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Global estimates of C stock changes in living forest biomass: EDGARv4.3 – 5FL1 time series from 1990 to 2010

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Abstract

While the Emissions Database for Global Atmospheric Research (EDGAR) focuses on global estimates for the full set of anthropogenic activities, the Land-Use, Land-Use Change and Forestry (LULUCF) sector might be the most diverse and most challenging to cover consistently for all world countries. Parties to UNFCCC are required to provide periodic estimates of GHG emissions, following the latest approved methodological guidance by the International Panel on Climate Change (IPCC). The aim of the current study is comparing the IPCC GPG 2003 and the IPCC AFOLU 2006 by calculating the C stock changes in living forest biomass, and then using computed results to extend the EDGAR database. For this purpose, we applied the IPCC Tier 1 method at global level, i.e. using spatially coarse activity data (i.e. area, obtained combining two different global forest maps: the Global Land Cover map and the eco-zones subdivision of the GEZ Ecological Zone map) in combination with the IPCC default C stocks and C stock change factors. Results for the C stock changes were calculated separately for Gains, Harvest, Net Deforestation and Fires (GFED3), for the years 1990, 2000, 2005 and 2010. At the global level, results obtained with the two set of IPCC guidance differed by about 40 %, due to different assumptions and default factors. The IPCC Tier 1 method unavoidably introduced high uncertainties due to the "globalization" of parameters. When the results using IPCC AFOLU 2006 for Annex I countries are compared to other international datasets (UNFCCC, FAO) or scientific publications, it emerges a significant overestimation of the sink. For developing countries, we conclude that C stock change in forest remaining forest can hardly be estimated with Tier 1 method. Overall, confronting the IPCC 2003 and 2006 methodologies we conclude that IPCC 2006 suits best the needs of EDGAR and provide a consistent global picture of C stock changes in living forest biomass independent of country estimates.

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1 Introduction

Large uncertainties exist on the magnitude of the global effect of forests on atmospheric CO_2 concentration. For the 90s, IPCC (2007) indicates a global terrestrial net sink of $-1.0 + 0.6\,\mathrm{Gt\,C\,yr^{-1}}$, comprising a net source of $+1.6$ ($+0.5$ to $+2.7$) $\mathrm{Gt\,C\,yr^{-1}}$ from land use changes and a residual terrestrial sink of -2.6 (-4.3 to -0.9) $\mathrm{Gt\,C\,yr^{-1}}$. Most of these fluxes can be attributed to forests. More recently, Pan et al. (2011) estimated a net global forest sink of $-1.1 \pm 0.8\,\mathrm{Gt\,C\,yr^{-1}}$ for the period 1990–2007, comprising a source of $+2.9 \pm 0.5\,\mathrm{Gt\,C\,yr^{-1}}$ from gross deforestation and a sink of $-4.0 \pm 0.7\,\mathrm{Gt\,C\,yr^{-1}}$ from established forests and from the regrowth of forests after past deforestation and logging. The large uncertainty on these numbers is among the reasons of the partial inclusion of the emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF) sector in the commitments by industrialized countries (Annex I) under the Kyoto Protocol (KP). The recent developments in UNFCCC negotiations with regard to both LULUCF and a mechanism for reducing emissions from deforestation and forest degradation (REDD) in developing countries (Non-Annex I countries) will certainly increase the attention on the need to estimate C stock changes from forests (sinks/sources) in a consistent way for all countries.

An accurate estimation of these emissions can help in better understanding the impacts on future climate change and the potential of different mitigation options (Lu et al., 2002). Remotely sensed data of high spatial resolution are possibly most suitable to estimate the biomass spread over large areas, but remain scarce. Due to increasing greenhouse gases (GHG) in the atmosphere it is essential to know and monitor changes in the amount of forest land (Iverson et al., 1994). Several studies focused mainly on C losses from deforestation, land use conversions and forest fires (Hughton et al., 2002, 2010; van der Werf, 2009) while others aim on the effect of socio-political changes on land use pattern in Eastern Europe (Olofsson et al., 2009). As a result of combining different sources and information on forestry and land use change, during the last years several vegetation/ecological maps were created (GLC

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2000, GlobCover 300 m, FAO Global Ecological Zones, USGS-GLCC, GLCNMO, GlobCover 2009). Even before the UNFCCC and KP came into force, other legally binding mechanisms such as the Ramsar Convention, UN Convention for Biological Diversity and the International Tropical Timber Agreement fostered supranational collaboration between countries aiming at collectively protecting forests, fighting deforestation and illegal-logging and monitoring the GHG levels. Associated to these processes there are online databases like IPCC database and AFOLU GHG where biomass expansion factors (BEFs) and other parameters can be found.

Parties to UNFCCC are required to provide periodic estimates of GHG emissions, following the latest approved methodological guidance by the International Panel on IPCC. While Annex I countries report on a yearly basis their GHG emissions from LULUCF, the current rules foresee only a periodic reporting by Non-Annex I countries. For the first commitment period of the KP (2008–2012), Annex I countries follow the IPCC GPG 2003. With the recent approval by UNFCCC of the IPCC AFOLU 2006 guidelines, the use of IPCC AFOLU 2006 will become the standard for Annex I countries after 2012, and it will likely become a relevant source of information to be used by Non-Annex I countries. The overall approach provided by the IPCC to estimate C stock changes in a given C pool is essentially the same in the GPG 2003 and in the AFOLU 2006, i.e. estimates can be obtained either through the "gain-loss" method (i.e. sum of all gains and losses) or the "stock-difference" method (i.e. difference between C stocks at two points in time); a system of three tiers of increasing methodological complexity is also provided. However, some difference exists between the IPCC GPG 2003 and in the AFOLU 2006, e.g. the latter contains some updated value and/or improved assumption in the default Tier 1 method. Therefore, it is of great importance to know what is the potential impact of using either GPG 2003 or AFOLU 2006 on the estimates of C stock changes.

The aim of the current study is comparing the IPCC GPG 2003 and the IPCC AFOLU 2006 by calculating the C stock changes in living forest biomass, and then using computed results to extend the EDGAR database. For this purpose, we applied the IPCC

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Tier 1 method at global level, i.e. using spatially coarse activity data (i.e. area, obtained from combining two different global forest maps) in combination with the IPCC default emission/removal factors (i.e. C stock change per unit of area). The resulting database of C stock changes in living forest biomass, representing the main source of emissions and removals from the land use sector at global level, will be included in EDGAR database version 4.3. The forthcoming EDGAR v4.3 is an extension of the bottom-up inventory EDGAR v4.2 (EC-JRC/PBL, 2011) with a completion for the human-made biogenic GHGs, CO and BC trends from 1970–2008 for all world countries, derived with the same technology-based methodology and following IPCC and EMEP/EEA international standard values and references. The database is unique because of its global coverage (geospatial, sectorial and chemical) and its consistency, with minimized biases between countries and sectors and constraint by global closure. While the use of the Tier 1 method for estimating C stock changes in living forest biomass certainly introduces larger uncertainties than higher tiers, the added value of the paper is the global consistency of the resulting estimates and the highlight of the differences in results when using Tier 1 method and the IPCC GPG 2003 or IPCC AFOLU 2006.

2 Material and methods

Estimates of net C stock changes in living forest biomass frequently suffer in accuracy. For Forest Land remaining Forest Land the challenge is given by the the large bidirectional fluxes of CO_2 from/to the atmosphere, i.e. the net change is often a small difference between two much larger numbers. For land use changes from/to forests, the main challenge is estimating accurately the area affected and its average C stock. In line with EDGAR's approach of estimating bottom-up with international statistics and published parameters for each world country, this study computed the C stock changes in living forest biomass following the Tier 1 method. For this purpose, for each country the gain-loss method was used for forest remaining forest, using the IPCC default values for the gains (i.e. forest growth, as provided in the GPG methodology (IPCC, 2003)

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and in the AFOLU guidelines (IPCC, 2006)) and by using their mean default values and data from FAOSTAT for harvest (ForesSTAT) and fire emissions from the Global Fires Emission Database GFED3 (van der Werf, 2010). Consistent global country-specific estimates of C stock changes for Land Use, Land-Use Change and Forestry (LULUCF) sector were obtained separately for Gains, Harvest, Fires and Net Deforestation for the years 1990, 2000, 2005 and 2010. In this study the activity data (forest land area) was estimated for all the countries and climatic regions using a combination of satellite maps of land use cover and vegetation type (see Sect. 2.1). Year 2000 was used as starting point and changes in forest area from 2000 to 1990 backwards in time and from 2000 to 2010 forward in time were calculated based on the share of forest area change reported by FRA 2010.

2.1 Dataset structure

The dataset consists of four different C stock change categories: Gains (G), Harvest (H), Fires (F) and Net Deforestation (net D). All of them were calculated (except fires) following the IPCC GPG 2003 and IPCC AFOLU 2006 guidelines. The Gains are presented with a negative sign as they correspond to a sink. A comparison between results was performed in order to detect the best available methodology for EDGAR's purpose. For the definition of the subcategories, we follow as much as possible the IPCC guidelines but noticed slight methodological differences between IPCC 2006 and IPCC 2003 (see Tables S1 and S2 in Supplement). By *Gains* we mean gross annual increase in biomass C stocks (i.e. forest growth), by *Harvest* annual C losses due to harvest, by *Fires* losses due to forest fires and by *Net Deforestation* annual losses in C due to deforestation calculated with the stock change method.

For a better understanding of our results and the assumptions we made, we are using the diagrams (Fig. 1a, b) to illustrate the differences between Annex I and Non-Annex I parties and to show why we kept the split of four categories and why we avoided their combination towards net global totals. Figure 1a, b shows the assumptions made in calculating the C stock changes in Annex I and Non-Annex I parties. We assume that

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for Annex I countries (Fig. 1a) the four categories do not overlap, i.e. the losses due to harvest or fire are quite well separated from the losses due to deforestation. Therefore, the total net emissions can be calculated as a sum between gains, harvest, fires and deforestation because of the very low probability of omitting or double-counting. Contrary to this, Fig. 1b shows different ways in which changes can be affected depending how the balance is done. It is risky to perform a net total as we do not know if harvest, fires or deforestation overlay with each other (e.g. if fires occurred in a deforested area or in a harvested area or in both).

2.2 Available international statistics

GLC 2000 map

The Global Land Cover (GLC) map was developed by the European Commission Joint Research Centre's Global Environment Monitoring Unit in collaboration with worldwide partners (GLC, 2000). It provides a harmonized classification of the land cover at 0.5° × 0.5° resolution comprising 23 classes (GLC, 2000, European Commission, Joint Research Centre, 2003).Only the first 6 classes were used to compute the forest area for each country as they define tree cover under forest definition (see Supplement, Table S1).

FAO Ecological zone (GEZ) map

This map was developed by Food and Agriculture Organization of the United Nations (FAO) to meet the requirements of Forest Resource Assessment (FRA, 2000) reporting process. FAO's Global Ecological Zone (GEZ) classification relies on a combination of climate and potential vegetation. It was first developed by Zhu (1997) and Preto (1998). For the choice of climatic parameters to be used in the FRA 2000 map a number of global zones/areas were surveyed including Köppen modified by Trewartha (Köppen, 1931; Trewartha, 1968), Thorntwaite (1933) and Holdridge (1947) (FRA, 2000). Ta-

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ble S1 provides an overview of vegetation classes as defined by GEZ map which were currently used to calculate the forest area.

ForesSTAT

FAO through its database FAOSTAT provides time series of data related to food and agriculture for some 200 countries. ForesSTAT is part of FAOSTAT and contains data and detailed information for the forestry sector. The forest product statistics on harvest were used to compute the C stocks changes (losses) for the years 1990, 2000, 2005 and 2010 (FAOSTAT-FAO, 2011).

GFED3

The C losses from forest fires are based on GFED3 data (van der Werf, 2010). This fires dataset consists of a modelling framework that utilises satellite data on vegetation characteristics and productivity to estimate fuel loads combined with satellite derived burned area to estimate fire emissions (GFED3, 2011). It consists of 0.5° × 0.5° gridded monthly fire emissions from 1997 to 2010.

2.3 Applied methodologies

IPCC 2003 – GPG LULUCF

The Good practice Guidance for Land Use, Land Use Change and Forestry (GPG-LULUCF) is a report of IPCC requested by the UNFCCC to provide countries a supplementary methodology and guidance for measuring, monitoring, estimating and reporting on C stock changes and GHG emissions from LULUCF activities (IPCC, 2003). Its main aim is to assist countries in producing national GHG inventories for the LULUCF sector and presents the choices in GHG estimation methodology for all C pools and GHG sources. Current study uses the methodology described by Chap. 3, Sect. 3.2 point 3.2.1 and complemented by the Annex 3A.1 Biomass default values for Forest

Land. The GPG provides sufficient information and data to allow a Tier 1 estimate of various emissions at the country-scale. The step by step methodology is presented in Supplement – Table S1 where the changes and variations from original formulas are explained.

IPCC 2006 – AFOLU

The Agriculture, Forestry and Other Land Use (AFOLU) sector provides in its Chap. 4 – Forest Land, guidance for preparing annual greenhouse gas inventories for the Forestry sector. It builds on the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (*1996 IPCC Guidelines*) and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (*GPG-LULUCF*). This approach is intended to improve consistency and completeness in the estimation and reporting of greenhouse gas emissions and removals (IPCC, 2006). Current study uses the methodology described by Sect. 4.2 complemented by the tables in Sect. 4.5 which provides methods for estimating the C changes, sources and sinks of greenhouse gasses for Forest Land remaining Forest Land. The step by step methodology is presented in Supplement – Table S2 where the changes and variations from original formulas are explained.

3 Results

We compare the results for C stock changes calculated with both IPCC 2003 and 2006 methodologies after we first present our results in a global perspective and compare it with the global available datasets: FRA 2010, UNFCCC and Pan et al. (2011) (Table 1).

For IPCC 2003 and IPCC 2006 the deforestation values represent the net deforestation while Pan et al. (2011) calculated the gross deforestation for the tropical regions and included into Gains the deforestation for boreal and temperate regions. FRA 2010 values represent the net C changes therefore a split between the three remaining categories is impossible.

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Figure 2 shows the Gains in $Mt C yr^{-1}$ for all world major regions as a comparison between IPCC 2003 and 2006.

Figure 3 presents the C stock losses from Harvest in $Mt C yr^{-1}$ for all world major regions as a comparison between IPCC 2003 and 2006.

To highlight major differences between allocation of different parameters in the two calculations (above ground biomass growth and BCEF, see Supplement, Tabels S3 and S4, respectively), Table 2 presents the different stratification of eco-zones and vegetation (i.e. forest) types used by the two guidelines. We should notice that 1) the climatic zone "subtropical" from IPCC 2006, which is in particular of high occurrence in Non-Annex I countries, was not present in IPCC 2003 and 2) IPCC 2006 has more vegetation types addressed separately.

Figure 4 presents the C stock losses from Net Deforestation in $Mt C yr^{-1}$ for all world major regions as a comparison between IPCC 2003 and 2006.

In Fig. 5 we plotted the results for *Gains* in tons CO_2 which will be included into the EDGAR v4.3 database representing the absolute difference between CO_2 stock change in 2000 and 2010 having as proxy the distribution of the trees computed after GLC 2000 map classes 1–6 (Supplement, Table S1). Positive values represent a higher CO_2 removal in 2000 compared to 2010 while negative values show an increase in CO_2 removal in 2010 compared to 2000.

4 Discussion

As shown in Sect. 3 (Figs. 2, 3, 4), there is a systematic overestimation of IPCC 2003 calculations in comparison to IPCC 2006 and overall the differences can be critical for the majority of world regions.

Method for area estimation in current work implements a definition which is not likely consistent with countries' definitions applied in GHG inventories or in FAO reports, but shows the results under hypothetically harmonized forest definition across borders. Our method practically assesses the "net of forest area under land cover definition" in the year 2000, contrary to, i.e. national GHG inventory of Annex I countries or FRA 2010, where "forest land" is generally included for all land under forestry use (thus including areas with temporarily loss of forest cover). To these differences, 20 % uncertainty is added (i.e. GLC 2000 map compared with MODIS- harmonizing the legend, Fritz and See, 2005). Moreover, MODIS has 75–80 % global accuracy (Hodges, 2002) and in addition the forest average certainty reported by Fritz and See (2008) is 0.557 (55 %) and adds an uncertainty of 45 %.

Due to the different availability and type of data at national level, countries show freely varying implementations of the agreed guidelines. As original data and time series were originally designed for forestry, the appropriateness for a national GHG inventory could be rather limited. Further on, suitability of historic data for emission reduction compliance purpose is also questionable (and as such the ability to establish accurate historical base inventory, like 1990 one). Consistency among international reporting frames is requested for GHG inventories with the words "each Party shall justify in its reporting that such values are consistent with the information that has historically been reported to the Food and Agriculture Organization of the United Nations or other international bodies, and if they differ, explain why and how such values were chosen" (so called Marrakesh Accords, UNFCCC, 2001). Difference on the land data availability is fully reflected in the UNFCCC reporting obligation by full land reporting in Annex I parties and partial reporting of Land-Use Change and Forestry related removal or sources in Non-Annex I parties. Under these circumstances, the reporting between Annex I and Non-Annex I countries are difficult to compare in practice (see Fig. 1).

While assessing the global estimates based on default values from the two IPCC guidelines (assuming same activity data), the comparison of these results with other available global data sources and estimates is difficult, sometime nonsensical. Major differences derive from inconsistent definitions of forest/forestland and parameters collected under various underlying methodologies involved. Regarding FRA 2010 we notice that the estimates account only for net changes and a split between gains and losses is not possible to be made. Under the assumption of complementary between

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the categories we could give a global estimate of all net C changes "gain-loss" from our IPCC 2006 results but only for Annex I, mounting to a net average global C change of −0.80 Gt C (1990–2010) representing app. factor two difference with FRA2010 estimate of −0.27 Gt C, 0.41 Gt C yr^{-1} of Pan et al. (2011) and 0.35 Gt C yr^{-1} for UNFCCC 2011. We also see that our IPCC 2006 average estimate of total global C gain (living biomass) for the four years is −1.9 Gt C while Pan et al. (2011) reports an averaged gain from biomass of −2.9 ± 0.5 Gt C (1990–2007). The main difference is the inclusion of C losses from deforestation into gain calculations of boreal and temperate forest by Pan et al. (2011) whereas current study does neither account C gained from forest regrowth nor C lost from disturbances (i.e. diseases). Regarding deforestation Pan et al. (2011) estimates a gross budget from tropical regions which includes the gain from regrowth of forests because the C uptake by tropical regrowth forests is implicitly included in commonly estimated *net* emissions of tropical land-use changes rather than to estimate it independently as a sink. Our average estimate for net deforestation of 0.6 Gt C (1990–2010) fits well within the range of these publications (Table 1).

4.1 Breakdown and analysis for critical issues in comparing IPCC 2003 and IPCC 2006 estimates

C gains in living forest biomass

The quality of proxies for C stock change estimations is mainly affected by outdated data assumed to be valid for the year 2000 (IPCC, 2003), which is the data used for present estimation. In the GPG LULUCF 2003, 28 % of data comes from forest inventory (apparently 60 % of the countries in Africa have integral or partial forest inventories). For the rest of the countries the specific source is not mentioned, but for Annex I countries obviously originate from their forest inventories. IPCC default data is given as "mean value and as the range of possible values", which may be heavily biased by limited references especially poor for Non-Annex I countries. IPCC provides breakdown values on each biomass component. Furthermore, assumptions behind estimation with

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IPCC default values are crucial as controversial results may occur, like when modelling Canadian forest for a certain period, the results ranged from sink to source by either including or not the natural disturbances (Greenough et al., 1997).

Available default parameters in the IPCC Annex 3.A.1 tables of GPG LULUCF recommended to be used by countries when applying EDGAR/Tier 1 were used in this comparison. The aim of this study was to apply these parameters and analyse the differences with IPCC 2006 AFOLU. Key to the major difference between the two methodologies was the inclusion in 2003 of R (root to shoot parameter) which is the ratio of below-ground to above-ground biomass. IPCC 2003 included this parameter into its calculation of annual increment in biomass (Supplement, Eq. 1) while IPCC 2006 assumes no changes in below ground biomass allocation pattern and is set for Tier 1 to zero. This counts for 30 % difference (uncertainty) in total *Gains* between the two approaches (Fig. 3). Regarding this matter we notice that IPCC 2006 is consistent in using R (applied to harvest losses too, Supplement, Eq. 10) while IPCC 2003 is using it for the Gains but not for Harvest losses. Another minor difference is the use of carbon fraction (CF) which in 2003 is set to 0.5 while in 2006 is 0.47.

The main regions which contribute to the total increase in C stock are Europe including Russia and North America. Despite C stock change factor values are expected similar for all geographical regions under similar ecological conditions, the differences among countries are generated by the country-specific forestry practices (i.e. intensity of the management, harvest size, harvest structure on species, disturbances). Major impact on the forest growth is also given by the age structure of the forests and artificial or natural origins of forest growth (with plantations showing much higher growth rates). Especially for Non-Annex I countries, the definitions of "increment" are generally not very transparent which may create artefacts in building default values or estimates. This may be because of unclear inclusion of post-disturbances effects or parameter reported (i.e. current vs. average or principal vs. total forest stand increment/stock).

C losses in living forest biomass – harvest

Wood harvest remains one of the most uncertain statistics at global level, which obviously affects any attempt to estimate GHG from it. For example, in majority of Annex I countries, i.e. EU/EFTA group, the amount of wood resulted from unregistered cuttings contributed 16 % of the overall forest related wood consumption between 1987 and 2005 (Mantau, 2007).

From Fig. 4 we notice that the differences between C stock losses due to harvest are minor. The input harvest data was taken from the ForesSTAT (FAO, 2011) statistics and is the same for the two approaches. Both computation methodologies use similar methods (Supplement, Eqs. 4 and 12). There is nevertheless a difference (∼ 9 %) which is likely due to the use of wood density (D) which in IPCC 2003 is set as an independent value (see Supplement, Table S2) whether in IPCC 2006 is included into the BCEF (biomass conversion and expansion factor). Regarding the BCEF factor another very important difference was found to be its allocation to major climatic zones and forest types and the fact that it is dependent on the growing stock (see AFOLU, Vol. 4, Table 4.5). The growing stock was taken from the FRA 2010 country reports, estimated for the year 2005 (FAO, 2010). The stratification of IPCC 2003 is poor compared to IPCC 2006 where more vegetation types have been introduced decreasing in this way the uncertainty of using and allocating the parameters according to its climate related zones and vegetation type (Table 2).

The major regions which show an abrupt decrease in C stock because of the Harvest are South and Southeast Asia, Africa and South America. Another small difference in calculations is caused by the percentage applied for conversion of FAO statistical roundwood without bark into merchantable wood removals including the bark. In calculation based on GPG 2003 we applied 12 %, while for AFOLU 2006 15 % (IPCC, 2006). It is easy to notice that the regions with intensive harvest have also the smallest increase in biomass growth (Fig. 3), while net deforestation adds up and plays an important role in the C losses (see Fig. 5).

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C losses in living forest biomass – net deforestation

The changes from net Deforestation were calculated based on the stock change method. The difference between forest areas in 1990–2000, 2000–2005 and 2005–2010 respectively divided by the number of years and multiplied with the above ground biomass allowed us to account with high assumptions for net losses from deforestation. The uncertainty around this approach is that a constant forest area does not guarantee that there is no deforestation, as this may have been compensated by an equal afforestation. That makes simple statistics of forest or forestland area to include suitable parameters from resource assessment point of view, but insufficient for a national GHG inventory.

Presuming that the changes in area are correct (we used same changes reported in FRA 2010 with respect to 2000 – the base year for GLC map) and assuming that the information from the maps used for 2000 apply also for the other years, we notice (Fig. 4) that the most affected regions by deforestation over the whole period are South America and Africa while South and South East Asia losses decreased in 2005–2010 with respect to 1990–2000. According to Friedlingstein et al. (2010), steadily increasing temperate forest regrowth in Eurasia is observed since 2000 in these latitudes. A recent decrease in land use change emissions is consistent with the reported downward trends of deforestation detected from satellite data in the Brazilian Amazon (Regalado, 2010) and Indonesia (Hansen, 2009).

It should be noted that our approach is not a dynamic estimate accounting for long term effects of fires and post-burn effects on the C gain/loss from year to year. Diseases are also not included into losses, assuming they also have a local and isolated effect. To this adds the assumption that, for forestland where forest cover is permanent, change in other C pools is rather insignificant on medium–long term on large scale. Smaller differences are noticed due to a similar classification of eco-zones and forest types for the above ground biomass stock which is used in calculating the net deforestation (see

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Supplement, Table S3.). The difference in using the above ground biomass stocks as global average adds up to 27 % between the two IPCC methods.

5 Conclusions

The aim of the current study was comparing the IPCC GPG 2003 and the IPCC AFOLU 2006 by calculating the C stock changes in living forest biomass with Tier 1 method for the main world regions, and then using computed results to extend the EDGAR database. At global level, the estimates obtained with the two set of guidance differed by about 40 %, mainly due to different ways to include roots in calculation and partly due to differences in default factors (i.e. BEF, wood density, above ground biomass) and ecological zones. We conclude that IPCC 2006 suits best the needs of EDGAR. It treats roots in a more consistent way, includes more updated default values, and a more detailed disaggregation of the ecological zones. Our results illustrate the applicability of IPCC guidelines at a lower Tier together with its shortcomings, including:

- The IPCC default values introduce high uncertainties due to the "globalization" of parameters. When the results using IPCC AFOLU 2006 for Annex I countries are compared to other international datasets (UNFCCC, FAO) or scientific publications, it emerges a significant overestimation of the sink. This is likely to be mainly due to the high default values for "gain" component (i.e. forest growth) and to the fact that we work with both unmanaged/managed forest area.

- For developing countries, our approach unavoidably led to an overlap of emissions estimated with gain-loss method (for forest remaining forest) and with the stock change method (for net changes of forest areas). A consequence of this is that the emissions from forest degradation in developing countries can hardly be estimated with Tier 1 method, because harvest data of these countries usually does not separate harvest of forest remaining forest from the harvest of deforestation. In the context of the future mechanism to reduce emission from deforestation and

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forest degradation (REDD), alternative ways to estimate emissions from degradation should be foreseen for those countries not capable of implementing higher tiers.

Overall, our work: (i) highlights that the use of different IPCC guidance leads to different results, and (ii) provide a consistent global picture of C stock changes from living forest biomass independent of country estimates, which will be integrated in the forthcoming EDGARv4.3 – 5FL1 time series 1990–2010.

Supplementary material related to this article is available online at: http://www.biogeosciences-discuss.net/9/3767/2012/ bgd-9-3767-2012-supplement.pdf.

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Table 1. Global estimates of C stock changes in Gt C yr^{-1} calculated with AFOLU Tier 1 and compared with other global available estimates. AFOLU 2006 calculates net deforestation. UNFCCC and FRA 2010 report only net C stock changes. G: Gains, H: Harvest, F: Fires and net D: Net Deforestation.

Region	Source	Category	1990	2000	2005	2010
Annex I	Edgar Tier 1 (AFOLU)	G	−1.57	−1.59	−1.59	−1.60
		H	0.67	0.64	0.68	0.60
		F	0.08	0.14	0.11	0.16
		net D	0	0	0.02	0.05
		total	**−0.82**	**−0.81**	**−0.79**	**−0.79**
	FRA 2010	**total**	**−0.23**	**−0.24**	**−0.29**	**−0.32**
	UNFCCC 2011 (managed forests)	**total**	**−0.34**	**−0.34**	**−0.33**	**−0.40**
	Pan*	**total**	**−0.39****		**−0.44*****	
Non-Annex 1	Edgar Tier 1 (AFOLU)	G	−2.37	−2.28	−2.24	−2.21
		H	2.38	2.72	2.84	2.90
		F	0.23	0.11	0.13	0.12
		net D	1.3	1.3	1.24	1.17

* Calculated from Table 2, Pan et al. (2011).
** Estimates for 1990–1999.
*** 2000–2007.

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Table 2. Differences in climatic zones and vegetation types between IPCC 2006 and IPCC 2003.

IPCC 2006		IPCC 2003	
Climatic zone	Vegetation type	Climatic zone	Vegetation type
TROPICAL	TROPICAL RAIN TROPICAL MOIST DECIDUOUS TROPICAL DRY FOREST TROPICAL SHRUBLAND TROPICAL MOUNTAIN SYSTEMS	TROPICAL	WET MOIST WITH SHORT OR LONG DRY SEASON DRY MONTANE MOIST OR MONTANE DRY
SUBTROPICAL	SUBTROPICAL HUMID FOREST SUBTROPICAL DRY FOREST SUBTROPICAL STEPPE SUBTROPICAL MOUNTAIN SYSTEMS	TROPICAL*	MOIST WITH SHORT OR LONG DRY SEASON TROPICAL DRY TROPICAL MONTANE MOIST OR MONTANE DRY
TEMPERATE	TEMPERATE OCEANIC FOREST TEMPERATE CONTINENTAL FOREST TEMPERATE MOUNTAIN SYSTEMS	TEMPERATE	CONIFEROUS BROADLEAF MIXED BROADLEAF-CONIFEROUS
BOREAL	BOREAL CONIFERUS FOREST BOREAL TUNDRA WOODLAND BOREAL MOUNTAIN SYSTEMS	BOREAL	CONIFEROUS FOREST – TUNDRA MIXED BROADLEAF-CONIFEROUS

* No Subtropical in IPCC 2003.

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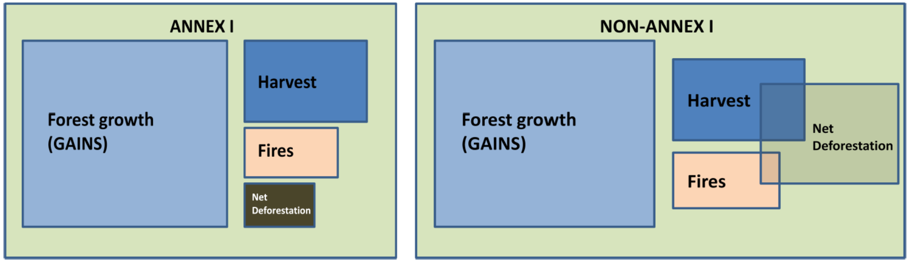

Fig. 1. Representation of assumptions made in the calculation the C stock changes for **(a)** Annex I and **(b)** Non-Annex I countries, parties to UNFCCC, when taking into account the gains and losses.

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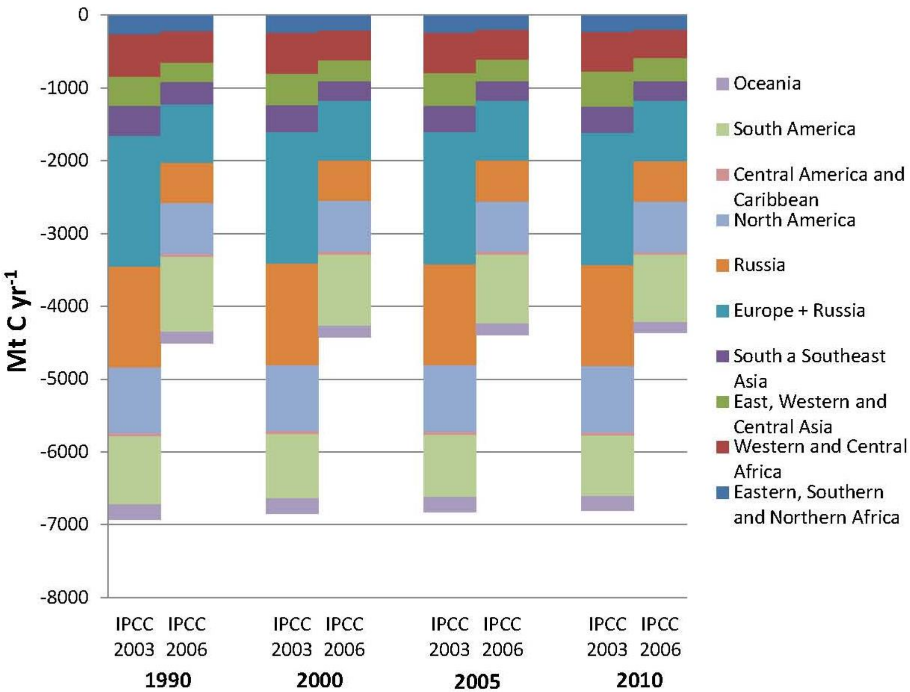

Fig. 2. Comparison of C stock Gains in Mt C yr^{-1} between IPCC 2003 and IPCC 2006 for major world regions.

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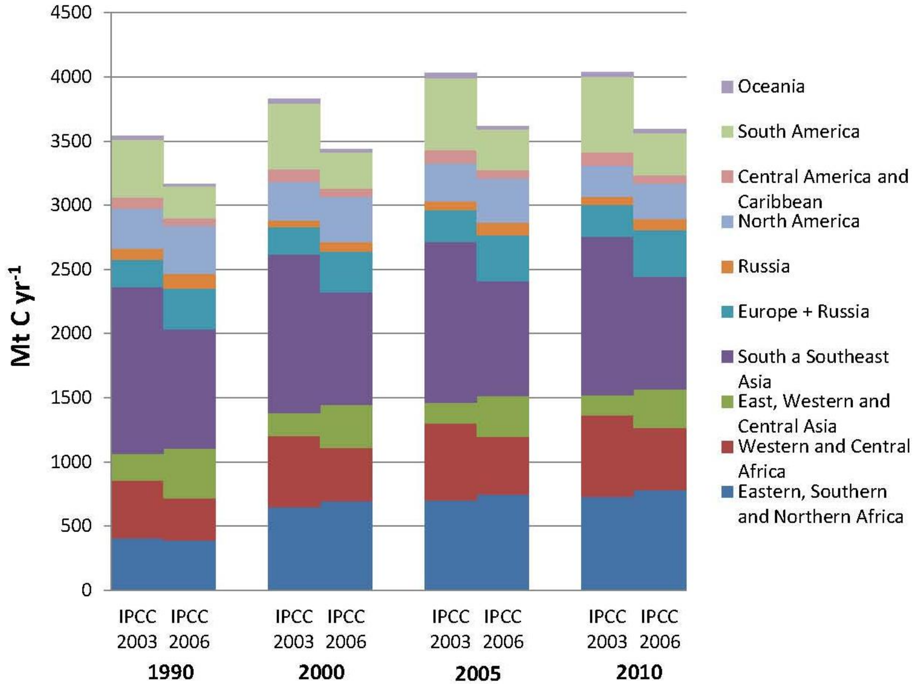

Fig. 3. Comparison of C stock losses – Harvest in $Mt\,C\,yr^{-1}$ between IPCC 2003 and IPCC 2006 for major world regions.

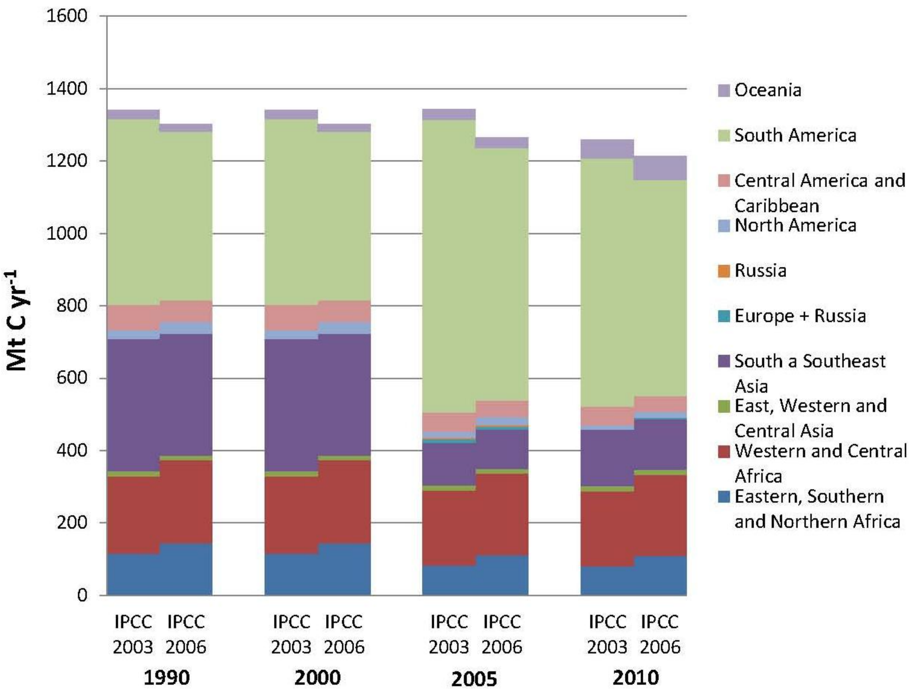

Fig. 4. Comparison of C stock losses – net Deforestation in Mt C yr^{-1} between IPCC 2003 and IPCC 2006 for major world regions.

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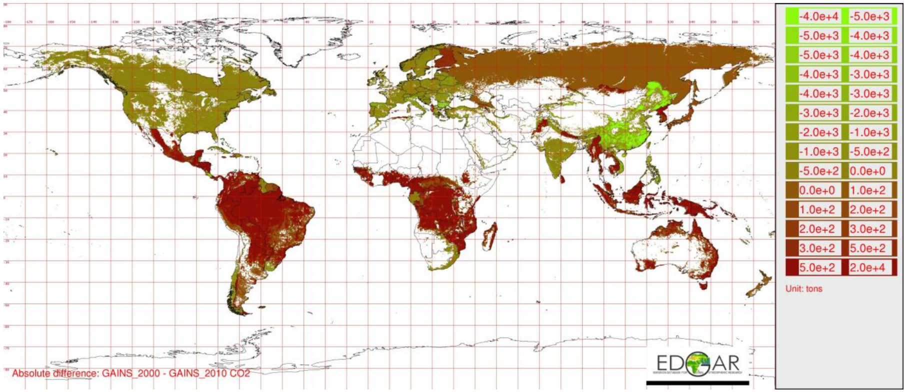

Fig. 5. Example of EDGAR grid map (0.1° × 0.1°) for GAINS in tons CO_2 representing the absolute difference between 2000 and 2010 where positive values represent a higher CO_2 removal in 2000 compared to 2010 and negative values show an increase in CO_2 removal for 2010 compared to 2000.

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