Atmos. Chem. Phys. Discuss., 9, S1051–S1056, 2009
www.atmos-chem-phys-discuss.net/9/S1051/2009/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Process-based modelling of biogenic monoterpene emissions: sensitivity to temperature and light" *by* G. Schurgers et al.

G. Schurgers et al.

Received and published: 26 March 2009

We would like to thank the reviewer for the extensive comments. They have pointed out some places where the clarity of the manuscript needs improvement, which we attempt to do in a revised version of the manuscript. In addition, a number of assumptions and discussion points will be extended. In the revised version of the manuscript, we will specifically address the following points:

Gaps in current understanding of processes involved (general comments)
Current estimates of regional or global monoterpene emissions are nearly always made applying the short-term temperature dependent algorithm by Alex Guenther. Whereas this algorithm gives a reasonable representation of short-term emissions, it is not made to simulate long-term effects (despite the fact that it is used to do so). Even though gaps in our current understanding of these long-term effects might be present,

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it does not hinder us from providing a more realistic description of emissions than in the Guenther algorithm - a description that is necessarily kept general in order to be widely applicable, yet contains more of the understanding we have about monoterpene production than only the short-term temperature dependence. Yes, there are gaps in our current understanding, and they will be mentioned more explicitly (see below). However, these gaps do not have to keep us from implementing those parts we understand. In the revised version, the discussion of temporary (or non-specific) storage will be extended. Leaf catabolism is not considered in the model, which will be stated more clearly (see below).

Title
The title will be adjusted to "Process-based modelling of biogenic monoterpene emissions combining production and release from storage"

Biological importance of monoterpenes in introduction
A paragraph on the biological importance of monoterpenes will be included in the introduction.

The derivation of epsilon
The explanation of this derivation in the text will be extended (see below). The reviewer is right that this derivation does not necessarily hold when photosynthesis and monoterpene emission are not coupled (due to emissions from storage), which cause either an over- or an underestimation of the value of epsilon. However, in order to take this into account, one would need much more information on storage pool size or past weather conditions (not only from the time of observation but as well from weeks or months prior to that), information which is generally not provided with a published emission capacity, and which is certainly not available for aggregated values as used in regional or global modelling studies. Therefore, we assume reported values to be valid for a longer period, with over- and underestimation to occur in equal amounts, which allows us to use the published values. This will be clarified in the text.

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Effect of monoterpene concentration

The implementation in the model is simplified in this respect, and does not necessarily hold for needles of different age on one tree, as the reviewer brings up. It rather assumes monoterpene concentrations to be higher at higher productivity (e.g. as caused by different weather conditions in different years), thereby accounting for the higher emissions that thus take place. When extending the model to leaf age classes or similar, one would have to take these kind of refinements into account.

Storage modulates the seasonal cycle

Monoterpene production and monoterpene emission are simulated as two independent processes. Production is thus not regulated by storage concentrations, and the annually produced amount depends solely on climate and CO_2 concentration. The total of produced monoterpenes is emitted throughout the year, and (averaged over a longer period) emission is thus equal to production. The timing of these emissions, however, depends (1) on whether or not part of the production is transferred to the storage pool, and (2) on temperatures and pool concentrations, which determine the annual cycle. The total of emissions, however, has to equal production as long as storage does not change considerably, i.e. on time scales longer than approximately one year.

Abbreviations

Abbreviations will be explained more clearly in the revised version.

Method calculating *J*

The photosynthesis rate *J* is calculated in the dynamic vegetation model LPJ-GUESS derived from the Farquhar et al. (Planta, 1980) photosynthesis scheme as adopted to a daily basis following the optimisation approach in Haxeltine and Prentice (Functional Ecology, 1996). The method does not differ from the way photosynthesis is calculated in the "standard"; versions of LPJ-DGVM and LPJ-GUESS (Smith et al., 2001; Sitch et al., 2003). This will be incorporated in the revised manuscript.

Seasonality of photosynthesis-dependent emissions

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The seasonal variability of monoterpene emissions caused by changes in enzyme activity will be included more clearly in the discussion of the results (p. 281, l. 25).

Unclear sentence (p. 281, l. 25)
Sentence will be replaced by "The commonly reported emission capacity M_s, expressed at a standard temperature, is not necessarily equivalent to the production capacity under similar standard conditions, because the latter is a light- and temperature-dependent process that takes place during daytime only. Therefore, in plants where a storage pool exists...". In order to clarify the sentence below that, additional characteristics in brackets will be inserted: "Or in other words: a (daytime) production-derived value for M_s must exceed an emission-derived M_s (that would cover daytime as well as nighttime emissions) notably."

Monoterpene metabolism
The model assumes no monoterpene catabolism in the plants. Simulated production and emissions represent those that would be observed outside the leaf. This assumption will be added to section 2.2.

Categorization in storing and non-storing species
The categorization in storing and non-storing species is coarse, however needed when distinguishing no more than 10 plant functional types. For refinement of the distinction (as well as other emission characteristics), one would ultimately try to simulate plant species separately. This is possible on a local or regional scale (e.g. as done in Arneth et al., 2008, Plant Biology for isoprene in Europe), but is not possible on a global scale. The discussion on this differentiation will be extended.

Effect of rain events
The effect of rain events is not accounted for in the simulation, and we have not seen any attempts to include this in models so far. However, if the mechanism could be quantified, it would be a valuable addition to the model (like any other mechanically-driven short-term release). We add a remark about it in the revised version.

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Stress-related release of monoterpenes
The effects of mechanical or biotic stress factors are not accounted for explicitly in the model, and these would contribute to the direct emission as well.

Annual cycle of monoterpene concentration
The studies from literature presented in the manuscript show different patterns of annual monoterpene concentrations, some of them in line with our simulation (Picea mariana, Lerdau et al., 1997), others with a different timing (Pinus banksiana, Lerdau et al., 1997; several mediterranean species, Llusia et al., 2006). There seems to be considerable variation in the timing of this concentration, so it is hard to use this information for model evaluation. The implementation of emissions in our model has two counteracting processes: (1) growth of storage, which is highest at times of high productivity (summer), and (2) release from storage, which is highest at times of high temperatures (summer). The net effect of these two processes is not straight-forward to estimate, and the timing of the peak of monoterpene concentrations depends on the parametrization of equations (5) and (6), in particular the value of tau$_s$.

Timing of emissions (p. 286, l. 20-25)
There is an error in this sentence: Photorespiration and winter assimilation were meant as examples affecting the timing of emissions, not those of storage. The sentence has been corrected accordingly: However, there are likely other factors playing an important role in the timing of emissions that are not considered in our vegetation model.

Figures 2 and 3
The figures illustrate the dependence of the new algorithm, and has additional sensitivities shown for the short-term temperature effects from equations (1) and (5)+(6). These short-term dependencies do not depend on GPP (and do not require a separate simulation of GPP), hence no additional lines in panels b and c. The axes are unitless, values are given relative to the "standard" case. We realise that the abbreviation "rel." is somewhat cryptic and replace it by GPP/GPP_0, Q/Q_0 and M/M_0, explaining in the figure captions that these parameters are given relative to their standard case.

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Low emissions

The fact that simulated emissions are low does not reflect a weakness of the model or of the paper, but an uncertainty in model estimates in general. There is no independent source of observations that enables a global estimate of monoterpene emissions, the only comparison one can make is to other models. This issue has been discussed in Arneth et al. (Atmospheric Chemistry and Physics, 2008).

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 271, 2009.

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