Project Number 282910

ÉCLAIRE

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

Seventh Framework Programme

Theme: Environment

D14.3 Validated and evaluated version of models (DGVMs and DSVMs) using databases on plant productivity

Due date of deliverable: 30/09/2013 Actual submission date: 29/10/14

Start Date of Project: **01/10/2011** Duration: **48 months**

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

Project co-funded by the European Commission within the Seventh Framework		
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 WP14 an ensemble of land surface models are used to simulate various scenarios of climate change, air quality (exposure to O_3 and CO_2) and deposition of nutrients on plant productivity and nutrient cycling of forests and semi-natural systems. The specific objective of deliverable 14.3 is to describe the evaluation of model outputs using a database on plant productivity based on direct observations of the land-atmosphere CO_2 exchange. As a reference dataset the MPI-MTE gridded product by Jung *et al*. (2011) was used. This data product is based on the statistical upscaling of site-level ecosystem fluxes observed across the FLUXNET network to generate global fields of carbon fluxes at a 0.5° spatial resolution and at monthly temporal resolution from 1982 to 2011. Model simulations have been carried out over Europe using as meteorological forcing hourly, non-bias corrected air temperature, precipitation, wind speed, specific humidity, atmospheric pressure and short wave incoming radiation from the simulations of the RCA3 regional climate model forced by the ECHAM5 global climate model for the scenario A1B. The hourly O_3 concentrations at 45 m height and monthly nitrogen depositions have been obtained using the European Monitoring and Evaluation Programme model (EMEP) model. The European maps of gross primary productivity (GPP) as predicted by four different DGVMs show that the spatial pattern of GPP is rather different both between models and observations and across models. These discrepancies are due to the structural model diversity and to the inherent complexity in modelling the impacts of land management on C fluxes, both in forest and agricultural systems. In addition, the use of non bias-corrected climate data to force simulations may have further reduced the match between DGVMs and observations. Despite the variability in the spatial pattern and in the frequency distribution of GPP, we are confident that statistics based on relative changes between contrasting scenarios will be meaningful and comparable for all DGVMs.

2. Objectives:

The main objective of Task 14.2 is the development and application of land surface models to the European domain to assess the joined impacts of climate and air quality on plant productivity. In particular, an ensemble of models simulate various scenarios of climate change, air quality change (exposure to O_3, PM and CO_2) and deposition of nutrients (N, S, P, base cations) on plant production/carbon sink strength and nutrient cycling of forests and semi-natural systems), using integrated DGVMs and DSVMs.

The specific objective of deliverable 14.3 is to describe the validation and evaluation of model outputs using databases on plant productivity based on direct observations of the land-atmosphere CO_2 exchange.

3. Activities:

Four DGVMs (OCN, JULES, LPJ and CLM) have been upgraded specifically for the ECLAIRE project to account for the combined effect of O_3 and nitrogen (N) deposition on plant photosynthesis and transpiration in combination with climate change and CO_2 fertilization.

Model outputs of gross primary productivity (GPP) have been evaluated against an observation-driven product. As a reference dataset we adopted the MPI-MTE gridded product by Jung *et al*. (2011). This data product is based on the statistical upscaling of site-level ecosystem fluxes observed across the FLUXNET network. The upscaling is based on observations of the combination of ecosystem fluxes, climate and Fraction of Absorbed Photosynthetically Active Radiation (FaPAR) with a machine learning algorithm (MTE) to generate global flux fields, among others of GPP, at a 0.5x0.5 degree spatial resolution and a monthly temporal resolution from 1982 to 2011.

To evaluate model outputs, monthly estimates of GPP have been averaged over the thirty years of the observational dataset (1982-2011) and compared on the same grid the MPI-MTE product.

4. Results:

4.1. Model setup

COMMUNITY LAND MODEL (CLM)

All simulations conducted in this study are performed with the Community Land Model version 4 (CLM4, www.cesm.ucar.edu/models/cesm1.0/clm/), the land component used in the Community Earth System Model (CESM) (Collins et al. 2006). The CLM4 model is based on several components: bio-geophysics and biogeochemistry processes, hydrological cycle and dynamic vegetation. The analysis has been carried out with the C-N biogeochemical active model (hereafter CLM4CN) (Thornton et al. 2007; Randerson et al. 2009. It is prognostic with respect to carbon and nitrogen state variables in vegetation, litter and soil organic matter; leaf and stem area index and vegetation heights are also determined prognostically. The potential gross primary production (GPP) is calculated from leaf photosynthetic rate without N constraint. The N required achieving this potential GPP is diagnosed, and the actual GPP is decreased for nitrogen limitation. Plant physiology is simulated using the coupled Farquhar photosynthesis and Ball-Berry stomatal conductance model. To include the impact of O_3 exposure in the analysis, the CLM4CN has been implemented with the O_3 parameterization developed by Lombardozzi et al. (2012a), which modifies the original photosynthesis and stomatal conductance models. More information about the development of the O_3 parameterization in the CLM4 model can be found in Lombardozzi et al. (2012b) and Lombardozzi et al. (2013). A detailed description of the parameterizations and the schemes used in CLM4CN can be found in Lawrence et al. (2011) and additional documentation of the structure and algorithms used in CLM4CN can be found in the CLM4.0 Technical Description (www.cesm.ucar.edu/models/cesm1.0/clm/CLM4_Tech_Note.pdf; Oleson et al. 2010).

Initial conditions for the simulations are calculated as described in the CLM user guide (http://www.cesm.ucar.edu/models/cesm1.0/clm/models/lnd/clm/doc/UsersGuide/c9218.html). To reach the steady state of the simulated carbon pools, first the model is run for 600 simulation years starting from arbitrary initial conditions using the “accelerated decomposition spin-up” mode and the model forcing released with CESM. To find this initial stage, it is integrated with atmospheric boundary conditions defined by a repeating 30-year hourly climate forcing (from 1960-1969 of the RCM used), and fixed, pre-industrial (1901) atmospheric CO_2, nitrogen deposition and O_3 concentrations.

OCN

Simulations were conducted with the terrestrial biosphere model O-CN (Zaehle and Friend 2010), an extension of the land surface scheme ORCHIDEE by Krinner et al. 2005. O-CN simulates the terrestrial energy, water, carbon, and nitrogen budgets of discrete grid cells (here 0.5° x 0.5°) which are occupied by up to 12 plant functional types (PFTs). In the O-CN model leaf-level photosynthesis directly depends on the plants leaf nitrogen status, based on the work of Friend and Kiang 2005, which is then integrated to canopy-scale carbon and water fluxes. O-CN was extended to account for ozone damage to net photosynthesis. Ozone deposition from the free atmosphere to leaf-level is calculated by an ozone deposition scheme that resembles the European Monitoring and Evaluation Programme (EMEP) model (Simpson et al. 2012). Leaf-level ozone concentrations are used to calculate ozone uptake into the plants and the resulting damage to net photosynthesis. Ozone damage to net photosynthesis is estimated by applying the damage relationship by Wittig et al. 2007.

LPJ

Simulations were done with the dynamic global vegetation modelling framework LPJ-GUESS. Plant dynamics are modelled using plant functional types (PFTs) that represent the globally most abundant trees and grasses. Plant distribution is modelled using differences between

PFTs in bioclimatic limits and strategies in the competition over resources e.g. water and light (Smith et al., 2014;Ahlström et al., 2012;Sitch et al., 2003). The model is here applied in cohort mode (with 'patch' vegetation dynamics). In this case, formulations for establishment and mortality, growth, and light and water competition between neighbouring plant individuals within a patch, are taken into account more explicitly. In the latter case, PFT sub-groups or even individual species can be defined in terms of resource use syndromes (e.g., their shade tolerance; (Koca et al., 2006;Hickler et al., 2004;Smith et al., 2001). The area of a single patch is approximately equal to the area of influence of one large individual. Because demography and community structure in a particular patch is influenced by stochastic processes, the model output is the average over a number of replicate patches. The physiological process descriptions in LPJ-GUESS; for instance, the coupling of photosynthesis and stomatal conductance, plant and ecosystem carbon and water balance, litter decomposition and soil processes, are identical to those used in LPJ-DGVM (Sitch et al., 2003), including improvements in the hydrology presented by Gerten et al. (2004), and recently updated with a coupled carbon-nitrogen cycle (Smith et al., 2014;Wårlind et al., 2014).

The model uses climate, atmospheric CO2 concentration, soil information and N deposition as input, and plant communities evolve dynamically through competition in response to these drivers. Soil C and N dynamics are based on the CENTURY model (Parton et al., 1998) and updated daily using 8 pools that differ in their C to N ratios (C:N) and decay rates (K_d). Both C:N and K_d are dynamic within certain limits. The decomposition of organic material depends on the C:N, K_d as well as soil temperature and water content, and results in heterotrophic respiration, transport of organic material between the soil compartments and either a mobilization or immobilization of mineral N in the soil pools. Plant N uptake varies between PFTs which differ in their N demand and their competitive strength for N uptake.

Allocation of the Net Primary Productivity (NPP) to different plant organs is done on a yearly basis based on a set of C allocation rules. If a plant experience water or N stress during the year, the C allocation scheme is flexibly adjusted so that relatively more of the assimilates are distributed for roots growth to alleviate these stresses during the following year.

JULES

The Joint UK Land Environment Simulator (JULES) is the land surface model of the Hadley Centre model. It is a process-based model that represents exchanges of carbon (Clark et al 2011), water an momentum between vegetation and the atmosphere (Best et al. 2011). The model represents vegetation at a gridbox using five functional types (broad and needleleaf trees, C3 (temperate) and C4 (tropical grasses) and shrubs. The surface CO2 fluxes associated with photosynthesis and respiration are estimated in the physiology component of JULES. This includes a multi-layer canopy scheme for light interception, accounting for sunfleck penetration (Mercado et al 2009), a coupled scheme of leaf photosynthesis and

stomatal conductance, representation of plant and soil respiration (N and T dependent) and representation of the effects of ozone on leaf physiology using a flux gradient approach (Sitch et al, 2007). For Eclaire, an update on the parameterization of O3 effects on photosynthesis from Sitch et al (2007) is included using observed dose-response relationships (CLRTAP Mapping Manual (2004), Karlsson et al., (2007)) but also the existing stomatal closure formulation in JULES has been replaced by the formulation from Medlyn et al (2011) which allows easy incorporation of data derived stomatal conductance (Gs) model parameters. Gs model parameters were derived from leaf level data from European ecosystems. Leaf phenology (bud-burst and leaf drop) is represented with using temperature-dependent leaf turnover rates and litterfall from vegetation flows into a model of soil carbon that determines the rate of microbial soil respiration and the consequent flux of CO2 back to the atmosphere.
A four pool soil model is available with choices between alternative descriptions of the response of heterotrophic respiration to soil temperature. Accumulated net primary productivity is used for plant growth and vegetation spread. The vegetation model includes competition among plant functional types (Cox et al 2001). Input of the model consists of subdaily meterological driving data atmospheric CO2 and O3 concentrations, ancillary information on soil texture.

4.2 Forcing data and simulation protocol

Model simulations have been carried out over Europe at a spatial resolution of 0.5 x 0.5 degree (Gaussian grid) and at time steps varying with the model (from hourly to daily), considering a fixed cover fraction for the year 2000. As meteorological forcing, hourly non-bias corrected air temperature, precipitation; wind speed, specific humidity, atmospheric pressure and short wave incoming radiation are used. The data come from the simulations of the RCA3 regional climate model (RCM) forced by the ECHAM5 global climate model (Kjellström et al., 2011) provided by the Rossby Centre of Swedish Meteorological and Hydrological Institute. As chemical drivers, the series of atmospheric CO_2 concentrations is based on measures for the period 1900 to 2005 (Etheridge et al., 1996; Keeling and Whorf 2006) and on CO2 predictions (A1B scenario) for 2005-2050. The hourly O3 concentrations at 45 m height and monthly nitrogen depositions have been obtained using the European Monitoring and Evaluation Programme model (EMEP) model. As an example the results of the EMEP simulated N deposition, used in the model simulations, is presented in Figure 1.

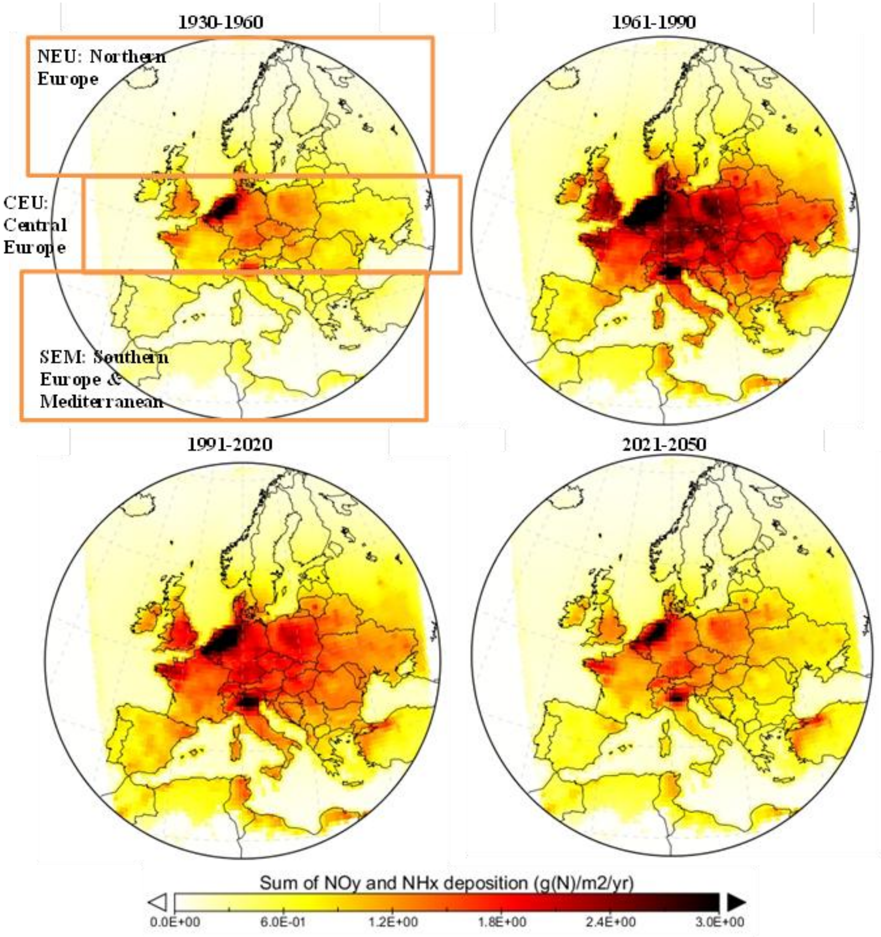

Figure 1: Simulated geographical patterns in N deposition over the period 1900-2050 as used in the model scenario evaluations.

4.3 **Validation with observational dataset**

Figure 2 shows the European map of GPP as predicted by the four different DGVMs together with the product developed by Jung et al (2011) based on the up-scaling of FLUXNET 0.5x0.5 degree of spatial resolution. Results show that the spatial pattern of GPP is rather different both between models and observations and across models. These discrepancies are due to the structural model diversity and to the inherent complexity in modelling the impacts of land management on C fluxes both in forest and agricultural systems. In addition, the use of non bias-corrected climate data to force simulations may have reduced the performances of DGVMs.

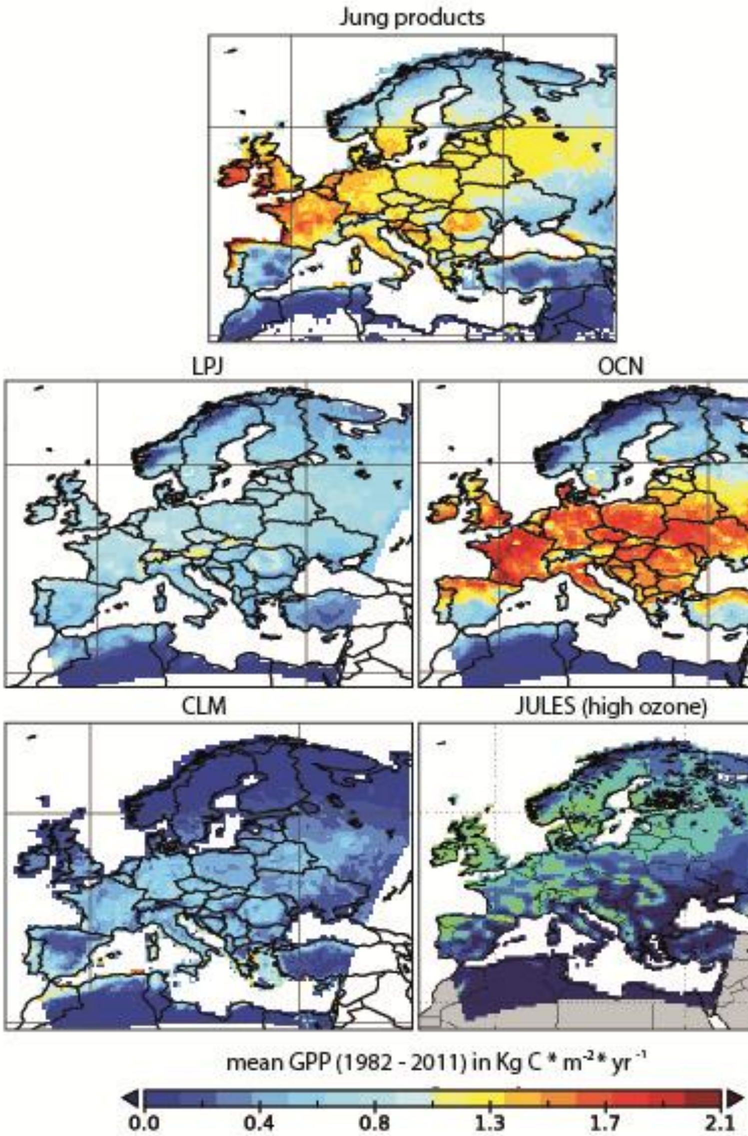

Figure 2: Comparison of the model performance with the observations. Mean annual GPP between 1982 and 2011 in (KgC * m^{-2} * yr^{-1})

The scatterplots of the mean annual GPP in the European domain between the data-driven products and the model prediction are reported in Figure 3. The spatial correlation between model and observation is stronger (OCN and JULES) than for others (CLM and LPJ), while the large variability in the correlation between models is the results of the independent development and parameterization of the different modelling platform. Despite the large variability in the spatial pattern and in the frequency distribution of results (Fig. 4) we are confident that statistics based on relative changes between contrasting scenarios will be meaningful for all DGVMs.

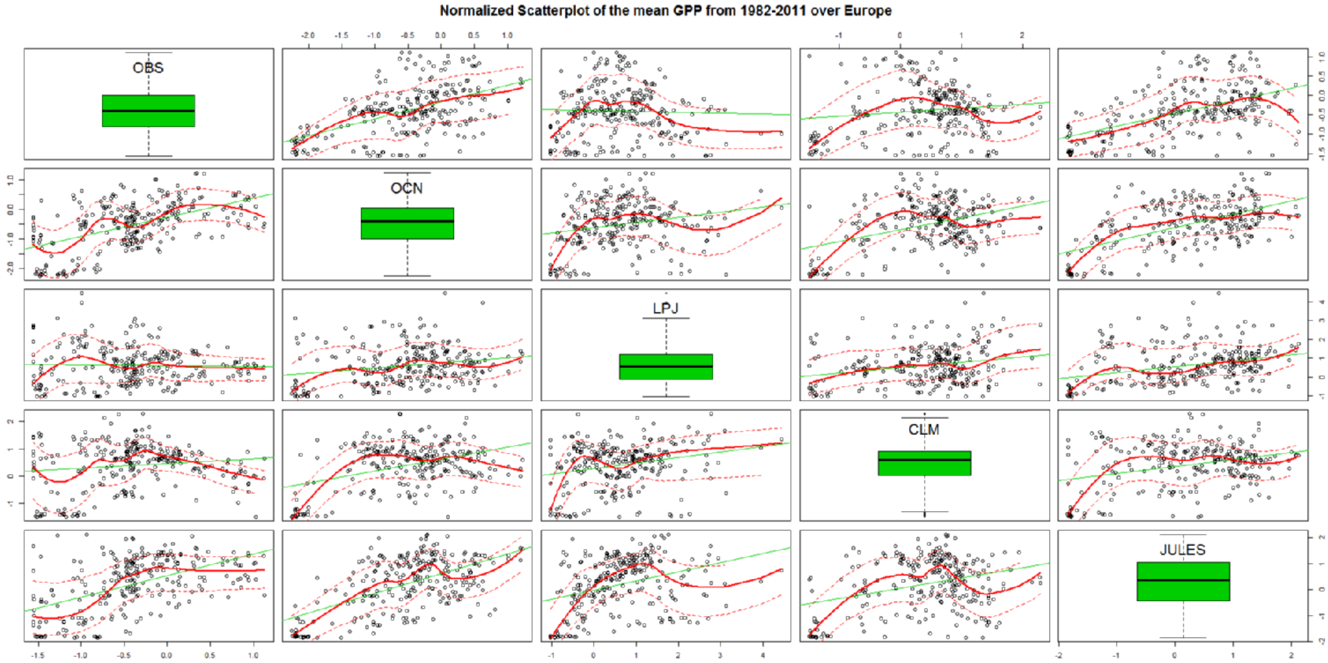

Figure 3: Correlations of the mean GPP 1982-2011 for each model and for the observations over Europe

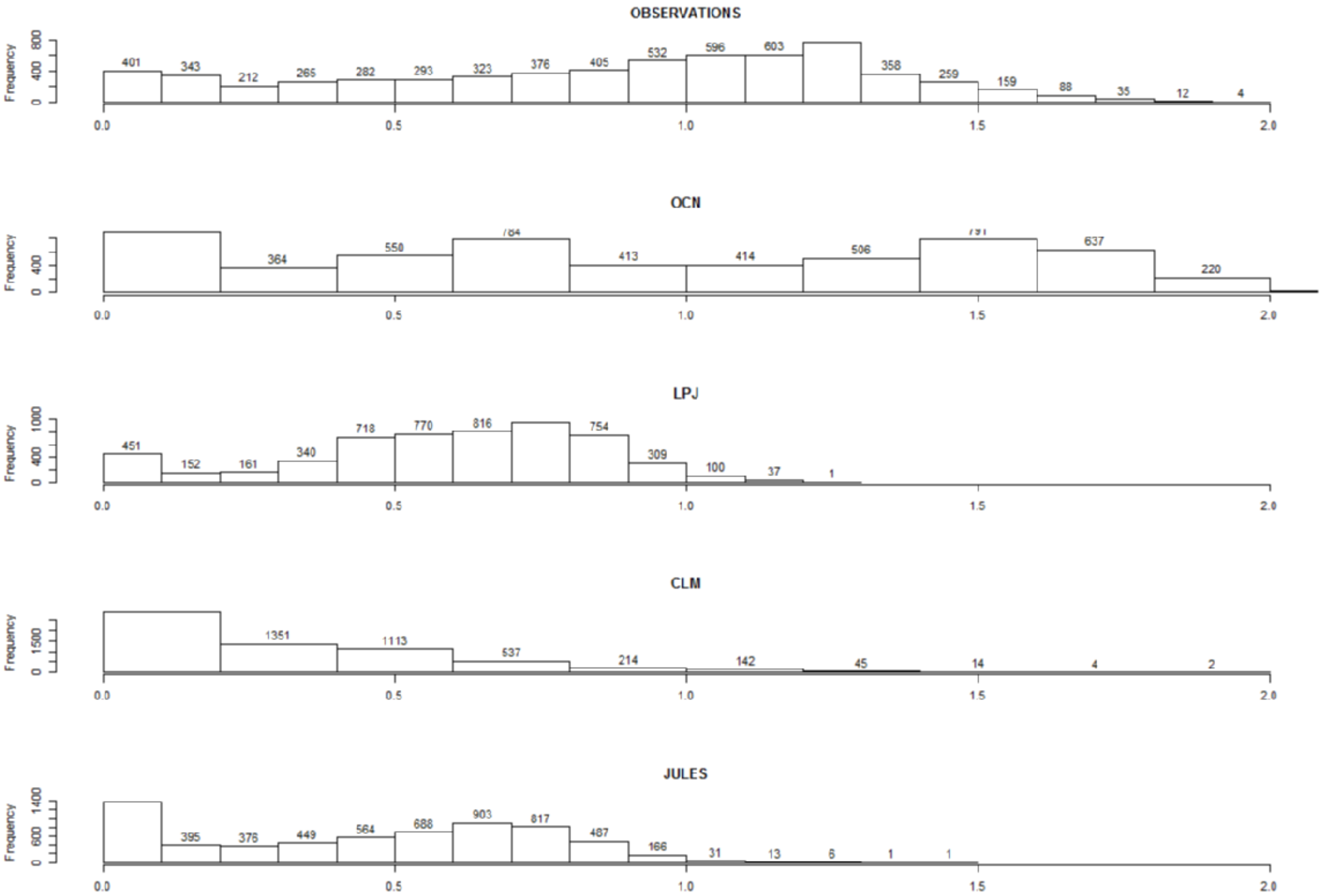

Figure 4. Histograms of the mean GPP 1982-2011 for each model and for the observations in (KgC * m^{-2} * yr^{-1}) over Europe

5. References

Ahlström, A., Schurgers, G., Arneth, A., and Smith, B.: Robustness and uncertainty in terrestrial ecosystem carbon response to cmip5 climate change projections, Environmental Research Letters, 7, 044008, doi:044010.041088/041748-049326/044007/044004/044008, 2012.

Best MJ, M Pryor, DB Clark, GG Rooney, RLH Essery, CB Menard, JM Edwards, MA Hendry, A Porson, N Gedney, LM Mercado, S Sitch, E Blyth, O Boucher, PM. Cox, CSB Grimmond, and RJ Harding (2011). TheJoint UK Land Environment Simulator (JULES), Model description, Part 1: Energy and water fluxes. Geoscientific Model Development 4, 677-699.

Clark DB, LM Mercado, S Sitch, CD Jones, N Gedney, MJ Best, M Pryor, GG Rooney, RLH Essery, E Blyth, O Boucher, RJ Harding and Cox P.M (2011). The Joint UK Land Environment Simulator (JULES), Model description, Part 2: Carbon fluxes and Vegetation. Geoscientific Model Development 4, 701-722.

Cox, P. M.: Description of the TRIFFID Dynamic Global Vegetation Model, Hadley Centre Technical Note 24, Hadley Centre,Met Office, Bracknell, UK, 2001

CLRTAP, 2004. Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends. UNECE Convention on Long-range Transboundary Air Pollution http://www.icpmapping.org/Mapping_Manual

Friend, A. D., and N. Y. Kiang (2005), Land-surface model development for the GISS GCM: Effects of improved canopy physiology on simulated climate, J. Clim., 18, 2883 – 2902

Hickler, T., Smith, B., Sykes, M. T., Davis, M. B., Sugita, S., and Walker, K.: Using a generalized vegetation model to simulate vegetation dynamics in northeastern USA, Ecology, 85, 519-530, 2004.

Jung, M., Reichstein, M., Margolis, H. a., Cescatti, A., Richardson, A.D., Arain, M.A., Arneth, A., Bernhofer, C., Bonal, D., Chen, J., Gianelle, D., Gobron, N., Kiely, G., Kutsch, W., Lasslop, G., Law, B.E., Lindroth, A., Merbold, L., Montagnani, L., Moors, E.J., Papale, D., Sottocornola, M., Vaccari, F.,

Williams, C., 2011. Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations. J. Geophys. Res. 116, 1–16.

Karlsson PE, Braun S, Broadmeadow M, et al. 2007. Risk assessments for forest trees: the performance of the ozone flux versus the AOT concepts. Environmental Pollution 146: 608–616.

Koca, D., Smith, B., and Sykes, M. T.: Modelling regional climate change effects on potential natural ecosystems in sweden, Climatic Change, in press, 2006.

Krinner, G., Viovy, N., de Noblet-Ducoudre, N., Ogee, J., Polcher, J., Friedlingstein, P., Ciais, P., Sitch, S., and Prentice, I. (2005). A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. Global Biogeochem. Cycles, 19(1):33.

Lawrence, D.M., K.W. Oleson, M.G. Flanner, P.E. Thornton, S.C. Swenson, P.J. Lawrence, X. Zeng, Z.-L. Yang, S. Levis, K. Sakaguchi, G.B. Bonan, and A.G. Slater, 2011: Parameterization improvements and functional and structural advances in version 4 of the Community Land Model. J. Adv. Model. Earth Sys., 3, DOI: 10.1029/2011MS000045.

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

Lombardozzi, D., Sparks, J.P., Bonan, G., 2013c. Integrating O3 influences on terrestrial processes: photosynthetic and stomatal response data available for regional and global modeling. Biogeosciences 10, 6815–6831.

Lombardozzi, D., Sparks, J.P., Bonan, G., Levis, S., 2012b. Ozone exposure causes a decoupling of conductance and photosynthesis: implications for the Ball-Berry stomatal conductance model. Oecologia 169, 651–9.

Medlyn BE, Duursma RA, Eamus D, Ellsworth DS, Prentice IC, Barton CVM, de Angelis P, Crous KY, Freeman M, Wingate L (2011) Reconciling the optimal and empirical approaches to modelling stomatal conductance. Global Change Biology 17: 2134-2144.

Mercado, L. M., Bellouin, N., Sitch, S., Boucher, O., Huntingford,C., Wild, M., and Cox, P. M.: Impact of Changes in Diffuse Radiation on the Global Land Carbon Sink, Nature, 458, 1014– 1018, 2009.

Oleson, K.W., D.M. Lawrence, G.B. Bonan, M.G. Flanner, E. Kluzek, P.J. Lawrence, S. Levis, S.C. Swenson, P.E. Thornton, A. Dai, M. Decker, R. Dickinson, J. Feddema, C.L. Heald, F. Hoffman, J.-F. Lamarque, N. Mahowald, G.-Y. Niu, T. Qian, J. Randerson, S. Running, K. Sakaguchi, A. Slater, R. Stockli, A. Wang, Z.-L. Yang, Xi. Zeng, and Xu. Zeng, 2010: Technical Description of version 4.0 of the Community Land Model (CLM). NCAR Technical Note NCAR/TN-478+STR, National Center for Atmospheric Research, Boulder, CO, 257 pp.

Parton, W. J., Hartman, M., Ojima, D., and Schimel, D.: Daycent and its land surface submodel: Description and testing, Global and Planetary Change, 19, 35-48, 1998.

Randerson, J. T., F. M. Hoffman, et al. (2009). "Systematic assessment of terrestrial biogeochemistry in coupled climate-carbon models." Global Change Biology 15(10): 2462-2484.

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L., Fagerli, H., Flechard, C., Hayman, G., Gauss, M., Jonson, J., et al. (2012). The emep msc-w chemical transport model–technical description. Atmos. Chem. Phys, 12:7825–7865.

Sitch, S., Smith, B., Prentice, I. C., Arneth, A., Bondeau, A., Cramer, W., Kaplan, J. O., Levis, S., Lucht, W., Sykes, M. T., Thonicke, K., and Venevsky, S.: Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model, Global Change Biology, 9, 161-185, 2003.

Mercado, L. M., Bellouin, N., Sitch, S., Boucher, O., Huntingford,C., Wild, M., and Cox, P. M.: Impact of Changes in Diffuse Radiation on the Global Land Carbon Sink, Nature, 458, 1014– 1018, 2009.

Smith, B., Prentice, I. C., and Sykes, M. T.: Representation of vegetation dynamics in the modelling of terrestrial ecosystems: Comparing two contrasting approaches within european climate space, Global Ecology & Biogeography, 10, 621-637, 2001.

Smith, B., Warlind, D., Arneth, A., Hickler, T., Leadley, P., Siltberg, J., and Zaehle, S.: Implications of incorporating n cycling and n limitations on primary production in an individual-based dynamic vegetation model, Biogeosciences, 11, 2027-2054, doi:10.5194/bg-11-2027-2014, 2014.

Thornton, P. E. and N. E. Zimmermann (2007). "An improved canopy integration scheme for a land surface model with prognostic canopy structure." Journal of Climate 20(15): 3902-3923.

Wårlind, D., Smith, B., Hickler, T., and Arneth, A.: Nitrogen feedbacks increase future terrestrial ecosystem carbon uptake in an individual-based dynamic vegetation model, Biogeosci. Discuss., 11, 151-185, 2014.

Wittig, V., Ainsworth, E., and Long, S. (2007). To what extent do current and projected increases in surface ozone affect photosynthesis and stomatal conductance of trees? a meta-analytic review of the last 3 decades of experiments. Plant, cell & environment, 30(9):1150–1162.

Zaehle, S. and Friend, A. (2010). Carbon and nitrogen cycle dynamics in the o-cn land surface model: 1. model description, site-scale evaluation, and sensitivity to parameter estimates. Global Biogeochemical Cycles, 24(1):GB1005.

5. Milestones achieved:

Milestone	Milestone Title	Month
MS62	ÉCLAIRE modelling platform linking DGVMs, DSVMs, climate and air pollution fields operational	24
MS63	Database with ensemble runs of DGVM on common climate and air pollution scenarios released, improved understanding of where models provide robust projections and where largest uncertainties lie.	36

MS62: The upgraded DGVMs, i.e. LPJ-Guess, JULES, CLM and O-CN and VSD+-EUgrow have been linked to relevant climate scenario data, that have become available both and with scenarios for N deposition and O3 exposure derived by the EMEP model (see WP6).

MS63: The database of DGVMs outputs related to the modelling experiments in WP14 is completed. The four mandatory scenarios (S1-S4) are now available in a common file format (monthly data, netcdf files) to perform ensemble statistics of the combined impacts of air pollutants on the C budget of terrestrial ecosystems and to assess the structural model uncertainty.

6. Deviations and reasons:

Delay in D14.3

Deliverable 14.3 was completed with a delay of about six months. The main reason was a delay in the further development of the models including the combined interaction of both N and ozone deposition that appeared to be more demanding than originally foreseen.

JULES development

The JULES modeling group used an improved stomatal conductance model and respective parameterization derived from observations from Europe. At present the group has been unable to run simulations with a fully coupled N cycle. This is because the soil N model (ECOSSE) and the vegetation N model (FUN) have led to conceptual issues when coupling the models into JULES, e.g. FUN has an annual time step and calculates N retranslation and its cost on an annual basis, whereas JULES works on a sub-diurnal time resolution; this is particularly difficult to solve for temperate deciduous vegetation with distinct periods of leaf-on and -off. Coupling these models and then testing and evaluating has taken a lot more time and people's resource than initially planned, especially as this N -cycle development was not funded through ECLAIRE.

7. Publications:

None

8. Meetings:

ECLAIRE plenary meetings.

9. List of Documents/Annexes:

None.