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ÉCLAIRE

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

Seventh Framework Programme

Theme: Environment

D13.2 New version of DO$_3$SE model to simulate the combined effects of O$_3$, N, S, diffuse radiation and climate on plant CO$_2$ uptake

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PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	☐
RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

The DO_3SE (Deposition of Ozone for Stomatal Exchange) model was developed to estimate both stomatal and non-stomatal deposition of ozone (O_3). The DO_3SE methods to estimate stomatal deposition have also been used to analyse experimental data for the derivation of stomatal flux-response relationships. These relationships allow estimates of O_3 damage (e.g. crop yield loss, forest biomass loss and shifts in grassland species composition) from knowledge of O_3 exposure under variable environmental conditions for particular species. Employing this model as the O_3 deposition scheme within the EMEP photo-oxidant model allows internally consistent estimates of both total O_3 deposition (important to determine the O_3 concentration remaining in the lower atmosphere) and O_3 damage (important to assess the damage associated with O_3 episodes and chronic exposures).

To estimate stomatal deposition, the DO_3SE model used a multiplicative scheme to estimate stomatal conductance. This identifies a species-specific maximum stomatal conductance that is then modified by time during the growing season and a number of environmental variables (irradiance, temperature, vapour pressured deficit and soil moisture status) to provide an estimate of the actual stomatal conductance under the prevailing plant and environmental conditions at a particular point in time. Although this method has been proven to work well (Büker et al., 2012), it is limited by the fact that, unlike other stomatal conductance models, it does not integrate with carbon assimilation and hence plant growth. This means that any estimates of damage need to be based purely on empirical data and limit the range of environmental situations under which the model can be reliably applied. Therefore, within this work package we have substituted the multiplicative version of the DO_3SE model with a photosynthetic based stomatal conductance algorithm based on (Farquhar et al., 1980) and (Ball et al. 1987).

This new photosynthetic algorithm now allows stomatal conductance to be estimated as a function of CO_2 concentration as well as other prevailing environmental conditions (i.e. relative humidity, irradiance (provided as diffuse and direct irradiance which can be influence by atmospheric aerosol load), leaf temperature (using energy balance equations to estimate leaf from air temperature) and soil moisture deficit (using methods developed for the original DO_3SE model)). The resulting model is therefore a hybrid photosynthetic – multiplicative model (since the influence of soil moisture on stomatal conductance is still estimated according to empirical relationships that modify the relative stomatal conductance value). The model also requires an estimate of leaf N since this determines the maximum carboxylation capacity at any given time. By providing N deposition and knowledge of soil N, estimates of leaf N availability can be made. This then allows stomatal flux (and therefore exchange of pollutant gases such as O_3, NOx and SO_2) to be estimated according to N deposition producing a deposition and effects model that is capable of estimating deposition and subsequent damage under a variety of pollutant and environmental conditions.

This new version of the DO_3SE model (version 5) will be tested with the ECLAIRE experimental datasets in the coming months as these data are quality checked and uploaded onto the ECLAIRE data management portal. This testing will assess the ability of the model to estimate key variables (i.e. stomatal conductance, photosynthesis, leaf N content, respiration) and try to understand the influence of polluting conditions (e.g. elevated CO_2, O_3 and N availability) on the plant physiological response of these parameters. Once fully tested and validated, the model can then be used to develop novel thresholds for these different pollutants under a range of environmental conditions for a number of different species.

2. Objectives:

The main objective of this work package was to develop a new version of the DO_3SE model that was capable of simulating the combined effects of O_3, N deposition, SO_2, diffuse radiation and climate (environmental variables) on plant gas exchange (i.e. CO_2 and pollutant gas uptake).

The DO_3SE (Deposition of Ozone for Stomatal Exchange) model, is a dry deposition model that was initially developed for the estimation of deposition and stomatal flux rates of the air pollutant ozone (O_3) (Emberson et al., 2001; Emberson et al., 2007; Büker et al., 2012). The model includes a SWAT (Soil-Water-Atmosphere Transfer) type approach to modelling water vapour exchange such that the loss of water through the plant system is controlled via the stomates which are also the main sites of control of stomatal O_3 deposition. This DO_3SE model has been developed to account for the effects of combined stresses, including O_3 and N deposition, on processes such as photosynthesis, stomatal conductance, respiration and transpiration.

3. Activities:

The DO_3SE model has previously used a multiplicative, Jarvis-type (Jarvis, 1976) stomatal conductance algorithm, which worked well for assessing - via the quantification of the stomatal O_3 flux - the risk O_3 poses on various plant functional types (Mills et al., 2011). However, to be able to simulate the combined effects of a number of different plant stresses (e.g. N deposition, O_3, CO_2 and aerosol pollution under a range of environmental conditions), which is a central deliverable of WP13 of ÉCLAIRE, it was clear that the application of a photosynthesis-based Ball-Berry-type (Ball et al., 1987) stomatal conductance algorithm would be necessary, since this type of algorithm directly relates stomatal conductance, which defines the gas exchange between the plant and its surrounding environment, to photosynthesis and hence CO_2 uptake. The DO_3SE model was extended accordingly, as described below.

Based on earlier observations of the constant ratio of stomatal conductance (g_s) to the net CO_2 assimilation rate (A_n), Ball et al. (1987) discovered an empirical linear relationship, which relates g_s to a combination of photosynthesis and environmental parameters, i.e. the leaf surface relative humidity (h_s) and CO_2 concentration at the leaf surface (c_s):

$$g_s = g_{min} + m * A_n * \frac{h_s}{C_s}$$

where g_{min} is the minimum daytime g_s observed under field conditions and m is a dimensionless slope representing the species-specific composite sensitivity of g_s to A_n. Since measurements of A_n are not easily available for most datasets, this approach required the introduction of a photosynthesis model; the most commonly used and thoroughly validated biochemical photosynthesis model developed by Farquhar et al., (1980) was chosen for this task.

The Farquhar model allows for the estimation and calculation of the CO_2 assimilation rate as a function of leaf temperature, irradiation and internal CO_2 concentration. The underlying assumption is that, according to prevailing environmental conditions, either the electron transport from the photosystem or the activity of the rubisco enzyme limits the rate of photosynthesis and that for both limitations theoretical assimilation rates can be computed independently. The lower of the two rates is then defined as the actual assimilation rate. To gain A_n, the rate of dark respiration is subtracted from the actual assimilation rate.

The new DO_3SE model also requires an estimate of leaf N to determine the maximum carboxylation rate. Leaf N can be related to N deposition since this will affect N availability to the plant. Therefore, the inclusion of this term within the photosynthetic model allows a route by which the influence of N deposition on pollutant gas exchange (including NOx as well as other pollutant gases such as O_3 and CO_2) can be assessed. The model also requires estimates of leaf temperature (where previous versions of the model relied on surface air temperature). The estimation of leaf temperature has been solved using energy budget equations consistent with those used to estimate evapotranspiration in the DO_3SE model (Büker et al., 2012). Finally, the effects of atmospheric aerosol loading can be investigated using the methods developed by (Mercado et al., 2009), whereby photosynthesis is increased as diffuse radiation is enhanced due to scattering of incoming and outgoing radiation in the presence of aerosol.

References:

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4. Results:

The following tasks have been achieved:

1. The Farquhar (Farquhar et al., 1980) and Ball-Berry (Ball et al., 1987) models have been coded in Fortran.
2. The modules to estimate leaf temperature and allow for variable leaf N have also been introduced.
3. These new modules have been incorporated into the overall DO_3SE model framework, substituting for the existing multiplicative model code, to create DO_3SE version 5.
4. The DO_3SE v5 has undergone preliminary testing to ensure the coding is bug free.

5. Milestones achieved:

“DO3SE v5 has been developed and tested”, which has been a necessary step for the completion of model applications to C3 sites.

6. Deviations and reasons:

None

7. Publications:

None

8. Meetings:

None

9. List of Documents/Annexes:

None