Methane emissions from terrestrial plants

On the discovery of CH_4 emissions from terrestrial plants and its potential implications – comments on the paper of Keppler et al. [Methane emissions from terrestrial plants under aerobic conditions, *Nature, 439,* 2006]

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On the discovery of CH_4 emissions from terrestrial plants and its potential implications

In a recent issue of Nature *Keppler et al*. [2006] report the discovery that terrestrial plants emit CH_4 under aerobic conditions. Until now it was thought that bacterial decomposition of plant material under anaerobic conditions, such as in wetlands and water flooded rice paddies, is the main process leading to emissions from terrestrial ecosystems. In a first attempt to upscale these measurements, the authors estimate that global total emissions may be 149 Tg CH_4/yr (62-236 Tg CH_4/yr), with the main contribution estimated from tropical forests and grasslands (107 Tg CH_4/yr with a range of 46-169 Tg CH_4/yr).

If confirmed, this new source of emission would constitute a significant fraction of the total global methane sources (estimated 500-600 Tg CH_4/yr for present day total natural and anthropogenic sources) and have important implications for the global CH_4 budget. To accommodate it within the present budget some sources would need to be re-assessed downwards and/or some sinks re-assessed upwards. Furthermore, also considering that methane is a ~23 times more powerful greenhouse gas than CO_2, the possible feedbacks of these hitherto unknown CH_4 emissions on global warming and their impacts on greenhouse gases (GHG) mitigation strategies need to be carefully evaluated.

The merit of the paper is without doubt related to the remarkable discovery of a new process of methane emissions active under aerobic conditions. However, we think that the applied approach of scaling up emissions from the leaf level to global totals by using only few measured data (mainly from herbaceous species) and the Net Primary Productivity of the main biomes is scientifically questionable and tends to overestimate considerably the global estimates, especially for forest biomes.

Furthermore, some significant constraints on the upper limit of the global natural CH_4 emissions arise from the pre-industrial CH_4 budget. Pre-industrial atmospheric CH_4 mixing ratios have been measured precisely from ice cores and it can be estimated that the CH_4 lifetime (mainly OH sink) has not changed by more than 20% between pre-industrial times (year 1800) and today. Assuming a lower limit for CH_4 emissions from wetlands of 90 Tg CH_4/yr would imply an upper limit of ~100 Tg CH_4/yr for the total global emissions from plants.

The paper raised an intensive discussion whether the CH_4 emissions from plants could significantly reduce the climatic benefit gained through carbon sequestration of afforestation / reforestation programs. However, we estimated that the CH_4 plant emissions would reduce this benefit by only a few percent as maximum. This is fully consistent with the clarification provided by Keppler et al. in a subsequent press release of the Max Planck Society (18 January 2006), where they stated that "for climate, the benefits gained by reforestation programs would be lessened by between 1 and 4 % due to methane emissions from the plants themselves".

Finally, the discovery of CH_4 emissions from plants is raising the question about potential impacts on top-down estimates, which derive total CH_4 emissions from atmospheric observations and inverse modelling. However, in temperate regions this effect is likely to be relatively small, and therefore results of inverse modelling studies performed on the European scale are likely to be influenced relatively little only.

The arguments presented here are discussed in some more detail in the appendix.

Appendix

Summary of the Keppler et al. study

The study of *Keppler et al.* [2006], based on measurements performed of a limited number of species (mainly herbaceous: grasses, maize and wheat), yielded emission rates of 12-870 ng CH_4 / g (dry weight of plant) h^{-1}. The same measurements carried out with detached leaf material resulted in 1-2 orders of magnitude lower emission rates (0.2-3 ng CH_4 / g (dry weight of plant) h^{-1}). Emission rates were found to depend strongly on exposure to sunlight (increase by a factor of 3-5 compared to emissions without direct sunlight). Furthermore, the authors found a strong temperature dependence, with emissions approximately doubling with every 10^oK increase (within the range between 30^o-70^oC).

The experiments indicated a hitherto unknown non-enzymic process, and excluded microbial activity as the CH_4 sources. Based on experiments with purified apple pectin the authors suggest that the structural plant component pectin plays a central role in the in situ formation of CH_4 in plants.

In a first attempt to upscale these measurements, the authors estimate that global total emissions may be 149 Tg CH_4/yr (62-236 Tg CH_4/yr), with the main contribution estimated from tropical forests and grasslands (107 CH_4/yr with a range of 46-169 CH_4/yr). Plant litter has been estimated to contribute 0.5-6.6 Tg CH_4/yr.

Uncertainties of applied upscaling approach

A limitation of the presented upscaling is that it is based on only few measured data (for only 8 species measurements were carried out on intact plants, and among these only one was a tree). Furthermore, since their study indicates that “the structural plant component pectin plays a prominent role in the in situ formation of CH_4 in plants", it seems more appropriate to use a structural parameter (e.g. leaf biomass) rather than a metabolic-related process such as the annual net primary productivity (NPP). Since the leaf biomass typically represents only 10-30% of the annual NPP [*Chapin et al.*, 2002], the approach used by Keppler et al. may have significantly overestimated (i.e., 3-10 times) the global emissions of CH_4 by plants.

Constraints from the pre-industrial atmosphere

Until now, wetlands were considered to be the most important natural CH_4 source, with estimates of 90-260 Tg CH_4/yr from bottom-up inventories. While all estimates of natural and anthropogenic source strengths have considerable uncertainties, an important constraint for the global total CH_4 emissions comes from the major sink via OH radicals, which is believed to be relatively well known.

Estimates of total natural emissions are largely based on the very well known atmospheric CH_4 mixing ratios in pre-industrial times of ~700 ppb [*IPCC*, 2001], and the estimate that the CH_4 lifetime (due to the OH sink) has not changed by more than 20% between preindustrial times and today [*Lelieveld and Dentener*, 2000; *Wang and Jacob*, 1998]. Based on such considerations, Houweling et al. [2000] estimate the total pre-industrial sources and sinks to be 252 (226-293) Tg CH_4/yr (year 1800). Accounting for some known small anthropogenic sources at that time (30 (15-65) Tg CH_4/yr) and some known minor natural sources (58 (38-78) Tg CH_4/yr, yields a remaining net source of 163 (130-194) Tg CH_4/yr which was entirely attributed by Houweling et al. [2000] to wetlands. If plant emissions contribute significantly, this would mainly imply that CH_4 emissions from wetlands have been overestimated.

As mentioned above the upscaling of wetland emissions from point measurement to global total emissions (bottom-up estimates) are very uncertain. However, wetlands have been investigated in much detail and considerable emissions have been documented in many studies. Therefore, global total wetland emissions of lower than 90 Tg CH_4/yr seem relatively unlikely. This lower estimate would imply an upper limit of ~100 Tg CH_4/yr for the total global emissions from plants.

Re-Assessment of global CH_4 budget

As discussed in the previous section, a significant CH_4 source from plants mainly implies that natural CH_4 sources and sinks need to be redistributed.

Particular CH_4 sources and sinks to be re-assessed are:

(1) wetlands

(2) other minor pre-industrial natural (e.g. ocean, geological sources, termites, wild animals) and anthropogenic source (adding up to ~90 Tg CH_4/yr [*Houweling et al.*, 2000])

(3) soil sink

Aerobic soils are known to consume atmospheric methane by methanotrophic bacteria. Global estimates of the sink strength are 30 Tg CH_4/yr but this is subject to considerable uncertainty (7-120 Tg CH_4/yr) due to the patchy distribution of measurements [Smith et al., 2000]. CH_4 production by living or dead plants implies that gross strength for the soil sink of methane [*Andersen et al.*, 1998] could have been underestimated as measurements were performed including varying amounts of plant material. The above discussed study of Houweling et al. [2000] assumes a soil sink of 12 (12-30) Tg CH_4/yr.

For an improved assessment of these sources and sinks more comprehensive measurements programs (ideally integrating over larger areas) and sophisticated upscaling techniques will be required**.**

Anthropogenic activities are also likely to have some influence on the natural sources. However, this effect is probably relatively small for the present-day CH_4 budget:

Compared to pre-industrial times, carbon stocks have decreased by about 10% [IPCC, 2001]. The effect of deforestation on CH_4 emissions from plants may have been offset, however, by increasing emissions due to the global temperature increase.

Similarly, it seems likely that the reduction of CH_4 emissions from natural wetlands by cultivation and drainage since pre-industrial times may have been approximately compensated by the increase of CH_4 emissions induced by the rise of temperature [*Walter et al.*, 2001a; *Walter et al.*, 2001b].

Compared to pre-industrial times, CH_4 concentrations have increased by a factor of about 2.5. It is generally believed that this dramatic increase is mainly based on the additional anthropogenic sources (mainly related to energy production and transport (coal, oil, gas), ruminants, rice cultivation and landfills). As the global total of anthropogenic CH_4 sources is strongly constrained by the precisely measured atmospheric increase (and assuming only small changes in OH and in total natural emissions since pre-industrial times), estimates of anthropogenic CH_4 sources are not significantly effected by the Keppler et al study.

Recent CH_4 measurements from space suggested larger CH_4 emissions from tropical regions than hitherto assumed in most bottom-up inventories [*Bergamaschi et al.*, 2006; *Frankenberg et al.*, 2006; *Frankenberg et al.*, 2005]. Thus, the additional natural CH_4 emissions from plants, located mainly in the tropics, could indeed help in the interpretation of these observations. As discussed above, however, this implies mainly a re-distribution between natural sources.

Potential implications for GHG mitigation strategies

The new discovery, if confirmed, would imply at least two questions regarding GHG mitigation strategies:

(1) Could the CH_4 emissions from plants significantly reduce the benefits of CO_2 sequestration from afforestation / reforestation?

Afforestations and *reforestations* (AR) are important land-use related means of mitigation of GHG emissions. Reporting on GHG emissions from AR activities is obligatory under the Kyoto Protocol, and afforestation is the only land-use activity that is allowed under the provisions of the Clean Development Mechanism. If CH_4 emissions from trees were substantial that would mean that the mitigation effect of afforestations is smaller than expected, or even “negative”, thus rendering this mitigation option obsolete. However, we estimate from the numbers given by Keppler et al. [2006] that the additional CH_4 emissions can only partly offset (few percent as maximum) the climatic benefit gained through carbon sequestration of afforestation / reforestation programs. Similarly, the estimate given for CH_4 emission reductions caused by *deforestation* in the tropics during the 1990s (6-20 Tg CH_4 y^{-1} [*Keppler et al.*, 2006]) represent only 2.5-8% of the carbon released, expressed in terms of radiative forcing (using a GWP for CH_4 of 23 [*IPCC*, 2001]). The fact that the CH_4 emissions offset only a small percentage of the climatic benefit gained through carbon sequestration has also been clarified in a Max-Planck press release, after some misinterpretation appeared in the media [*Wirsing*, 2006].

(2) Could some CH_4 reduction strategies be affected by CH_4 emissions from plants?

This question seems most relevant for agricultural practices related to rice paddies. However, emissions due to anaerobic conditions in wet rice cultivation are a factor of 10-100 higher than the corresponding CH_4 emissions from the plants under aerobic conditions. Furthermore, it has been observed in many field experiments that CH_4 emissions from rice plants decrease significantly with the change from anaerobic to aerobic conditions (e.g. after drainage before harvest) [*Sass et al.*, 1992].

Potential implications for feedbacks of CH_4 emissions to global warming

The strong temperature dependence found for the plant emissions may raise concerns about strong feedbacks of CH_4 emissions due to global warming. However, also wetlands show a strong temperature dependence of their CH_4 emissions with observed Q_{10} values between 1.7 and 16 [*Walter and Heimann*, 2000] (this Q_{10} factor represents the difference in emission rates for a 10^oC temperature increase). From ice core measurement over the last 600,000 years [*Spahni et al.*, 2005] it is indeed well established that CH_4 reacts rapidly to climate change (with atmospheric mixing ratios of ~400-500 ppb during glacial times, and ~700 ppb during interglacial times).

Potential implications for inverse modelling studies

The CH_4 emissions of plants will have some impacts on top-down estimates, which derive total emissions (i.e. sum of anthropogenic and natural sources) from atmospheric observations and inverse modelling [*Bergamaschi et al.*, 2004; *Bergamaschi et al.*, 2005; *Manning*, 2004]. Using the NPP based upscaling of Keppler et al. [2006], we estimate that CH_4 emissions of plants could represent ~10% of total emissions for EU-15 countries (as discussed above, however, this upscaling may significantly overestimate the plant emission). Consequently, top-down estimates of anthropogenic emissions would have to be reduced slightly. However, the main conclusions drawn from recent inverse modelling studies on the European scale [*Bergamaschi et al.*, 2004; *Bergamaschi et al.*, 2005; *Manning*, 2004] remain valid even when applying this upper estimate for the plant emissions.

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