General comments

This manuscript provides a well-structured framework with which the authors go on to quantify different LUC emission components and explain how they can be isolated formally. This is an extremely welcome contribution to the scientific community and helps to clarify the confusion about different definitions of what is to be counted towards "LUC emissions". A question that has been addressed differently by different research "sub-communities" (DGVM modelers, book-keeping modelers, satellite data users) and, as the authors demonstrate, may (partly) explain differences in their results.

The formalism in the present paper (thereafter referred to as GC13) is presented in a simplified and understandable form. However, in one aspect (as I try to demonstrate below) the simplification ignores what (fossil fuel emissions vs. land use change) causes what part of the land-atmosphere C flux. This inconsistency leads to an over-estimation of the land use change (LUC) C flux when assessed from the CCN+LUC and the CCN-only experiments ("CCN" used in the meaning of GC13). A more rigorous separation of different fluxes can solve this problem and can also serve to accomodate other flux components within the formalism introduced by GC13 that have been defined in previous publications (LUC fertilisation feedback flux, replaced sinks/sources). In general, a strengthening of such references to and comparisons with previously published Strassmann et al. (2008); Pongratz et al. (2009); Stocker et al. (2011) flux component definitions could - in my view - even further improve this important paper. In particular, the paper by Strassmann et al. (2008) already provides a formalistic framework to quantify LUC flux components.

I'll start with arguing why I suggest to separate the CCN perturbation into a part caused by FF emissions and a part caused by LUC. The CO_2 increase since pre-industrial times is partly caused by LUC. In other words, today's CO_2 levels would not be as high as they are, if there was no LUC and consequently, the C sink flux into the biosphere (in models usually resulting from higher CO_2) would not be as strong. This feedback has been termed, e.g. by Strassmann et al. (2008), as land use-climate/fertilisation feedback. As demonstrated by Pongratz et al. (2009) and Stocker et al. (2011), this flux is indeed important and compensated for about 35%-48% of $ELUC_0$. In other publications, $ELUC_0$ has been termed "book-keeping flux" Strassmann et al. (2008), or "primary emissions" Stocker et al. (2011). I would argue that when asking "What flux is due to anthropogenic LUC", then one should compare worlds with and without LUC (but with fossil fuel (FF) emissions in both cases). The inconsistency arises because the world without LUC (GC13 experimental setup 1: CCN, no LUC) comes with a prescribed CO_2 from observations which contains the effect of actual historical LUC.

Clearly, a hypothetical world without LUC but with the effect of FF emissions can only be simulated when feeding a coupled model (ocean+atmosphere+biosphere system) with *emissions*. In the setup as presented here, the $LNSK_0$ flux is over-estimated and consequently the sum of the remaining terms in Eq. (16) as well. In the following, I am trying to formally demonstrate this.

Consider a unit land area which is fully converted from natural to agricultural land at time $t = 0$. In a world with LUC, the C storage on (now agricultural) land is $C^{\star\,\mathrm{FF+LUC}}_{\mathrm{agr}}$ (the star denoting equilibrium). Note that the superscripts denote what drivers to environmental change (CO_2, climate, etc) are acting in the two worlds. In a world that has *not* been affected by LUC, but is affected by higher CO_2 levels due to FF emissions, the unit C storage consequently is $C^{\star\,\mathrm{FF}}_{\mathrm{nat}}$. The cumulative emissions caused by the LUC disturbance can be quantified as

$$\Delta C^{\star} = C^{\star\,\mathrm{FF}}_{\mathrm{nat}} - C^{\star\,\mathrm{FF+LUC}}_{\mathrm{agr}} \tag{1}$$

Both terms on the right-hand-side can be expressed as the sum of the preindustrial equilibrium storage plus the cumulative sink/source flux due to the indirect effects of FF emissions (and LUC).

$$C_{\mathrm{nat}}^{\star\,\mathrm{FF}} = C_{\mathrm{nat}}^{\star\,0} + \int_0^\infty f_{t'}^{\mathrm{FF}} dt' = C_{\mathrm{nat}}^{\star\,0} + \Delta C_{\mathrm{nat}}^{\star\,\mathrm{FF}} \tag{2}$$

$$C_{\mathrm{agr}}^{\star\,\mathrm{FF+LUC}} = C_{\mathrm{agr}}^{\star\,0} + \int_0^\infty f_{t'}^{\mathrm{FF}} + f_{t'}^{\mathrm{LUC}} dt' = C_{\mathrm{agr}}^{\star\,0} + \Delta C_{\mathrm{agr}}^{\star\,\mathrm{FF}} + \Delta C_{\mathrm{agr}}^{\star\,\mathrm{FF}} + \Delta C_{\mathrm{agr}}^{\star\,\mathrm{LUC}} \tag{3}$$

Combining above equations and re-arranging the terms illustrates different fluxes:

$$\Delta C^\star = \underbrace{C_{\mathrm{nat}}^{\star\,0} - C_{\mathrm{agr}}^{\star\,0}}_{\text{ELUC0}} + \underbrace{\Delta C_{\mathrm{nat}}^{\star\,\mathrm{FF}} - \Delta C_{\mathrm{agr}}^{\star\,\mathrm{FF}}}_{\text{"lost FF-fert. sinks"}} - \underbrace{\Delta C_{\mathrm{agr}}^{\star\,\mathrm{LUC}}}_{\text{"LUC-fert. feedback"}} \tag{4}$$

By not discriminating the CCN perturbation that is due to FF from what is due to LUC, the emissions due to LUC are quantified as

$$\Delta C^\star = C_{\mathrm{nat}}^{\star\,\mathrm{FF+LUC}} - C_{\mathrm{agr}}^{\star\,\mathrm{FF+LUC}} \tag{5}$$

Expanding the components as above yields

$$\Delta C^\star = C_{\mathrm{nat}}^{\star\,0} - C_{\mathrm{agr}}^{\star\,0} + \Delta C_{\mathrm{nat}}^{\star\,\mathrm{FF}} - \Delta C_{\mathrm{agr}}^{\star\,\mathrm{FF}} - \Delta C_{\mathrm{agr}}^{\star\,\mathrm{LUC}} + \underbrace{\Delta C_{\mathrm{nat}}^{\star\,\mathrm{LUC}}}_{\text{additional term}} \tag{6}$$

The right-most term does not appear in Equation 4. For a historical simulation, it will be positive, the flux $\Delta C^\star$ derived from Equation 6 will thus be higher than in Equation 4 where the CCN perturbations caused by LUC and FF are rigorously separated. This issue is common to all quantifications of LUC emissions that rely on uncoupled DGVMs with prescribed observational CO_2. The present paper could make a strong additional point by demonstrating this using the formalism they introduced.

The additional term in equation 6 is $\Delta C_{\mathrm{nat}}^{\star\,\mathrm{LUC}}$ and represents a flux caused by LUC-induced changes in CO_2 (and climate, N-deposition, etc.), it is thus something like the LUC fertilisation feedback. I have tried to write above equations in the form introduced by GC13, but made some changes. Similar as above, I will use a superscript denoting the sort of environmental condition the fluxes are affected by; and subscripts for the type of land where the flux is ocurring. E.g., f_{nat}^0 is flux on natural land that (would) occurr under preindustrial conditions, while $\Delta f_{\mathrm{nat}}^{\mathrm{FF+LUC}}$ is change of that flux in response to higher CO_2 altered climate, etc. caused by FF and LUC. The Fs are thus the sum over all biological units b, istead of the b-specific flux as in GC13 (see their Equation 5). I found this notation very helpful to intuitively understand to define different flux components (see below).

Following a more rigorous separation of the CCN perturbation by its causes (FF vs. LUC), the total flux due to LUC can - as above - be quantified as the difference between the flux in a world where only the FF perturbatin is acting, and a world where the FF perturbation and LUC, including its (indirect) effects on CO_2/climate, are acting.

$$F_{\mathrm{LUC}} = F^{\mathrm{FF+LUC}} - F^{\mathrm{FF}} \tag{7}$$

The flux in the FF-only world is

$$F^{\mathrm{FF}} = \Delta f_{\mathrm{nat}}^{\mathrm{FF}}\, A_0 \tag{8}$$

while the (total) flux in the FF+LUC world is

$$F^{\mathrm{FF+LUC}} = \underbrace{\Delta f_{\mathrm{nat}}^{\mathrm{FF+LUC}}\,(A_0 - \Delta A^-)}_{\text{undisturbed lands}} + \underbrace{(\mathbf{f^0} + \mathbf{\Delta f}^{\mathrm{FF+LUC}}) \bullet \delta \mathbf{S}^+}_{\text{disturbed lands}} \tag{9}$$

With $\Delta f^{\mathrm{FF+LUC}} = \Delta f^{\mathrm{FF}} + \Delta f^{\mathrm{LUC}}$ the flux due to land use change F_{LUC} becomes

$$F_{\mathrm{LUC}} = \Delta f^{\mathrm{LUC}}_{\mathrm{nat}} A_0 - \Delta f^{\mathrm{FF}}_{\mathrm{nat}} \Delta A^- - \Delta f^{\mathrm{LUC}}_{\mathrm{nat}} \Delta A^- \tag{10}$$

$$+ \mathbf{f^0} \bullet \delta^+ \tag{11}$$

$$+ \mathbf{\Delta f}^{\mathrm{FF}} \bullet \delta \mathbf{S}^+ + \mathbf{\Delta f}^{\mathrm{LUC}} \bullet \delta \mathbf{S}^+ \tag{12}$$

By not discriminating what part of the CCN perturbation is due to LUC and what due to FF, the authors write for the CCN only simulation:

$$F^{\mathrm{CCN}} = \Delta f^{\mathrm{FF+LUC}}_{\mathrm{nat}} A_0 = \Delta f^{\mathrm{FF}}_{\mathrm{nat}} A_0 + \Delta f^{\mathrm{LUC}}_{\mathrm{nat}} A_0 \tag{13}$$

In that sense the flux due to LUC, quantified as $F'_{\mathrm{LUC}} = F^{\mathrm{FF+LUC}} - F^{\mathrm{CCN}}$ becomes

$$F'_{\mathrm{LUC}} = -\Delta f^{\mathrm{FF}}_{\mathrm{nat}} \Delta A^- - \Delta f^{\mathrm{LUC}}_{\mathrm{nat}} \Delta A^- \tag{14}$$

$$+ \mathbf{f^0} \bullet \delta^+ \tag{15}$$

$$+ \mathbf{\Delta f}^{\mathrm{FF}} \bullet \delta \mathbf{S}^+ + \mathbf{\Delta f}^{\mathrm{LUC}} \bullet \delta \mathbf{S}^+ \tag{16}$$

The difference betwee the two quantifications is $F_{\mathrm{LUC}} - F'_{\mathrm{LUC}} = \Delta f^{\mathrm{LUC}}_{\mathrm{nat}} A_0$, analogous to $\Delta C^{\star\,\mathrm{LUC}}_{\mathrm{nat}}$ in Eq.6.

Specific comments

- I was puzzeled by whether ΔS^+ and ΔS^- were equal. Obviously they are not, because fluxes are presented for each g (geographic location) and b (biological unit/PFT). I personally would prefer to see fluxes presented for the integral (sum) over all bs (see GC13, Eq. 5), but differentiated between two types of land: natural and agricultural. I find such a distiction helpful because it makes evident that fluxes ($\Delta f^{\mathrm{FF+LUC}}$) are different on natural and agricultural land, and that this difference defines the "replaced sources/sinks flux" (F_{RSS}).
- An integral over b would imply that b is a "continuous dimension", but it's not. Distinguishing between natural and agricultural lands, or by PFTs, or biomes, always leads to discretisations. Thus, presenting sums instead of integrals would make more sense. But, as mentioned above, I would suggest to reduce b to natural and agricultural land and always present the sum explicitly written out to make the difference in associated fluxes ($\Delta f^{\mathrm{FF+LUC}}$) evident.
- page 191, line 9: "... without any LUC perturbation after the year 2005": I assume it means without any further change (land distribution is "frozen") rather than returning immediately to zero land use areas? However, then I don't understand why ELUC_0 is negative after 2005 AD. Can you clarify?

References

Pongratz, J., Reick, C. H., Raddatz, T., and Claussen, M.: Effects of anthropogenic land cover change on the carbon cycle of the last millennium, Global Biogeochemical Cycles, 23, GB4001+, doi:10.1029/2009GB003488, 2009.

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Strassmann, K. M., Joos, F., and Fischer, G.: Simulating effects of land use changes on carbon fluxes: past contributions to atmospheric CO_2 increases and future commitments due to losses of terrestrial sink capacity, Tellus B, 60, 583–603, doi:10.1111/j.1600-0889.2008.00340.x, 2008.