Responses to Referee #2

The Referee's suggestions were thoughtful and constructive, and the revised manuscript is much improved as a result. Specific responses are detailed below.

Comment #1) *The paper reads more like a book chapter. The overall structure is not so stringent and I had a bit of trouble following. Some sections (i.e. section 2) tend to be rather lengthy. Some are focused more on review and some more on actual synthesis. Maybe there should be one section on review (of data and approaches and estimates), one on the presentation of "open questions and missing issues" as done Sections 4-7, and one on synthesis and new/integrated analysis that actually generates new knowledge (i.e. as done in parts of section 1 and section 8 and should show how the authors got to the new data currently presented in the abstract). This could make it easier for the reader to follow.*

Response: We have reorganized the paper in accordance with this comment. We have a new paragraph early in section 1 that describes the new organization:

This review is organized into three parts. The first part (sections 1.1 – 1.4) starts with definitions and then provides a synthesis of recent estimates of emissions from LULCC, including an evaluation of their collective uncertainty. The second part (sections 2-6) then reviews the data and models used to estimate these emissions. The review considers uncertainties in the data and in the processes and activities contributing to LULCC. Thus, the first part provides the context for the review, and the second part supplies the details. The third part (section 7) is a brief concluding section that integrates the uncertainties and open questions into priorities for the next steps in constraining estimated emissions from LULCC.

Comment #2) *Page 837, line 5-15 – needs references and the land/missing sink needs to be explained a bit more comprehensively because currently it appears like a loose statement.*

Response: We have added references and elaborated the discussion of the terrestrial sink as follows:

The flux of carbon from LULCC does not represent the net flux of carbon between land and atmosphere. Unmanaged terrestrial ecosystems also contribute to changes in the land-atmosphere net flux (Phillips et al., 2008; Lewis et al., 2009; Pan et al., 2011). There are large annual exchanges of CO_2 between ecosystems (plants and soils) and the atmosphere due to natural processes (photosynthesis, respiration) with substantial interannual variability related to climate variability. The land is currently a net sink despite LULCC emissions (Canadell et al., 2007; Le Quéré et al., 2009). This net sink is likely attributable to a combination of LULCC (e.g., forests growing on abandoned croplands) and the affects of environmental changes on plant growth, such as the fertilizing effects of rising concentrations of CO_2 in the atmosphere and nitrogen (N) deposition, and changes in climate, such as longer growing seasons in northern extra-tropical regions. These environmental drivers affect both managed and unmanaged lands

and make attribution of carbon fluxes to LULCC difficult. LULCC, in theory, includes only those fluxes of carbon attributable to direct human activity and excludes those fluxes attributable to natural or indirect human effects. In practice, however, attribution is difficult, in part because of the interactions between direct and indirect effects. It is difficult to establish how much of the carbon accumulating in a planted forest, for example, can be attributed to management, as opposed to increasing concentrations of CO_2 in the atmosphere.

Comment #3) *Page 839, line 8 – this is a strong statement. Does it mean it will never be possible? Are the authors suggesting that all Kyoto LULUCF inventories are flawed?*

Response: We have softened the sentence to the following:
Besides the difficulty in separating management effects from natural and indirect effects (CO2 fertilization, N deposition, and the effects of climate change), the ideal of including all land management activities requires more data, at higher spatial and temporal resolution, than has been practical (or possible) to assemble at the global level. Thus, most analyses of the effects of LULCC on carbon have focused on the dominant (or documentable) forms of management and, to a large extent, ignored others.

Comment #4) *Page 839 line 15 – definitions, of course always tricky but most important to be consistent. I personally have a problem with naming conversion from forest to cropland a land cover change, well in fact it is but it is also the classical example of a land use change. But OK, as long as it is used consistently. What I am missing is (in that context) a definition for land/forest management and/versus forest degradation. It should be clear how they are separated since they play an important part in the later discussions.*

Response: We have moved the definitions section closer to the beginning of the paper and now distinguish between management and degradation as follows:

In this paper the term “land use” refers to management within a land-cover type. For example, the harvest of wood does not change the designation of the land as forest although the land may be temporarily treeless. “Land-cover change”, in contrast, refers to the conversion of one cover type to another, for example, the conversion of forest to cropland. The largest emissions of carbon have been from land-cover change, particularly the conversion of forests to non-forests, or deforestation. All of the analyses reviewed here have included change in forest area, and most have included other changes in land cover (e.g. natural grassland to pastureland). However, most analyses include little if any land use (management within a cover type) despite the effects of land use on terrestrial carbon storage.

The term “management” is used here, broadly, as any direct anthropogenic effect, ranging from deforestation to crop rotation. The intensity of land management has received little attention in global analyses, except as wood harvests may be either selective or clear-cut. “Degradation” refers here to a reduction in carbon density. Thus, sustainable harvests “degrade” forests because the mean carbon density of a sustainably logged forest is less than it would be if the forest were not logged.

Comment #5. *Page 842, line 6- it would be good to add the reference to the recent FAO/JRC report on the global remote sensing survey that is described as was presented at UNFCCC COP 17 in Durban.*

Response: The recent study by FAO/JRC is cited here and elsewhere (conclusions and legend of Fig. 1). The study limits our ability to say anything about a recent trend in deforestation rates and emissions.

Comment #6) *Section 1 and 8 and on the expert judgement on the overall uncertainty (+-0,5 PgC/y). This is one of the key result but not very well explained well in the text (section 8 and table 2). I consider the authors as world-leading experts in the field so I am sure they can provide some additional reasoning for their assumption.*

Response: The new section (1.3 Uncertainties) elaborates the evidence and reasoning for the error advanced here (Overall, the error for emissions of carbon from LULCC is estimated to be ±0.5 PgC yr^{-1}). Five paragraphs, most of them taken from other sections in the original paper and one new, now present an explanation for this estimate of uncertainty.

Comment #7) *What about land/forest conversion to settlements, infrastructure (incl. hydropower), mining etc? – They can be quite significant in some parts of the world. Do we know anything about this in terms of magnitude and importance since emission factors and legacy effects can be quite different than for conversion to agriculture.*

Response: A new sections has been added to note these other types of land use:
5.4. Human settlements and infrastructure

Urban ecosystems account for a small area, <0.5% (Schneider et al., 2009) to 2.4% (Potere and Schneider 2007) of the land surface, but exurban areas were nearly 15 times greater than urban areas in the U.S. in 2000 (Brown et al. 2005). Furthermore, much of the deforestation in China is currently for residential, industrial, and commercial use rather than for agriculture (Liu et al., 2005). Highways, mining, and hydropower add more to the areas modified intensively by human activity. Despite these 'uses' of land, they have been largely ignored in global analyses of LULCC. The magnitude of net C emissions from the expansion of settled lands is uncertain. Newly established areas may be net sources initially but may become net sinks if trees are re-established or if irrigation is used to expand the areas vegetated.

Comment #8) *Figure 1 - if one shows figures they need to be explained. The "obvious" dynamics from the diagram is in 50's versus 60's versus 70's with magnitude much larger than for our recent more data rich times – this needs to be explained what is*

behind that – a natural or an anthropogenic phenomenon? Otherwise somebody may assume it is because FAO national statistics start in 1961?

Response: The Figure legend has been expanded as follows to explain the most obvious patterns in emissions:

Figure 1. Recent estimates of the net annual emissions of carbon from land use and land-cover change. The closed boxes (DeFries et al., 2002) and circle (Achard et al., 2004) represent 10-year means for the 1980s or 1990s and are for the tropics only. The peak in the 1950s results from a rapid expansion of croplands into the southern Siberian lowlands (SAGE data, Ramankutty and Foley 1999) and, to a lesser extent, from deforestation in NE and SW China (Houghton and Hackler 2003). The apparent decline in emissions after 2000 results from decreased rates of tropical deforestation (FAO 2010), a trend contradicted by a recent assessment based on remote sensing (FAO/JRC 2012).

Comment #9) *Figure 2 – a) – e) should be explained in the figure caption (so far only 2c)*

Response: The Figure legend of what is now Figure 3 has been expanded, as follows:

Figure 3. Mean annual net (a) and gross (b) sources and sinks of carbon 2000-2009 attributable to LULCC (from Houghton's analysis as reported in Friedlingstein et al., 2011). Units are TgC yr^{-1}. 'Legacy' in 2c refers to the sinks (regrowth) and sources (decomposition) from activities carried out before 2000; 'Fast' in 2c refers to sinks and sources resulting from the current year's activity. Most of the net flux (2d) is attributable to deforestation, with a smaller fraction is attributable to forest degradation. The reverse is true for gross emissions 2e): degradation accounts for more of the gross emissions than deforestation. Most of the gross annual sink (2e) is attributable to regrowth (in logged forests or the fallows of shifting cultivation), with a smaller sink attributable to reforestation (an increase in forest area following abandonment of agricultural land.

Comment #10) *Conclusion – I think could be stronger in the following areas:*

1) Highlighting the need for a data driven approach – this is somewhat done but we will see much more actual data coming in the next few years and these opportunities should be highlighted stronger since it is done in the manuscript itself

2) There needs to be a conclusion with respect to Table 2 – does this table help us to define priorities to be addressed – where are actual opportunities to do much better with more data and studies on the horizon? The authors do such a great job in sections 4-7 but the overall lessons learned from reviewing and analysing existing knowledge could be stronger.

3) Parts of the current abstract appears to be more as a missing part of the conclusion. I suggest to take a look into that and adjust.

Response: We have replaced the second and third paragraphs of the initial conclusions section with two new paragraphs in the revised paper. The revisions to the first paragraph and the new paragraphs accommodate the three comments of the referee.