BIOGEOSCIENCES

REFEREES COMMENTS ON:

Hooijer et al. - Current and future CO_2 emissions from drained peatlands in Southeast Asia

GENERAL:

This paper deals with the very important topic of how much carbon is being transferred from tropical peatland to the environment as a result of land use change and fire and the information should be published. The manuscript contains, however, errors, inconsistencies and confusing statements that must be addressed and corrected.

There should be consistency in the use of terms, e.g. peat depth and peat thickness; these are the same and both are used; suggest that only 'thickness' should be used as far as possible.

Much reliance is placed on information derived from Hooijer et al (2006) which is fine but some summary information needs to be included in this paper in several places because the principal reference is a consultancy report that is not generally available.

The term 'groundwater depth' is used throughout the paper but it is better to use 'peat water table' since this is generally used and accepted by peatland ecologists and hydrologists.

There are numerous general, vague or undefined statements that need to be made more scientifically stringent. Examples are given below.

SPECIFIC:

7209, l.7: delete 'by most definitions' – too vague

7209, l.8/9: 'at least 17% over 4 m deep' insert reference; expect it is Wetlands International 2003/2004

7209, l.10: The estimate of 42,000 Mt carbon in Southeast Asian peat based on a carbon density of 60 kg m^{-3} – these values are not from Page et al (2002) which focuses on Indonesia's peatland only.

7209, l.20-24: Plant respiration, especially from roots should be mentioned here since this an important component of peatland carbon gas flux

7210, l.1: Figure 1; the caption needs to be more informative and correct; In the natural system tropical peatland is covered in rain forest trees up to 40 m tall; thickness is shown as 1-10 metres but text says peat can be up to 20 m thick – which is correct?; the schematic representation shows peat subsidence as a result of drainage not CO_2 emission although it is assumed that most of the carbon 'lost' is released to the atmosphere as CO_2.

7210, l.21: We know 'where' tropical peatland is because that has been stated already. The information 'obtained' is the 'area' and 'thickness' of tropical peatland. It is not possible to know ‘where’ peatlands are drained from the information in this paper but only country and regional estimates of the area drained.

7211, l.0: Section 2.1.1 heading should more correctly be ‘Peatland location, area and thickness’

7211, l.3: Fig. 2 is of poor quality and relatively uninformative because it does not include all countries in SE Asia with peatland. It is not clear why the caption refers to ‘forest cover on peatland in the year 2000’. It is impossible to distinguish forested from deforested peatland and it seems pointless to state that certain FAO information has not been included. Better maps of peatland in SE Asia are available. The legend does not say that the map is of Indonesia and Malaysia.

7211, l.4: The map (Fig. 2) also contains peatland distribution information for West Papua (formerly Irian Jaya), Indonesia

7211, l.5: ‘peat percentage in soil classes’ – this does make sense, better leave out!

7211, l.8: without further information it is impossible to know how peat thicknesses in these countries were derived from those in Indonesia.

7211, l.11: after ‘carbon stock’ add in ‘Southeast Asia’

7211, Section 2.1.2 heading should be ‘Area of drained peatlands....’

7211, l.16: This is confusing because not all 16 cover categories are on peatland. Better to say ‘of the 16 cover categories those on peat were allocated to 4 drainage categories...’

7211, l.19: The drainage class terms introduced here should be the same as those used in Table 1

7211, l.20: replace ‘natural vegetation’ by ‘natural peat swamp forest’; it is not clear what ‘cells’ means in this context; are they cells in Table 2 or are they something else; the word is not used again

7211, l.21: It is not clear how this allocation of ‘cells’ to ‘drainage classes’ was carried out

7212, l.0: Section 2.1.3 heading; should be ‘Peat water table depths in the drainage classes’

7212, l.1: replace ‘groundwater’ by ‘water table’

7212, l.1-2: This is long winded; better to say ‘Mean water table depths for each drainage class were estimated from published data’; then there are several references but no indication of what information is in them that provides the water table depth information referred to. This section should be expanded and clarified.

7212, l.5: It is meaningless to state ‘field observations by the authors’ without including some data obtained by them!

7212, l.6: Section 2.1.4 heading. More appropriate would be ‘Rate of deforestation and future...’

7212, l.7: ‘peatland cover’ should this be ‘peatland forest cover’?

7212, l.13: ‘business as usual’ does not convey anything unless it is defined for this specific context; suggest change to ‘assuming continuation at the same annual rate of deforestation’

7212, l.16: the ‘relationships’ need to be explained so that readers can understand how they were arrived at

7212, l.20: insert ‘analysis of’ before ‘the results of’

7212, l.20-21: better to say ‘The first is CO_2 emission monitoring...’

7212, l.23: delete ‘type of study’

7212, l.24: ‘measurements of’ before ‘carbon content’

7212, l.25: change ‘factor out’ to ‘separate’

7213, l.2: ‘analysis’ is not mentioned before; see suggested insert on 7212, L.20; change ‘relation’ to ‘regression relationship’

7213, l.7: delete ‘value’ and insert ‘rate’ since this is what it is!

7213, l.10: Page et al (2002) uses a value of 57 kg m^{-3}; has this been rounded up to 60?

7213, l.22: change ‘groundwater’ to ‘peat water table’

7213, l.22-24: This sentence is cumbersome; suggest changing to ‘Different peat water table depths were applied to the three drainage classes (“cropland”, “mosaic cropland and shrubland” and “shrubland”) and CO_2 emissions calculated......(Table 1).

7214, l.2: ‘will’ – all of this is in the past so tense should reflect this

7214, l.7-9: the sentence beginning ‘Subsequently’ should be moved to precede the sentence beginning ‘Peatland’ on 7214, l.1; delete ‘as presented in’ and place ‘Table 1’ in brackets

7214, l.9: ‘Overall emissions were estimated...’; what are they – annual or cumulative? where are they? Are they in a figure or table?

7214, l.14: ‘extended to 2000-2006’; how was this done and where is it? Is it Figure 3? Were the subsequent values/predictions (e.g. 47% and 121.9 Mha) derived by reading off from this small and rather inaccurate graph that projects up to 2100?

7214, l.22: why use ‘organic matter decomposition’ when before ‘peat decomposition’ is referred to

7214, l.23: the estimate of 632 Mt y^{-1} presumably comes from Hooijer et al (2006) determined from the graph reproduced in Fig 5 but this is not made clear; also H et al give a range of 355-874 Mt whilst this paper refers to 355-855; which is correct?

7214, l. 23-24: I made various attempts to obtain the range of 6-100 t CO_2 ha^{-1} but was unsuccessful! It is not clear how these values were obtained; I assumed that the range values 355-855 (or 874) would be divided by the drained peatland area of 11.1 Mha (9.5-12.7 Mha) but I was wrong. Please explain the process/steps.

7214, l.26-27: The amount of these emissions from Sumatra and Kalimantan should be explained but with more detail of how they were obtained; surely emissions from West Papua (Irian Jaya) should be referred to since it is included in Table 2

7215, l.7-9: How are these 'cumulative emissions' obtained? They are not referred to in methods unless they are the 'overall emissions' mentioned in 7214, l.9; are they estimated by extracting values from Fig 5? Explanation is required and also a reference.

7215, l.10 'groundwater' change to 'peat water table'

7215, l.12: The mention of 'temperate and boreal areas' requires one or more references; several papers have been published on this topic but it is unclear what the relevance is in this paper since the potential role of temperature in CO_2 emissions in tropical peatland was not studied.

7215, l.12-16: The inclusion of the reference to emissions from 'arable land on drained fen peat', presumably in Poland, is a very poor comparison to the tropical situation which is mostly on ombrotrophic peat. It would be more appropriate to use references to CO_2 emissions from boreal/temperate raised bog used for peat extraction for energy or horticulture. There are several of these. What is the implication of the 'order of magnitude' difference?

7215, l.17-20: Uncertainties are dealt with at length towards the end of the paper so don't mention them here. Suggest 'This assessment of CO_2 emissions from drained peatlands (it is peat that decomposes not peatland) in Southeast Asia of 355-855 (or is it 874?) in 2006 are equivalent to 1.3% to 3.1% of the 28 Billion metric tonnes (why change units)....'

7215, l.21: 'Flux' implies two way movement while drainage emissions are one way! Suggest changing to 'In addition to continuous CO_2 emissions as a result of drainage of tropical peatland...'

7215, l.21-22: What are 'incidental emissions'?

7215, l.21-24: This section on fires is very short bearing in mind the importance of these and large amounts of carbon they release from tropical peatland. I suggest this is expanded.

7215, l.29: delete 'various numbers' and replace by 'data'

7215, l.29 – 7217, l.8: This mostly discussion of the numbers obtained in the evaluation but it is poorly expressed and contains vague and unsubstantiated statements. The meaning of parts (e.g. 7217, l.3-9) is difficult to understand.

7216, l.4-5: 'Contributing fluxes' is not a good way to describe the situation; they are not fluxes but emissions and they cannot contribute to 'net carbon balance'. A flux cannot contribute to a balance!

7216, l.6-8: It is unclear why the very large emissions present a significant opportunity for emissions reductions. The situation is much more complicated than this.

7216, l.8-12: These are vague statements without logic and anything to support them (e.g. references). Water management is mentioned without explaining why or what it is.

7216, l.13-25: This section is very confusing and a mixture of several topics. It needs to be unravelled and presented more logically

7216, l.26-7217, l.2: This section would be better located (after 7216, l.8) where emissions reductions are first mentioned. This section mentions post-Kyoto but it lacks purpose and reasons/explanation of what part tropical peatlands might play and how REDD could operate.

7217, l.3-9: This paragraph is unintelligible.

7217, Section 3.1.1: This section is important because it stresses the shortcomings in current data available to calculate CO_2 emissions from tropical peatland. The text is longwinded, however, and lacking in logical assessment and presentation. Some suggestions follow but the entire section needs to be read through very carefully and improved. It would benefit from being shortened. Se suggested rewrite for Section 3.1.1 at end.

7217, l.10-12: This sentence does not convey correctly what is being discussed in this section. Suggest: “In this section the main uncertainties in the data used are highlighted and research needs identified to improve estimates of CO_2 emissions from drainage of tropical peatland.”

7217, l.19-20: It is normal to discuss peatland area first, followed by thickness and then carbon content. It is presumed that ‘extent’ means ‘area’ and the latter term should be used as it is more generally adopted. Distribution of tropical peatland, i.e. in which countries and regions of countries is well known, uncertainty arises owing to lack of accuracy in inventories of area and thickness.

3.1.1 Uncertainties and research needs

In this section the main uncertainties in the data used are highlighted and research needs identified to improve estimates of CO_2 emissions from drainage of tropical peatland.

Peatland area:
The area of peatland in the various countries in Southeast Asia is reasonably well documented and is listed in national soil and land use inventories. The accuracy of these could be improved by adopting standardized methods for survey and evaluation of peatland and peat. There is no generally accepted definition of 'peat' and this varies from country to country, some of which adopt a minimum organic matter accumulation of 30 cm, with less than 35% ash content as the basic requirement while others use 40 or 50 cm. Another definition specifies there need only be a minimum of 35% organic matter present which includes all Histosols and some Histic soils.

Peat thickness:
This is subject to the largest degree of uncertainty owing to a lack of geographically wide field data. Information from parts of Central Kalimantan and East Sumatra, where intensive research has been carried out (e.g. the Ex Mega Rice Project area and 'Natural Laboratory' in the upper Sungai Sabangau catchment and the Kampar Peninsula in Riau Province), is quite detailed. Elsewhere, data are few, usually from the edges of these vast peatland landscapes where peat is shallow with the internal 'domes' on deeper peat remaining under sampled. This is a major problem in West Papua, Indonesia, Papua New Guinea and parts of Malaysia.

Carbon content:
Peat carbon content is obtained by combining the area of peatland with the bulk density of and carbon concentration in peat. The carbon 'density' of Southeast Asian peat used in this paper is based on a mean peat dry bulk density of 100 kg m^{-3} and average carbon concentration of 60% Wösten at al., 2001; Rieley et al., 2008) both of which vary greatly across the surface of tropical peatland and in peat profiles (Page et al., 2004). Carbon densities between 24 kg C m^{-3} and up to 95 $kgCm^{-3}$ (Page et al., 2004; Wetlands International, 2003; 2004) have been reported.

Drainage depth classification:
This was derived from the GLC 2000 global land cover classification (Bartholomé and Belward, 2005) and needs to be improved with the addition of more drainage classes to encompass the diversity of land uses and drainage depths. For example, areas in Papua (Indonesia) are classified as "mosaic cropland+shrubland" while they are known to be savannah-like swamps created as a result of traditional land management that involves regular burning (Silvius and Taufik, 1990). These areas are generally not "drained" in the normal sense because agriculture is often carried out on elevated islands of organic mud dug up from the submerged swamp soil

The *percentages of peatland drained* within the drainage classes are conservative estimates derived from surveys carried out in Indonesia and focussed on deforested peatland. It is assumed that the situation in other countries in Southeast Asia is similar but it may not be. The percentage of drained peatland may be considerably larger than expressed in this paper, as several activities affecting the hydrology of tropical peatland were not taken into account. These include construction of canals in forested areas for transport of legal or illegally logged timber, drainage for plantation development and maintenance and roadside drainage.

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research needs to improve future estimates of carbon emissions from peat decomposition

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regions outside of Kalimantan and Sumatra.¶

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to be greatest in the central parts of the inaccessible, dome-shaped peat bodies, which¶
are often tens of kilometres across. Most of the measurements on peat thicknesses¶
are nearer to the fringes. New carbon estimates will improve by acquiring new datasets¶
on peatland thickness particularly for Malaysia and Papua New Guin ... [3]

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Water table depths:

Drainage water table depths used in this assessment (Table 1) are greater than those recommended in existing management practices (e.g. Wösten et al (1997) but, in the case of croplands and plantations they are shallower than depths observed frequently by the authors in the field where it is common to find water tables of below one metre from the surface in oil palm and pulp wood plantations. There is a need for an extensive system of peat water table monitoring in the range of tropical peatland types under different forms of management.

~~Values for *2006 land use* were projected from GLC 2000 data for the year 2000.~~#
Land cover trends and rate of peatland deforestation in 2006 were derived from peatland cover in 2000 (GLC, 2000) and the rate of deforestation from 1985 to 2000 (Global Forest Watch, 2002) as described by Barthtolomé and Belward (2005). These data are still the most up-to-date and validated information available for all of Southeast Asia, although they are now far out of date and need to be updated.

~~Projections have not taken into account *peatland drainability and future management responses*. When subsidence brings the peat surface close to the drainage base, resulting in increased flooding and reduced agricultural productivity, they may be abandoned and drainage intensity would decline. In such cases CO_2 emissions may be reduced. Part of the carbon stock in peatlands is below the drainage base and may never be oxidized. However, a common observation is that drainage systems in abandoned peatlands continue to draw down water levels for decades, because no funding is available for canal blocking.~~

CO_2 emission rate and water table depth:

The relationship between these is affected by drainage and is very important but difficult to determine precisely. Data are obtained from two sources of information: gas flux measurements and peat subsidence monitoring. The former can be difficult to interpret because CO_2 emissions resulting from peat oxidation (decomposition) must be separated from that originating from plant root respiration. There are very few datasets of CO_2 emissions and even less of annual fluxes over multiple years to determine the likely high interannual variation. Monitoring of peat subsidence provides a more direct and accurate measurement of net carbon loss provided the effects of peat oxidation are separated from those of compaction and shrinkage of the peat. Subsidence measurements have the additional advantage that they account for lateral export of particulate and dissolved organic matter into rivers and canals, a component that is not included in CO_2 emissions measurements.

~~A much larger network of long-term subsidence measurements will be required to improve regional estimates and links to CO_2 emissions. New relationships need to be explored to best characterize the water table regimes; recent unpublished findings suggest that a relation between minimum water depth (e.g. the 25 percentile) and peat decomposition rate could be more appropriate.~~

Our assessment is based on a linear relationship between water table depth and CO_2 emissions, fitted through data points derived from 6 different studies (Fig. 4). This needs further refinement as more field data, particularly under different land uses and at different times since the start of drainage, become available. The linear relationship is considered the best estimate currently available for determining CO_2 emissions at water table depths between 0.5 and 1 m, which covers the range of the most common groundwater depths in the study region. As additional information is incorporated it may be that the relationship proves to be curved. If this is the case it will make little difference to estimates of CO_2 emissions at water tables down to one metre below the surface.

~~CH_4) *emissions* from both undrained and drained peatlands are found to be modest in~~

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~~comparison with CO_2 (Jauhiainen et al., 2005, 2008; Rieley et al., 2008), but may still be significant from a climate perspective given that CH_4 is a much stronger greenhouse gas (23 times stronger in "CO_2 equivalents"). New continued CH_4 flux measurements over multiple years will confirm to what extent this gas plays a significant role in the net ghg balance of peatlands. Likewise, very limited information on nitrous oxides (N_2O) emissions in peatlands requires new continued measurements, particularly in agricultural areas with nitrogen inputs.~~

REFERENCES

7209, l.4: There is no Wosten et al 2006b

7218, l.4: Silvius and Taufik, 1990 in text – 1992 in refs.

7220, l.3: Jauhiainen et al, 2008 is not in refs.

7223, l.18: Wibisono 2006 is not in text.

FIGURES

Figure 1: Consider if this figure is necessary. It does not show that natural tropical peatland is forested. Caption is misleading. "Schematic representation of a 'dome' in tropical peatland and how drainage causes subsidence, leading to increased CO_2 emissions.

Figure 2: This figure is of poor quality and does not cover the whole of Southeast Asia. The location of deforested peatland is virtually impossible to identify. The relevance of the statement on FAO soil types that are not included is unclear.

Figure 3: Caption is confusing; better to state "Past land use change in tropical peatlands of Southeast Asia and future projections (total and for each of the three deforested drainage classes). (Mention this figure is from Hooijer at al, 2006)

Figure 4: Modify caption: "Linear relation between peat water table depth and CO_2 emission.......Measurements in forest and abandoned, degraded peatlands.......not representative of drained areas...." (Mention this figure is from Hooijer at al, 2006)

Figure 5: (Mention this figure is from Hooijer at al, 2006)

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Comment [r4]: This paper focuses on CO_2 emissions so it seems pointless to include reference to CH_4 and N_2O

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TABLES

Table 1: Caption is not very informative of what this table contains. Better might be “Area, water table depth and CO_2 emissions in drainage classes on tropical peatland in Southeast Asia in 2000 (is this correct?). It is not clear how the numbers in this table for 1 and 2 are obtained. Should there be an additional row under 3 for Total CO_2 emissions?

Table 2: Caption should be revised – “Lowland tropical peatland area, drainage classes and rate of deforestation (1985-2000)”. The table is confusing, e.g. (a) It is not land uses that are represented but cover types grouped into drainage classes (see text!). There should be a box above shrubland, cropland etc that says ‘drainage classes’; (b) I presume that the numbers (6, 8, 2, 9 etc are GLC land cover types, but this is not made clear. There needs to be more detailed explanation of how the data in the body of this table were obtained. The totals do not always equal the sum of their parts! Is this to do with rounding? Also need to make it clear that peatland area in Indonesia is derived from Wetlands International (2003,2004) sources while that for other countries is from DSM (2004).