.3. Ecological response processes and thresholds

Data mining and meta-analyses

The effort in the data mining has been to identify large-scale datasets that can be used to evaluate and develop the ecosystem models. These datasets should represent different ecosystem types (e.g. forests, agriculture and semi-natural land covers) and cover the geographic range of Europe. Ideally they will be for a long time-series and record some kind of experimental manipulation (i.e. pollutant deposition). The ideal datasets have been identified based on an inventory of the ecosystem model input, parameterisation and evaluation data requirements.

Improved model parameterisation

For the DO_3SE (*Deposition of Ozone for Stomatal Exchange*) model the key parameters to be targeted for improvement have been identified and include those algorithms related to photosynthesis, respiration and C allocation. Experimental protocols have been developed to allow standardisation in the collection of these parameters from the ÉCLAIRE experiments. Once the first data are available the parameterisation will be performed.

The N14C model of C and N turnover has now been published (Tipping *et al.*, 2012), linking N inputs to Net Primary Production (NPP), soil C and N accumulation, and leaching or organic and inorganic N. The model has been operationally linked to models of acid-base chemistry and organic matter solubility to create the integrated 'MADOC' model, which is now being tested and refined. Key process and parameter requirements to incorporate ozone impacts within this model structure have been identified, linking to other models including DO_3SE and JULES.

Novel thresholds and dose response relationships

The method to define novel thresholds using the DO_3SE model has been refined. This will require the DO_3SE model to be developed to include simple plant growth algorithms that allow for C assimilation and efflux (via photosynthesis and respiration respectively) and C allocation. This model will then be used to simulate conditions in the ÉCLAIRE experiments so that plant response to a variety of conditions (pollutant and climate) can be explained. From this, novel thresholds (or tipping points) can be defined to identify the pollutant load causing response related to key ecosystem processes and functions.

Climate change interactions on air pollutant impacts

Different nitrogen forms affect carbon cycling in peatlands via pH effects (S4): Soil pH response and thus decomposition / mineralisation effects are linked to N form. Nitrate and ammonia increased the pH, while ammonium caused soil water to be more acidic.

New sources of methyl vinyl ketone in planta (S4): Isoprene-ROS reactions produce MVK. Ozone exposure induced a transient peak of MVK emission

2.4. Ecological response at regional and European scales

Model developments

The dynamic global vegetation models (DGVMs) and dynamic soil vegetation models (DSVMs) to be applied within ÉCLAIRE were further developed by including (i.e. LPJ-Guess and VSD+-Forspace) or working on the inclusion (JULES-MADOC, CLM, O-CN) of process descriptions for the impact of ozone exposure and/or nitrogen deposition on productivity.

A separate simple empirical forest growth and management model, GrowUp, was developed for rapid assessment of the interacting impacts of air quality and climate change making use of (meta-analysis of) literature information and published data.

Develop novel thresholds and dose-response relationships

A contribution was made to a detailed data mining from the literature to IMPROVE process parameterisation within the models, focusing on detailed described effects of ozone and other stresses on photosynthesis, C partitioning, for use in DGVMs.

A meta-analysis was conducted to assess the single and combined effects of changes in climate (temperature and water availability), nitrogen availability, carbon dioxide (CO_2) exposure and ozone (O_3) exposure in forests and forest soils. We limited our study to boreal, temperate and Mediterranean regions particularly those in Europe, US and Canada. Results are used in the empirical GrowUp model.

Apply novel thresholds and dose-response relationships at European scale

A preliminary mapping was carried out of critical phytotoxic ozone dose (POD) thresholds for forests, based on a spatial explicit assessment of tree species and their exceedances by applying the current DO_3SE approach coupled to the EMEP model.

The combined effects of past and expected future changes in climate (temperature and water availability), nutrient (nitrogen, base cations) availability, carbon dioxide (CO_2) exposure and ozone (O_3) exposure on carbon sequestration in European forests for the period 1900–2050 were modelled with GrowUP. Forest inventory data around 2005 (European Forest Institute, EFI database) were used to assess reference forest growth rates, which were then modified for other years by factors accounting for deviations in climate and air quality compared to 2005.

2.5 Integrated Risk Assessment and Policy Tools

Emission scenarios

New spatially explicit global emission scenarios until 2050 have been developed by IIASA. These scenarios provide projections of future emissions of air pollutants and greenhouse gases at a 0.5*0.5 degree longitude/latitude resolution. Based on 'business as usual' trends in energy use and agriculture, they project future emissions in the absence of further air pollution policies (i.e., they assume full and timely implementation of current national legislations on air pollution controls). Thereby they differ from the Representative Concentration Pathway (RCP) scenarios developed for the IPCC/AR5, which assume further tightening of emission controls occurring autonomously with increasing wealth. As the IIASA scenarios do not imply further policies, they will be better suited to explore the need for future policy interventions.

While these scenarios are harmonized with projections of aerosol and ozone precursor emissions developed for the ECLIPSE and PEGASOS projects, work under ÉCLAIRE focused on future trends in agricultural emissions. These scenarios will serve as input for the modelling studies in ÉCLAIRE and the other projects, as well as for the work of the UNECE Task Force on *Hemispheric Transport of Air Pollutants* (HTAP).

A workshop at IIASA reviewed the current understanding of the driving forces and critical policy interventions that determine nitrogen emissions in the 21st century. As the currently available global scenarios have been developed with a focus on greenhouse gas emissions, they do not span the full range of possible developments. It has been agreed to contribute to the currently ongoing development of the SSP (*Shared Socio-ecosystem Pathways*) scenarios that support the scenarios developed for IPCC/AR5.

Ecosystems valuation

A review of the set of literature on ecosystems valuation reveals the importance of a clear apportionment of the share of total damage that can be related to air pollution. While high figures are reported for the total value of ecosystems, damage from poor air quality will usually account only for a fraction of the total value. There are indications that the monetary value of damage to ecosystems from air pollution could be lower than monetized health impacts, but higher than the damage to materials or crops.

New indicators

In the *GAINS model* a new database of critical loads has been implemented in 2012. This new database includes most recent country contributions, while the resolution of critical loads now enables assessments on a 5x5 km^2 grid providing an improved focus on Natura 2000 areas.

Regarding the *GAINS system* two advances have been realized. The first is the implementation on a European scale (Hettelingh *et al.*, 2012) of nitrogen-dose-response functions which have been developed on the basis of gradient studies (Stevens, et al. 2010). The second involves the implementation of limits to assess impacts of ozone. In collaboration with ALTERRA, a tree species data base covering Europe (excl. RU) on a 0.01 by 0.01 degree grid was acquired/established. This database has been used to compute exceedances of POD, using POD1 computations from met.no, exploring different critical limits, obtained from the ICP Vegetation (CEH Bangor), and their consequences for 4 different tree species. This work is meant to guide further developments in this field: (a) review of critical limits; (b) extension of POD calculation for specific species (now only coniferous and deciduous PODs are available).

A tentative new method is being developed in collaboration with counterparts in ÉCLAIRE and under the Convention on Long-range Transboundary Air Pollution, including tests, to enable the (transboundary) comparison of effect indicator-values on a harmonized scale. This harmonized scale is developed to assess to which extent "no net loss of biodiversity" is achieved using suitable - but not necessarily the same - biodiversity indicators of interest on a regional scale and relative to a well chosen reference. This method is in an early experimental phase, of which success is still to be demonstrated.

3. Progress in addressing the specific objectives

Objective S1: To develop improved process-based emissions parameterization of NH_3, NO and VOCs from natural and agricultural ecosystems in response to climate and pollutant deposition for incorporation into atmospheric Chemistry-Transport Models (CTMs), based on existing and new flux measurements in the field and laboratory, applying these to develop spatially resolved emission scenarios in response to climate, CO_2 and air pollutant change [WPs 1, 2, 3, 6./Month 42].

Component 1

Field measurements have started of soil NO emission fluxes in relation to meteorological parameters at 9 flux measurement sites. The now established measurement sites will also host VOC and NH_3 flux measurements during the Intensive Measurement Periods. These will provide the data for the improvement of flux parameterisations. Similarly, laboratory measurements of the emission of NO (as well as N_2O, CH_4 and CO_2) from soil cores originating from the ÉCLAIRE flux network sites has started to provide new relationships for soil and litter emissions in relation to soil moisture and temperature.

Using a coupled plant / smog chamber system, we have quantified the effect of drought stress on VOC emissions and their potential for O_3 production for temperate, Boreal and Mediterranean vegetation and these data are being written up. In a separate lab study, the effect of O_3 stress on NO and VOC emissions from plants was investigated.

Updated parameterisations of soil NO emissions have been developed for the DNDC model (see below), and a new controlled soil incubation system has been constructed to further investigate and parameterise the effect of rewetting on soil emissions and their underlying processes, focussing on Mediterranean soils.

Component 2

LPJ-GUESS: Model developments include: (1) an improved process description of O_3 uptake and phytotoxic effects (Sitch et al., 2007); (2) a European tree-species specific version of BVOC (iso- and monoterpene) emissions; (3) coupled C-N cycles (currently undergoing evaluation and testing). Results from (1) and (2) could be made available to project partners by the end of 2012, and from (3) during 2013.

DNDC: Model developments include: (1) a revision of the model structure to facilitate computation of inventories at continental scale; (2) implementation of routines and database approaches needed for assessing model parametric uncertainty; (3) initial runs with LandscapeDNDC at EU scale have revealed short-comings of the NitroEurope database with regard to soil properties and fertilizer applications, as well as the need for further improvements to parameterization scheme; (4) meta-analysis of soil NO emissions has been started and will be used for testing new process descriptions and parameterization schemes.

Model developments include: (1) sensitivity studies of the effect of climate and climate change on ammonia emissions in Europe have been analysed; (2) an extension of the emission model to cover all of Europe. Results from this work will be available to ÉCLAIRE partners in 2013; (3) preliminary links with WP3 explored to improve the description of the emissions from soils following e.g. fertiliser application.

INTEGRATOR: Model developments include: (1) provision annual NH_3 emissions for housing systems and manure storage, grazing animals, fertilizer application, manure application per animal/manure category with first results provided to NERC; (2) use of animal number data at a 1×1 km resolution with results to become available during 2013.

EMEP4UK model zooming application: Detailed planning undertaken and model runs with the EMEP4UK model planned for early 2013 and to be made available to ÉCLAIRE partners.

Objective S2: To determine the chief processes in atmospheric chemistry that respond to climate and air pollution change and the consequences for ozone and aerosol production and atmospheric lifetimes, in the context of the global O_3 background [WPs, 5, 7/Month 36 & through collaboration with PEGASOS FP7 project].

Component 2

JRC and EMEP Work in work packages 5 and 7 focussed on the analysis of existing emission scenarios in the framework of the multi-model ensemble simulations performed in the Task Force Hemispheric Transport Air Pollution. A range of boundary conditions were propagated into the EMEP model to assess low-median- and high impacts of external ozone onto the development of ozone within Europe. This range will be taken up by the EMEP-GAINS modelling chain to perform supporting calculations for the European Commission in the frame of the review of thematic strategy air pollution. Linkage to PEGASOS new scenario analysis will be ensured during a workshop and follow-up work scheduled for November 2012; analysis is scheduled to start in 2013.

CNRS: performed analysis of past-present and future scenarios with the IMPSL –CM5 Earth system model within the ACCMIP activity in support of IPCC-AR5. The emissions were based on compilations of past emissions and future RCP emissions harmonized for IPCC. The analysis focussed on providing consistent calculations of climate effects of these emissions scenarios.

Objective S3: To develop improved multi-layer dry deposition / bi-directional exchange parameterisations for O_3, NO_x, NH_3, VOCs and aerosols, taking into account near-surface chemical interactions and the role of local/regional spatial interactions, based on existing and new flux measurements and high resolution models and to estimate European patterns of air concentrations and deposition under climate change [WPs 1, 2, 4, 7, 8/Month 42].

Components 1 and 2

As a collaboration between WPs 4 and 7, the **ÉCLAIRE S**urface E**x**change (ESX) model mentioned above has started to be developed to bridge the gap between fine vertical resolution models (for assessment of in and near-canopy chemistry and fluxes of BVOC, NH_3, etc.) and CTMs. The ESX model makes use of a chemical solver from the EMEP CTM combined with a Kz-based dispersion system. The intention is that the ESX model will be a community (and public-domain) effort, involving participants from C1, C2 and other components, which will be made available to all modelling groups within ÉCLAIRE, PEGASOS and beyond.

Because virtually all former parameterisations of biosphere / atmosphere exchange modelling has applied so-called big-leaf approaches, it will be necessary to reanalyse existing measurements of exchange fluxes with the new multi-layer modelling framework to derive suitable parameterisations. ESX will be used to assimilate the data emerging from the ÉCLAIRE flux network sites. A hierarchy of ESX model versions will be developed so that computationally efficient, simplified implementations can be fully traced to a version that provides the best representation of the current state-of-the-art. This will allow the effect of simplification to be quantified.

LPJ-GUESS: is currently being coupled with a detailed canopy model to simulate in-canopy processes such as emissions, chemistry, dynamics and deposition, including fluxes of bVOCs, N and O_3 and the uptake of O_3

Objective S4: To integrate the results of meta-analyses of existing datasets with the results of targeted experiments for contrasting European climates and ecosystems, thereby assessing the climate-dependence of thresholds for land ecosystem responses to air pollution, including the roles of ozone, N-deposition and interactions with VOCs, nitrogen form (wet/dry deposition) and aerosol [WPs 9, 10, 11, 12/Month 30].

Component 3

Progress in defining the roles of ozone, N deposition, BVOCs, and aerosol for the assessment of climate-dependent thresholds of land ecosystem responses to air pollution and impact on air chemistry has been made, including the following:

- Consolidation and refinement of the experimental peatland Whim
- Data collection for modelling of GHG fluxes
- Start of measurement of foliar O_3 deposition under water and temperature stress and during leaf development and seasonal metabolic changes in a Mediterranean evergreen oak forest
- First measurements of the fraction of O_3 that is taken up due to detoxification in the leaf by constitutive BVOC
- Targeted experiments for the estimation of transpiration increase by simulated aerosols
- Progress toward parameterization of water use efficiency for model use under conditions of particle pollution

Objective S5: To develop improved process-based parameterizations in dynamic global vegetation models (DGVMs) and soil vegetation models (DSVMs) to assess the combined interacting impacts of air quality, climate change and nutrient availability on plant productivity, carbon sequestration and plant species diversity and their uncertainties [WPs 14, 15, 17/Month 44].

Component 3

Substantial work has been undertaken to identify and prioritise model data requirements, to enable consistent and comparable model testing (for C3 and C4 models) and to identify key data requirements from data mining and experiments. Model development activity has included: A set of core 'ecosystem functions' (i.e. those ecological processes that determine ecosystem service flows) has been identified which are considered potentially sensitive to air pollution. The objective of this work has been to define a set of measurable processes that can be used to develop novel dose-response functions linking air pollution and ecosystem services.

Component 4

The dynamic global vegetation models (DGVMs), dynamic soil vegetation models (DSVMs) and biodiversity models to be applied within ÉCLAIRE, i.e. LPJ-Guess, JULES-MADOC, CLM, O-CN, VSD+-Forspace and EUMOVE were further developed by including process descriptions for the impact of ozone exposure and/or nitrogen deposition on productivity. More specifically, the activities included:

- *LPJ-GUESS:* An improved process description of O_3 uptake and phytotoxic effects has been incorporated following the parameterisation described by Sitch *et al.* (2008). The new version of LPJ-GUESS includes the capability of modelling photosynthesis and VOC emissions on a sub-daily time step. LPJ-GUESS is currently being coupled with a detailed canopy model (MLC-CHEM) that will allow LPJ-MLC to simulate in canopy processes such as emissions, chemistry, dynamics and deposition, including fluxes of N and O_3 and uptake of O_3. The O_3 uptake and phytotoxic damage algorithms that have been incorporated are based on the POD metrics.
- JULES and MADOC: A set of fieldwork data has been collected this summer to improve the existing leaf level O_3 uptake model in JULES. When this is done, it will be linked with soil N and vegetation N uptake models within JULES. MADOC is being tested against experimental data on soil responses to N additions. Ozone effects will be incorporated by either a) use of JULES algorithms; b) use of NPP values calculated by JULES; or c) incorporating simple dose-limitation functions derived from experiments and/or JULES sensitivity analyses.
- *O-CN:* A flux scheme has been implemented into O-CN, to estimate surface ozone concentration and stomatal ozone uptake. Modules for calculating the impact of ozone uptake on net assimilation and transpiration rates are currently under development. This will link to the coupled carbon-nitrogen cycle parameterisation of O-CN to calculate the impact of ozone on terrestrial C and N budgets

- CLM: A version of the Community Land Model v4 (CLM4) incorporating the description of O_3 uptake and damage has been developed (Lombardozzi *et al.*, 2012). This new version of the CLM4 model describes the O_3 damage by modifying photosynthesis and stomatal conductance in a Farquhar photosynthesis/Ball-Berry conductance model. The originality of the approach stays in the independent parameterization of response function to O_3 for photosynthesis and transpiration.
- *Forspace:* the effects of O_3 uptake, base cations availability and soil pH on the photosynthetic machinery and plant growth were included. The improved model was linked to VSD+ as input for simulations of soil carbon sequestration while VSD+ output on base cations availability and soil pH is used by FORSPACE
- *EUMOVE*: This model was further developed by relating measured plant species diversity at about 30000 sites in Europe to estimates of climate (temperature and precipitation based on CRU data), N and S deposition (EMEP model estimates), pH, moisture content and N availability (combined measurements and modelling). - The model chain VSD+ Inverse EUMOVE has been chosen for the assessment of the local variation in critical load exceedance in WP17
- *GrowUp*: a separate simple empirical forest growth and management model, GrowUp, was developed for rapid assessment of the interacting impacts of air quality and climate change making use of (meta-analysis of) literature information and published data.

Objective S6: To *develop novel thresholds and dose-response relationships* for air pollutants (especially for O_3 and N) under climate change, integrated into process-based models verified by experimental studies at site scales and mapped at the European scale, quantifying the effect of climate change scenarios [WPs 14, 15, 16/Month 44].

Component 4

Endpoints: A short document on indicators for geo-chemical and biological endpoints is underway to enable the mapping of critical thresholds. This document is based on two chapters in a critical load book (edited by Wim de Vries and Jean-Paul Hettelingh; C4 component leader and WP 19 leader, respectively) to be published in 2013

Data mining: A contribution was made to a detailed data mining from the literature to IMPROVE process parameterisation within the models, focusing on detailed described effects of ozone and other stresses on photosynthesis, C partitioning, for use in DGVMs. The development of novel parameterizations of the response functions for O_3 and N depositions will be based on an original and comprehensive dataset of experimental observations. The content and structure of the database, the template and the methodology for the data-mining exercise have been developed in cooperation between C3 and C4. For reviewing purposes, C3 and C4 participants have been testing the methodology by archiving a selected number of publications. Results of this test will be jointly discussed during the annual meeting in order to agree on the final methods to be applies in the data-mining process. In the following months C3 and C4 contributors will compile the database according to the agreed methodology. The database will finally serve as a common platform to perform meta-analysis and for the estimation of parameter sets.

Meta-analysis: A meta-analysis was conducted to assess the single and combined effects of changes in climate (temperature and water availability), nitrogen availability, carbon dioxide (CO_2) exposure and ozone (O_3) exposure in forests and forest soils. Combined effects, which were limited to the interactions of CO_2 × N, CO_2 × O_3, CO_2 × *warming* and N × *precipitation* change, were investigated to see whether effects are synergistic (amplifying), antagonistic (dampening) or neutral (no interaction). The meta-analysis was conducted of published manipulative field studies that reported above-ground C responses (above-ground net primary productivity-ANPP, leaf litterfall) and below-ground C responses (below-ground NPP, below-ground root litter, soil respiration) as well as total forests ecosystem CO_2 exchanges (NPP, net ecosystem productivity-NEP, net ecosystem exchange-NEE). We limited our study to boreal, temperate and Mediterranean regions particularly those in Europe, US and Canada. Results are used in the empirical GrowUp model.

Objective S7: To assess the extent to which climate change alters the transport distance and spatial structure of air pollution impacts on land ecosystems considering local, regional, continental and global interactions, focusing on nitrogen and ozone effects [WPs 5, 6, 7, 8, 9/Month 44].

Component 2

LPJ-GUESS: Preliminary emissions data for precursors of O_3 (bVOCs) will be provided to CTM project partners by the end of the year. Improved estimates will follow over the course of next year as model developments (see above) and further climate input become ready.

Initial simulations of climate change, change in CO_2, O_3 and N-deposition impacts on ecosystem properties and trace-gas exchanges will commence in winter 2012/13.

S8: To *apply the novel metrics* to quantify multi-stress response of vegetation and soils, including effects on carbon storage and biodiversity to improve the overall risk assessments of pollution-climate effects on ecosystems at the European scale as the basis for development of mitigation options [WPs 14, 15, 16/Month 44].

Component 3

This activity will follow the development and testing of models described above, and the development of novel metrics under S6.

Component 4

CLM: The new CLM version, in which the parameterization of the impacts of O_3 on photosynthesis (CO_2 exchange) and conductance and thereby transpiration (water exchange) is uncoupled was applied at a global scale. Results show that the uncoupled photosynthesis and conductance caused substantially lower decreases in transpiration and CO_2 uptake in response to elevated O_3 than the coupled approach, being the typical approach in most DGVMs. In other words, impacts of O_3 appear to be less.

GrowUp: The combined effects of past and expected future changes in climate (temperature and water availability), nutrient (nitrogen, base cations) availability, carbon dioxide (CO_2) exposure and ozone (O_3) exposure on carbon sequestration in European forests for the period 1900–2050 were modelled. Forest inventory data around 2005 (EFI database) were used to assess reference forest growth rates, which were then modified for other years by factors accounting for deviations in climate and air quality compared to 2005.

Biodiversity indicator: A biodiversity indicator was further developed and described in the above mentioned critical load book based on the presence or absence of species or species combinations, weighting to the intrinsic 'importance' of each species from a nature conservancy point of view (i.e. considering rareness, decline; the IUCN concept of 'Red Lists', lists of endemics etc).

POD exceedance at European scale: A preliminary mapping was carried out of critical phytotoxic ozone dose (POD) thresholds for forests, based on a spatial explicit assessment of tree species (using EFISCEN-space) with different POD limits in view of adverse effects (focusing on birch, beech, spruce and oak) and their exceedances by applying the current DO3SE approach coupled to the EMEP model. The planning is to improve results by including the updated photosynthesis-based DO3Se and EMEP models further developed under ÉCLAIRE.

Component 5

The strategy to apply new metrics under WP19 includes the design and development of a methodology that relates biodiversity endpoints to indicators in soil chemistry and plant species diversity. The set of operational indicators has been extended to include (a) a new critical loads database better suited for assessments of adverse effects on *Natura 2000* areas (b) a new set of European dose response relationship for certain specified EUNIS classes (c) the implementation of a tree species database to assess impacts of ozone.

Source-receptor matrices have been tested to include indicators not applied previously. Specifically, this includes the phytotoxic ozone dose, POD, with threshold deposition velocities of 1 or 3 $nmol/m^2/s$ (POD1 and POD3, respectively). Thus any linear combination of such indicators, including N deposition, now can be mimicked in the effects module of the GAINS model.

S9: To quantify the overall economic impacts of air pollution effects on land ecosystems and soils, including the valuation of ecosystem and other services, and the extent to which climate change contributes by altering emissions versus ecosystem vulnerability [WPs 3, 4, 6, 7, 12, 14, 15, 16, 18/Month 42].

The review of available and required indicators to quantify overall impacts has been addressed at (a) the 22nd CCE workshop, (b) the 41st session of the Task Force on Integrated Assessments and (c) a workshop of the Network of Experts on Benefits and Economic

Instruments entitled “Further quantification of the effects of air pollutants on ecosystems” (St. Petersburg, 29 February 2012). An important finding is not to confuse the often high estimates for the overall value of nature with the damage to ecosystem functions due to air pollution and the benefits of policy measures, these being only part of the overall value. Valuation of air pollution effects for productive ecosystems (forests, crops) has been demonstrated. Consideration now needs to be given to how complete those estimates are. For example, how will a changing climate influence the abundance of crop and forest pests and how might this affect a response to nitrogen deposition.

4. ÉCLAIRE Science & Policy briefing

4.1. Emissions and Exchange Processes & Upscaling

Recent measurements and model simulations show that the chemistry in and just above plant canopies significantly alters the amount of pollutants (O_3, N_r) that reaches the plant and is therefore available to cause plant effects. These chemical interactions cannot be resolved by current chemical transport models, which therefore need to be extended to provide a more robust mechanistic framework for simulating effects and surface/atmosphere exchange under modified climate conditions. As a corollary, the near-ground chemical sources and sinks also compromise the ability to verify numerical models through ground-based concentration measurements.

Laboratory measurements suggest that in some ecosystems / soil types, leaf litter can provide the dominant source of ground-level NO emissions, which were previously attributed to the soil. The leaf litter emission responds differently to moisture than soil emissions, and thus this attribution is important to understand NO emissions under future climate.

Methacrolein (MACR) and methyl-vinly ketone (MVK) are the first order oxidation products of isoprene, the most important volatile organic compounds globally emitted by plants, and are found in the gas phase. New measurements show that these compounds can be produced by oxidation processes within the leaf and therefore be emitted by plants. This likely has implications for the ability of plants to detoxify O_3 and calls for a re-interpretation of existing MVK/MACR flux data.

Biotic stresses such as fungal attack appear to stimulate the emission of biogenic volatile organic compounds (bVOCs) that are particularly efficient in resulting in secondary aerosol production. This does not appear to the case for bVOCs that are emitted in response to drought or ozone stress.

The deficiencies in available agricultural management data (in particular fertiliser input and timing) provide a key constraint on the accuracy with which we can predict emissions of NO and N_2O from agricultural soils.

Ammonia emission potentials almost double with every 5 °C temperature increase. Thus, to accurately project emissions and the associated biosphere / atmosphere feedbacks under future climate conditions, emissions should be calculated online within the chemical transport models as is commonly done for biogenic VOC emissions. This requires a move away from static ammonia emission inventories.

Four review papers were written as background documents for a joint COST-ABBA (ES0804) / ÉCLAIRE workshop held in Paris, September 2012, focussing on advances in knowledge and models of surface/atmosphere exchange for NH_3, O_3, NO_x, acid gases, volatile aerosols and VOC (see Flechard *et al.*; Guenther; Ganzeveld *et al.;*, Nemitz; 2012; https://colloque.inra.fr/cost_eclaire/Background-documents). While these papers were science- rather than policy-oriented, they addressed issues relevant to (Q1) (expected impacts on ecosystems due to changing ozone and N-deposition under a range of climate change scenarios), highlighting the need to couple dynamic ecosystem modelling to chemistry and transport models for all reactive compounds (S1, S3), in order to simulate long-term responses to climate and land-use changes.

4.2. Ecological response processes and thresholds

The discovery of nano-particle uptake into the stomatal pores ended a 40-yr-old paradigm. Assuming clean, hydrophobic leaf surfaces, the paradigm considered liquid water transport through stomata to be impossible as a result of water surface tension. However, real leaves are not clean, and deposited aerosols may change leaf hydrophobicity. Aerosol deposition is ubiquitous and cumulative. This new result could change the common view about plant–atmosphere interactions and global water budget modelling.

Application of the N14C model to 42 published European plot studies suggests that N deposition could have approximately doubled net primary productivity of some semi-natural ecosystems, and increased soil carbon storage, during the last 200 years. Model simulations suggest that most areas remain N-limited, but that conifer and shrub ecosystems have inherently greater susceptibility to mineral N leaching compared to grassland and broadleaf ecosystems, due to differences in rates of soil organic matter turnover.

4.3. Integrated Risk Assessment and Policy Tools

Key outputs included:

- "Impact assessment: effects indicators as tools to evaluate air pollution abatement policies" ECE/EB.AIR/WG.1/2012/13 (UNECE-Convention on Long-range Transboundary Air Pollution (CLRTAP))
- Report by the Coordination Centre for Effects (CCE) and the Task Force of the International Cooperative Programme on the Modelling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends ECE/EB.AIR/WG.1/2012/10 (UNECE-CLRTAP)
- Contributions to informal EC reviews of methods and indicators for possible use in the thematic strategy on biodiversity 2020.
- Cost estimates for agricultural abatement measures have been published in a scientific paper Application of these cost estimates in the latest CIAM calculations for the Gothenburg protocol revision (CIAM Report 5/2011 rev. version, v1.2, 2 May 2012)
- Improving the data coherence of nationally available N flows via establishing N budgets. A guidance document on national N budgets has been made available as an official UNECE document (Guidance document on national nitrogen budgets, ECE/EB.AIR/2012/L.8, UNECE-CLRTAP)

- Presentation to the European Parliament in the context of relating air pollution threats to the key societal question of "whether there will be enough N, P and K to feed the world in 2050". (http://www.eclaire-fp7.eu/dissemination)

5. References

Arneth, A., Schurgers, G., Hickler, T. and Miller, P. A. (2008), Effects of species composition, land surface cover, CO_2 concentration and climate on isoprene emissions from European forests. Plant Biology, 10: 150–162. doi: 10.1055/s-2007-965247

Flechard, C., Massad, R.-S., Loubet, B., Personne, E., Simpson, D., Nemitz, E. and Sutton M.A. (2012) Advances in understanding, models and parameterisations of biosphere-atmosphere ammonia exchange.. Background document for the joint ÉCLAIRE/COST ES0804 Expert Workshop "From process scale to global scale: integrating our knowledge on biosphere / atmosphere exchange modelling of trace gases and volatile aerosols"; available online at https://colloque.inra.fr/cost_eclaire/Background-documents

Ganzeveld, L., Ammann, C., Loubet, B. (2012) Review on modelling atmosphere-biosphere exchange of Ozone and Nitrogen oxides. Background document for the joint ÉCLAIRE/COST ES0804 Expert Workshop "From process scale to global scale: integrating our knowledge on biosphere / atmosphere exchange modelling of trace gases and volatile aerosols"; available online at https://colloque.inra.fr/cost_eclaire/Background-documents

Guenther, A. (2012) Bidirectional exchange of volatile organic compounds. Background document for the joint ÉCLAIRE/COST ES0804 Expert Workshop "From process scale to global scale: integrating our knowledge on biosphere / atmosphere exchange modelling of trace gases and volatile aerosols"; available online at https://colloque.inra.fr/cost_eclaire/Background-documents

Hettelingh, J-P., W. de Vries, M. Posch, G. J. Reinds, J. Slootweg, K. Hicks, 2012. Development of the critical loads concept and current and potential applications to different regions of the world. In: Sutton, M.A., Mason, K.E., Sheppard, L.J., Sverdrup, H., Haeuber, R., Hicks W.K. (eds.) Critical loads, nitrogen deposition and biodiversity. Chapter 30, Springer.

Lombardozzi, D. ,S. Levis, G. Bonan, and J.P. Sparks (2012) Predicting photosynthesis and transpiration responses to ozone: decoupling modeled photosynthesis and stomatal conductance. Biogeosciences, 9, 3113-3130, 2012

Nemitz E. (2012) Surface / atmosphere exchange of atmospheric acids and aerosols, including the effect and model treatment of chemical interactions. Background document for the joint ÉCLAIRE/COST ES0804 Expert Workshop "From process scale to global scale: integrating our knowledge on biosphere / atmosphere exchange modelling of trace gases and volatile aerosols"; available online at https://colloque.inra.fr/cost_eclaire/Background-documents

Schaufler G., Kitzler B., Schindlbacher A., Skiba U., Sutton M.A. and Zechmeister-Bolternstern S. (2010) Greenhouse gas emissions from European soils under different land use: Effects of soil moisture and temperature. *European Journal of Soil Science*, **61**, 683-696.

Sitch, S., Cox, P. M., Collins, W. J., and Huntingford, C. (2007) Indirect radiative forcing of climate change through ozone effects on the land-carbon sink, Nature, doi:10.1038/nature06059, 2007

Sitch, S., Huntingford, C., Gedney, N., Levy, P.E., Lomas, M., Piao, S.L., Betts, R., Ciais, P., Cox, P., Friedlingstein, P., et al (2008). Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs). Global Change Biol, 14(9), 2015-2039.

Sutton M.A., Reis R., Riddick S.N., Dragosits U., Nemitz E., Theobald M.R., Tang Y.S., Braban C.F., Vieno M., Dore A.J., Mitchell R.F., Wanless S., Daunt F., Fowler D., Blackall T.D., Milford. C., Flechard C.F., Loubet B., Massad R., Cellier P., Coheur P.F., Clarisse L., van Damme M., Ngadi, Y., Clerbaux C., Skjøth C.A., Geels C., Hertel O., Wichink Kruit R.J., Pinder, R.W., Bash J.O., Walker J.D., Simpson D., Horvath, L., Misselbrook, T.H., Bleeker A., Dentener F. &Wim de Vries V. (2013) Toward a climate-dependent paradigm of ammonia emission & deposition. *Phil. Trans. Roy. Soc.* (Ser. B). *(submitted).*

Tipping, E., Rowe, E.C., Evans, C.D., Mills, R.T., Emmett, B.A., Chaplow, J., Hall, J.R. (2012) N14C: a plant-soil nitrogen and carbon cycling model to simulate terrestrial ecosystem responses to atmospheric nitrogen deposition. *Ecological Modelling*, 247, 11-26.

ANNEX I: Key questions of ÉCLAIRE:

Q1: What are the expected impacts on ecosystems due to changing ozone and N-deposition under a range of climate change scenarios, taking into consideration the associated changes in atmospheric CO_2, aerosol and acidification?

Q2: Which of these effects off-set and which aggravate each other, and how do the mitigation and adaptation measures recommended under climate change relate to those currently being recommended to meet air pollution effects targets?

Q3: What are the relative effects of long-range global and continental atmospheric transport vs. regional and local transport on ecosystems in a changing climate?

Q4: What are the appropriate metrics to assess ozone and nitrogen impacts on plants and soils, when considering state-of-the-art understanding of interactions with CO_2 and climate, and the different effects of wet vs. dry deposition on physiological responses?

Q5: What is the relative contribution of climate dependence in biogenic emissions and deposition vs. climate dependence of ecosystem thresholds and responses in determining the overall effect of climate change on air pollution impacts?

Q6: Which mitigation and/or adaptation measures are required to reduce the damage to "acceptable" levels to protect carbon stocks and ecosystem functioning? How do the costs associated with the emission abatement compare with the economic benefits of reduced damage?

Q7: How can effective and cost-efficient policies on emission abatement be devised in the future?

ANNEX II: Specific objectives of ÉCLAIRE:

S1: To develop improved process-based emissions parameterization of NH_3, NO and VOCs from natural and agricultural ecosystems in response to climate and pollutant deposition for incorporation into atmospheric Chemistry-Transport Models (CTMs), based on existing and new flux measurements in the field and laboratory, applying these to develop spatially resolved emission scenarios in response to climate, CO_2 and air pollutant change

S2: To determine the chief processes in atmospheric chemistry that respond to climate and air pollution change and the consequences for ozone and aerosol production and atmospheric lifetimes, in the context of the global O_3 background.

S3: To develop improved multi-layer dry deposition / bi-directional exchange parameterisations for O_3, NO_x, NH_3, VOCs and aerosols, taking into account near-surface chemical interactions and the role of local/regional spatial interactions, based on existing and new flux measurements and high resolution models and to estimate European patterns of air concentrations and deposition under climate change.

S4: To integrate the results of meta-analyses of existing datasets with the results of targeted experiments for contrasting European climates and ecosystems, thereby assessing the climate-dependence of thresholds for land ecosystem responses to air pollution, including the roles of ozone, N-deposition and interactions with VOCs, nitrogen form (wet/dry deposition) and aerosol.

S5: To develop improved process-based parameterizations in dynamic global vegetation models (DGVMs) and soil vegetation models (DSVMs) to assess the combined interacting impacts of air quality, climate change and nutrient availability on plant productivity, carbon sequestration and plant species diversity and their uncertainties.

S6: To develop novel thresholds and dose-response relationships for air pollutants (especially for O_3 and N) under climate change, integrated into process-based models verified by experimental studies at site scales and mapped at the European scale, quantifying the effect of climate change scenarios.

S7: To assess the extent to which climate change alters the transport distance and spatial structure of air pollution impacts on land ecosystems considering local, regional, continental and global interactions, focusing on nitrogen and ozone effects.

S8: To apply the novel metrics to quantify multi-stress response of vegetation and soils, including effects on carbon storage and biodiversity to improve the overall risk assessments of pollution-climate effects on ecosystems at the European scale as the basis for development of mitigation options.

S9: To quantify the overall economic impacts of air pollution effects on land ecosystems and soils, including the valuation of ecosystem and other services, and the extent to which climate change contributes by altering emissions versus ecosystem vulnerability.