

Interactive comment on “Past and future scenarios of the effect of carbon dioxide on plant growth and transpiration for three vegetation types of southwestern France” by J.-C. Calvet et al.

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Received and published: 27 September 2007

The authors thank the anonymous referees for their in-depth review of the manuscript and for their comments.

Response to the anonymous referee #1

1.1 [The model is used for wheat, maize and coniferous forest, with past, present and future CO₂ levels, and meteorology from 4 recent years (2001-4). While it seems appropriate to use this approach for annual crops such as wheat or maize, it seems less suitable for the forest with a decadal life-span].

Response 1.1:

The ISBA-A-gs model used in this study simulates the green above-ground biomass. In the case of forests, the model is able to represent the leaf biomass but the wood part (presenting a decadal life-span) is not simulated. Thanks to a high value of the maximum leaf span time (τ_M of 365 days, see Table 2), the simulated LAI of a coniferous forest is higher than $2 \text{ m}^2\text{m}^{-2}$ at wintertime. Namely, an evergreen canopy is simulated, not an annual one. The simulated conifer LAI presents a marked annual cycle, with minimum values in January-February and maximum values in July-August, respectively. No (or little) interannual variability is simulated. This is consistent with in situ LAI observations at the Le Bray site in southwestern France (Berbigier et al. 2001, Rivalland et al. 2005).

1.2 [The response of forest vegetation over many successive years to CO₂ changes, and factors such as N deposition and climate change, is likely to have an important feedback on vegetation dynamics and process].

Response 1.2:

Yes. This effect is (briefly) discussed at the end of section 3.3. See Response 1.3.

1.3 [The decadal coupling between biomass/LAI change, alterations in canopy conductance, and local hydrology and perhaps meteorology need to be explored in more depth in this paper to justify the inclusion of the forest component of the study.]

Response 1.3:

Since the wood biomass is not simulated, the impact of [CO₂] on the decadal coupling between biomass and other variables of the conifer forest ecosystem is not considered in this study. However, the first order response of hourly to seasonal processes should be represented relatively well. Recent work has shown that the model used in this study is able to represent the hourly, seasonal and interannual variability of the water and carbon fluxes of conifer forests, both at the local scale (Rivalland et al. 2005)

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and at the global scale, in various climatic conditions (Gibelin et al. 2006). Moreover, the model was favourably compared to other approaches in the framework of a model intercomparison initiative (Viovy 2003), over the Scots pine forest of Loobos (Dolman et al. 2002).

1.4 [The authors make use of recent meta-analyses on leaf N response to changing CO₂, and also link their research to FACE and enclosure experiments with altered CO₂. However, the meta-analysis revealed major uncertainties in plant responses, and these are not properly acknowledged or incorporated in this work. How do the results of the paper change if uncertainty is introduced into equations 2 and 3?]

Response 1.4:

The meta-analysis of Yin (2002) shows that an empirical description of the relative change in leaf mass-based nitrogen (NL) in response to a change in [CO₂] explains 41 % of the variance, only. Eqs. (2) and (3) contain major uncertainties caused by experimental errors and by the difficulty in merging experimental data from diverse sources. The vast majority of [CO₂] enrichment experiments show that NL declines as [CO₂] increases. However, a number of experiments (e.g. 17% of the experiments listed by Roderick et al. 1999) present no or insignificant response of NL to [CO₂]. In order to assess the effect of this uncertainty on the results presented in this study, a sensitivity analysis to NL was conducted. Two modelling experiments were performed: the influence of [CO₂] on NL was assumed (1) insignificant (i.e. no change on the value of NL), and (2) twice the impact given by Eq. (2). The impact of experiments (1) and (2) was found to be:

- small on the gc response to [CO₂], in all cases
- small for the wheat LAI response to [CO₂]
- critical for the LAI response to [CO₂] of corn and conifer.

Experiment (1) increases the LAI response to [CO₂] of corn and conifer, to a level

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close to the LAI response simulated for wheat. Experiment (2) virtually suppresses the [CO₂] effect on LAI for the conifer and reverses the [CO₂] effect on LAI for corn (i.e. LAI declines as [CO₂] increases). This result is related to the values of the plasticity parameters e and f (Table 2) prescribed (from Gibelin et al. 2006) for the three vegetation types. The parameter e represents the SLA sensitivity to NL. The corn e value is almost twice as large as that for wheat, and the conifer presents an intermediate value. Note that the values of e and f given by Gibelin et al. (2006) are derived from a meta-analysis, which is affected by uncertainties, also. In conclusion, this sensitivity analysis suggests that the g_c response to [CO₂] is relatively insensitive to uncertainties in the representation of nitrogen dilution. On the other hand, the prescribed value of SLA sensitivity to NL has a large impact on the LAI response to [CO₂].

1.5 [It would have been very useful to see some corroboration of the model for current (past and future) conditions of CO₂, and to see that the model effectively addresses vegetation responses to changing temperature, soil moisture and atmospheric humidity. Currently the paper only addresses corroboration of the high CO₂ runs using experimental data, and the discussion of this is overly brief. A historical modelling study, using crop data from past decades for corroboration would be very useful. This paper suggests that changes in LAI are likely to be significant in counteracting the antitranspirant effect of CO₂. However, predicting future biomass remains a very difficult goal. Without a clear test of the model capability (and likely errors) in this paper (for instance, can wheat and maize dynamics be predicted across the years 2001-4?) the conclusions of this paper seem insubstantial. Currently none of the figures includes any independent data for model corroboration.]

Response 1.5:

In this study, it is shown that changes in LAI caused by [CO₂] are likely to be significant. This result is consistent with many studies (e.g. Piao et al. 2006 over the northern hemisphere). However, the corroboration of modelling results for present, past and future conditions of [CO₂] is not an easy task. In particular:

- The model used in this study is not a crop (forestry) model and does not account for changes in agricultural (forestry) practices with time (such as the use of fertilisers, herbicides, pesticides, or the genetic improvement of the cultivars). In the case of wheat and corn, the crop yield is not simulated. In the case of conifers, the wood biomass is not simulated. Optimal irrigation of corn is simulated, which may differ from the actual irrigation resulting from the agricultural practices.

- The [CO₂] effect is analysed alone. Namely, the same plant, in the same climate and nutrient availability conditions is considered for past, present and future situations.

- Local simulations are performed and the spatial variability of important factors like soil texture and water holding capacity, precipitation, is not investigated.

Existing field experiments and agricultural statistics can be used to assess a number of variables simulated by the model:

- By using [CO₂]-enrichment experiments over grass, Calvet and Soussana (2001) have shown that the ISBA-A-gs approach is able to simulate the response of the leaf biomass to [CO₂]-enrichment. In the case of wheat, the high LAI increase of simulated by ISBA-A-gs for 2050 (average value of +0.62 m²m⁻²) is consistent with the FACE study of Brooks et al. (2000) for fertilized wheat (+11%).

- Field observations (Dolman et al. 2006) performed in 2005 in southwestern France over an irrigated corn crop (Saint-Sardos) showed that maximum LAI was attained in July and remained stable till the senescence, which occurred in October. In the case of a wheat crop (Lamasquère), maximum LAI was attained in May and the senescence occurred in June. Our simulations over 4 consecutive years are consistent with these observations. It is more difficult to validate the absolute value of LAI, which is affected by a high spatial variability. Bondeau et al. (2007) give maximum LAI values for fertilized wheat and corn comprised between 3 and 7 m²m⁻², and our simulations fall into this interval.

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- Estimates of irrigation amounts for corn are given by Teyssier (2006) over Haute-Garonne, an administrative region of 6309 km² covering the SMOSREX site. From Y1 to Y4, he gives: 198, 130, 294, 228 mm y⁻¹, respectively. These estimates are strongly correlated ($r^2 = 0.88$) with the optimal irrigation produced by the model (Table 3). During the wet years Y1 and Y2, the modelled irrigation is markedly underestimated by the model (78 and 70 mm y⁻¹, respectively). The difference is smaller during the dry years Y3 and Y4 (24 and -12 mm y⁻¹, respectively, less than the 30 mm irrigation step used in the model). The difference between the simulated optimal irrigation and the actual irrigation amounts during wet years may be caused by higher irrigation intensities when the water resource available for irrigation is not limited by drought. This effect is particularly noticeable in Y1 (Teyssier 2006, Debaeke et al. 2006).

- Crop yield estimates for Haute-Garonne are available (Agreste, 2007). The model simulates the above-ground biomass of crops (Table 3) and does not simulate the crop yield. However, the correlation between the maximum above-ground biomass and independent yield estimates may help verify the model capability to represent the interannual variability. First, the long-term trend in yield increase has to be removed from the observed time series (Debaeke et al. 2006) and yield anomalies are obtained from 2001 to 2004: -0.03, +0.03, -0.07, +0.01 kg m⁻² for wheat, and +0.05, -0.04, -0.17, -0.06 kg m⁻² for corn, respectively. A positive correlation is found for wheat and corn, relatively good for wheat ($r^2 = 0.47$), poor for corn ($r^2 = 0.18$). In the case of corn, the biomass simulated by the model does not present the severe drop observed for yield in Y3. The corn yield figures available on Agreste do not separate irrigated from rainfed corn but Debaeke et al. (2006) show that irrigated corn suffered a loss of yield in Y3 (12% instead of 30% for rainfed corn).

- The ratio of crop yield to the maximum above-ground biomass is called the harvest index. According to Bondeau et al. (2007), typical harvest index values for wheat and corn in well watered conditions are about 0.4 and 0.5, respectively. The average harvest index derived from yield estimates for Haute-Garonne and from the simulated

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maximum above-ground biomass for Y1 and Y2 is 0.41 for wheat and 0.45 for corn. The relatively low harvest index we obtain for corn may denote an overestimation of the simulated maximum above-ground biomass of about 10%.

- For conifers see response 1.1.

1.6 [It is not clear how the fourth conclusion, about light interception, is generated.]

Response 1.6:

The conclusion that "For C3 plants, the simulated net CO₂ effect on canopy conductance may depend, to a large extent, on the way light interception within the canopy is simulated" refers, especially, to the effect of CO₂ on the diurnal and seasonal cycle of *g_c* and *T_s* of fertilized wheat field discussed in p. 4769. At the canopy level, light can be limiting and the radiative transfer within the canopy has to be represented. The light interception mechanism is complex. It depends to a large extent on LAI but not only. Leaf orientation influences the distribution of solar radiation within the canopy. For wheat, Brooks et al. (2000) show that leaf orientation may depend on the nutrient availability and may change with increasing [CO₂]. This effect is not accounted for in the model used in this study.

1.7 [p. 4768, l. 23. How can canopy conductance increase +540%? This seems unrealistic.]

Response 1.7:

The values given in this paragraph correspond to the maximum simulated changes (i.e. the extreme values). The hourly values considered here are subjected to a high variability (caused by changes in LAI, soil moisture, and meteorological conditions). Fig. 2 shows the average of values above the 90% percentile and below the 10% percentile, not the extreme values. We think that it is useful to indicate, in the text describing Fig. 2, the range of the changes simulated by the model.

Response to the anonymous referee #3

3.1 [A weakness of the study is that there is very little comparison with data. Even for the recent period, where data are available, all we are presented with are simulated results (table 2). Are the results in table 3, for example, consistent with actual measurements in comparable years? The only observational data relevant to 2050 are FACE and enclosure data, and these are not particularly useful because the results from the two approaches are quite different. Hence the value of the paper all hinges on whether their biophysical model is trustworthy enough to make meaningful conclusions about a changed set of circumstances, and there does not really seem enough evidence here to do so with confidence.]

Response 3.1:

Existing field experiments and agricultural statistics can be used to assess a number of variables simulated by the model. In responses 1.1 and 1.5 (above) we detail the result of the comparison of the modelled variables with the available data.

3.2 [Some important information needed to interpret the paper is missing. The most important aspect of this is that nowhere do the authors define the population over which they are defining distributions and statistics such as medians and quartiles. Is it some random variation in the model parameters, for example? Without this being clearly described, interpreting the rest of the paper is problematical. For example, what does it mean to say that the distribution is bimodal?]

Response 3.2:

In this study, a sensitivity study to [CO₂] is performed. The direct, antitranspirant effect of CO₂ is modelled at the hourly scale, as well as the indirect, cumulative effect of CO₂ on LAI and soil moisture at the seasonal and interannual scales. Statistical indices are given about changes in biophysical variables caused by past and future changes in [CO₂], for three vegetation types (wheat, corn, conifer). The biophysical variables considered and the length of the time series are indicated in section 2.5. The changes are due to CO₂ variations only. The soil and vegetation parameters of the model (ex-

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cept for NL, which depends on [CO₂]) remain unchanged. The populations over which statistics are given consist of changes in the variables listed in Table 4: hourly values are considered for gc, Ts, NEE, and water and heat fluxes, daily values for LAI, and yearly values for peak biomass.

A bimodal response of LAI and gc to [CO₂] is simulated for wheat in 2050. The differences in gc aggregate into two populations presenting either positive or negative values.

3.3 [Section 3.3 is very confusing, with the text having little apparent connection with the Figs. Fig. 2 is quoted in support of values like +540 % increase in gc and -4.4 decrease in temperature, but these clearly are not on that fig. Similarly, the highest increase is around 1430, not noon, as stated. The largest decrease in gc is around 10:30, not in the afternoon. The discussion of Fig. 3 is in terms of gc, but that is not on the Fig.]

Response 3.3:

A bimodal response of LAI and gc to [CO₂] is simulated for wheat in 2050. In particular, gc either increases or decreases in our simulations, with about the same probability. Fig. 2 presents dawn-to-dusk curves of the most significant (10% highest and 10% lowest) hourly values of relative difference in gc and absolute difference in Ts. The probability distribution of the differences is not uniform in time. In Fig. 2, the probability of observing a difference at a given time of the day is represented by the size of the circles. It is shown that (1) the highest increase of gc and the concomitant decrease of Ts are more frequently observed around noon (from 1200 to 1400 LST) ; (2) the highest decrease of gc and the concomitant increase of Ts are observed, mainly, in the afternoon (from 1500 to 1700 LST). The highest simulated differences are not shown in Fig. 1 and 2. They can be very large because the hourly values considered here are subjected to a high variability (caused by changes in LAI, soil moisture, and meteorological conditions). In our simulations, gc may increase up to +540% (and Ts

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presents a concomitant decrease of -4.4 degree C) and decrease down to -80% (and Ts presents a concomitant decrease of +1.9 degree C).

3.4 [It is annoying to find gc introduced at l. 59, but not defined until l. 142. Similarly, but less extreme, FACE (l.228). Some use of acronyms is gratuitous and hinders the reading. Why not corn, wheat and conifer, rather than IRC, MTM and CNF? The vertical scale of Figure 2 should be increased.]

Response 3.4:

The variable gc is defined on p. 4762, at the beginning of the introduction section 1. We agree with the editorial issues.

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