The contribution of land-use change versus climate variability to the 1940s CO2 plateau: Former Soviet Union as a test case
Bastos et al. *Biogeosciences*

Response to Referee #2

We would like to thank the referee for reviewing the manuscript. We acknowledge that the clarity of the manuscript can be improved the relevance of the results better posed and are willing to revise the manuscript accordingly.
Still, we believe the referee may have missed some of crucial aspects of this work related with: (i) the goal of this study; (ii) the sources of the data used to update cropland area in fSU and their validity; (iii) the spatial representation of the new LUC dataset; (iv) the processes represented in the land-surface model and their credibility.

Regarding *(i)*, this work is a comparative study focusing on two different processes that may contribute to an increased biospheric sink as discussed in Bastos et al. (2016): natural climate variability versus land-use changes possibly unaccounted for in reference datasets (including the TRENDYv4 model results in Bastos et al. (2016)). Therefore, it is essential to compare our results to the DGVMs in TRENDYv4 (for climate variability) and with the LUC dataset used to force these models, i.e. LUH1, which is based on HYDE 3.1. These are **state-of-the-art models and datasets** used by the global carbon-cycle community to evaluate both processes (natural climate-driven C-sink and LUC emissions).
As for *(ii)*, we pointed out that LUH1, since it is based on HYDE3.1, does not rely on national statistics before 1961 (since then, FAO data is available), but on a simple extrapolation based on country-level population to estimate changes in cropland area and uses a simple linear interpolation to produce annual values from decadal changes (Fig. 1). The use of total population in societies that underwent drastic socio-economic changes during the early 20th century (industrialization, rural-exodus) likely fails to reflect real changes in cropland area, especially during periods of drastic shocks (as the Civil War or WWII periods). Therefore, we made an effort to collect **official statistics of cropland area from the Russian Empire and the fSU** (reference list in Supplementary Data and at the end of this reply) until 1961, when global FAO records start (which is also based on national statistics). These official records are, to the best of our knowledge, the most reliable source of information. Several economists who studied intensively the fSU have discussed that while official crop production estimates have been questioned, the official numbers of cropland extent are considered reliable, as discussed in the manuscript (e.g. Wheatcroft and Davies, 1994). Naturally, as in any inventory, official numbers are subject to a certain degree of uncertainty, and this is even more true for early periods in history. But again, we would like to re-emphasize that we are interested in understanding how much could the differences between LUH1 and the national statistics we collected contribute to the estimated LUC emissions, as this is a comparative study. We believe such an explorative approach, even though our collected data is also subject to uncertainty, can provide further insights on closing the carbon budgets for the period of 1940-1950.
(iii) Based on the new data collected for fSU totals (and country level), we produce spatially-explicit maps to force our model. These maps are updated based on the spatial distribution of cropland, forest and grassland in LUH1 and therefore take into account geographical differences in cropland distribution. These spatially-explicit maps essentially are based on satellite data, either the original LUC datasets (e.g. HYDE) or the ORCHIDEE reference PFT maps. We then **update** the gridded data in LUH1 on a pixel-by-pixel basis, distributing the differences between the two datasets at fSU level proportionally to the pixel-level fractional cover of cropland. This is common procedure in LUC studies (Peng et al., 2017). Even if the criterion is simple, the comparison of our updated maps with LUH1 at country level (Supplementary Figure A3) shows that our updated maps capture the country-level values reported in the national statistics, with especially good fit for the countries encompassing the largest fraction of total cropland extent. For a given pixel, a reduction of cropland is replaced by forest (FOR scenario) or grassland (GRA) plant-functional types. Again, we explain in the manuscript that this simple approach can provide two extreme scenarios that we further used to explore the carbon budget question, a typical approach in scientific investigation.
In the land-surface model *(iv)*, **cropland is NOT immediately replaced by a fully grown forest** nor does afforestation take place. It simply means that the model will simulate, after a decrease in cropland, forest-type (or grassland-type) vegetation slowly growing in place of crops, **taking several years to reach maturity**, and depending on climate conditions for growth and survival. The simulations we designed **follow exactly the protocol used by the LUC community** to estimate the legacy fluxes, loss of C-sink capacity and interaction with climate resulting from LUC, by using process-based models like ORCHIDEE-MICT (Houghton et al., 2012). This is common procedure for instance in the estimates of the Global Carbon Budget (LeQuéré et al. 2015), used in Bastos et al. (2016). Several factors cotribute to high uncertainty in LUC emission estimates (Pongratz et al., 2014), but **our approach and model used are among the state-of-the-art methods used by the community** and are therefore, scientifically valid.

We address these issues in more detail in a point-by-point reply to the referee's comments.

RC1: The authors in the current paper (The contribution of land-use change versus climate variability to the 1940s CO2 plateau: Former Soviet Union as a test case) elaborate on their prior finding published in Biogeosciences (Re-evaluating the 1940s CO2 plateau doi:10.5194/bg-13-4877-2016) about the observation of the plateau of SOC emissions around 1940s and its possible drivers. One interpretation they find, or better to say, hypothesize, WWII venue and associated withdrawal of cropland from land use (62 Mha) across the former Soviet Union, could heavily contribute to such plateauing of the carbon emissions.

AR1: Even though the referee's comments focus solely on the LUC aspect of this paper, but we would like to point out that the goal of this paper is to perform a comparative analysis of the potential contributions of two processes in terrestrial ecosystems proposed in Bastos et al. (2016) as mentioned in the abstract of the current manuscript:

> *They hypothesised that (i) the major socioeconomic and demographic disruptions during World War II (WWII) may have led to massive land-abandonment, resulting in an additional sink from regrowing natural vegetation which is not accounted for in most reconstructions and/or (ii) the warming registered at the same time, especially in the high-latitudes, might have led to increased vegetation growth and an enhancement of the natural sink.*

And discussed in Sections 4.2 and 5. We acknowledge that the second aspect (climate effects on natural vegetation) should be elaborated in more detail in the introduction, so that the motivation of this study is clearer to the reader, which could also explain the choice of the land-surface model to perform the simulations (cf. RC5).

RC2: On one hand, it is a very interesting hypothesis, but it has to be carefully validated. However, many statements and data used in this manuscript do not allow to validate such hypothesis. Presented study simplifies the process of LUC caused by war conflicts, which in some cases may yield to massive abandonment (case of Nagorno-Karabakh http://link.springer.com/10.1007/s10113-014-0728-3 and Bosnia http://dx.doi.org/10.1080/01431160801891879), or opposite-maintaining extensive farming on occupied lands (feeding the Caliphate –ISIS in Syria and Iraq http://iopscience.iop.org/article/10.1088/1748-9326/aa673a) (authors hypothesize all occupied land by Nazi was abandoned). Major issues here, A) authors do not account, not all Soviet agricultural land occupied by Nazis from 1941 to 1943 was abandoned (authors simply subtract numbers on cropland acreage from 1941 to 1943).

AR2: We agree with the referee that evaluating changes in LU and their associated impacts, especially in a period where few data were available requires careful analysis. In the case of the fSU, the massive land abandonment registered during the war period is not a new hypothesis, and has been extensively documented in several economic and social studies, most of which are referred to in our paper. Because many of these works provide different numbers or only general trends (as the referee points out below), we sought carefully collected and harmonized national statistics data from fSU (and Russian Empire) for the period preceding 1961 (starting from which FAO data is available as mentioned in p2 line 26). The main point of this paper is that the data we collected match better the variations in agricultural area previously reported (e.g. during the Russian famine and Civil War as well as during the WWII period) than LUH1. Regarding the war period, our data does indicate a decrease in cropland which is consistent with literature reports, while LUH1 reports only a slight decrease, since the latter is extrapolated based on total population statistics, as discussed in p2 lines 25-30.

Furthermore, nowhere in the paper do we hypothesize that all occupied land was abandoned. In fact, the referee may verify the data presented in Supplement where we present cropland areas for occupied and non-occupied territories (reproduced below):

		1940	1941	1942	1943	1944	1945
Total cropland (Million ha)	FSU TOTAL	150.4	108.1	87.7	94.1	109.9	113.6
	OCCUPIED AREA 1940-1945	70.8			23.1	46.2	51.3
	NON-OCCUPIED AREA 1940-1945	72.7	74.9	77.7	66.4	59.0	57.6

These numbers were collected from: National economy of the USSR in the World War II (1941-1945). (Statistical Digest), Chapter 13: Agriculture (pp. 83-92). Goskomstat USSR, Information and Publishing Center, Moscow, 235 pp., 1990. (Narodnoe xozyajstvo SSSR v Velikoj Otechestvennoj vojne 1941-1945 gg. (Statisticheskij sbornik)., Goskomstat SSSR., Glava 13: Selskoe xozyajstvo (str. 83-92), Informacionno-Izdatelskij Centr, Moskva, 235 s., 1990), (in Russian).

Even though there is a gap of two years in 1941 and 1942, it is evident that the decrease in cropland area was not all located in the occupied territory.

RC3: Authors also did not consider the role of trade and food supply by the Soviet Allies (for instance, in the States we see cropland expansion over this period) and C emissions associated with deforestation during the war, fires and such and spatially differentiated land use displacement (it would be best at least to go with stats at the subnational level).

AR3: This is a good point for the global LUC emission budget (which we do not try to re-evaluate here). According to the US government census (figure below), cropland increased only moderately during this period, from ca. 320

MAcres in 1939 (129Mha) to 351 MAcres in 1944 (142Mha) and then 342 MAcres in 1949 (138Mha)*. Thus, even though indeed there was an increase in cropland extent during the war period, it was rather moderate (13Mha), for such a large region.

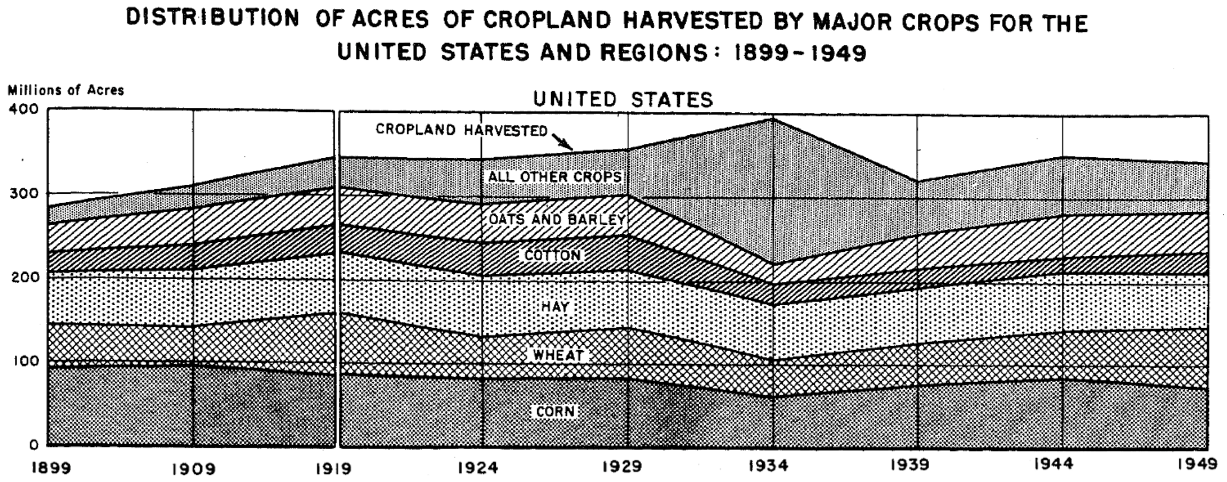


Figure from: https://www2.census.gov/prod2/decennial/documents/41667073v5p6ch4.pdf
* The numbers were calculated by http://arohatgi.info/WebPlotDigitizer/app/

RC4: B) Authors made a non-plausible assumption about immediate spontaneous afforestation (regarding the cropland extent Nazis occupied predominantly agricultural areas in forest-steppe and steppe zone, thus first would be grassland encroachment). The amortization period regarding C sequestration was not accounted in their model (ORCHIDEE-MICT modeling results were also not validated).

AR4: As mentioned in reply to Referee #1 (RC8), we do not assume "spontaneous afforestation. First, we test two different scenarios, one considering forest regrowth and the other grassland regrowth. We further note that (page 7 lines 5-6):

> *[…] these two cases correspond to the two extremes of the possible range of forest vs. grassland trajectories in regions where agricultural area was abandoned.*

After a decrease in crop fraction in a given pixel, the resulting change is attributed to a forest PFT already present in the pixel (or a grassland PFT in the grassland scenario). This does not mean that a fully grown forest immediately follows land-abandonment, but that trees (or grasses) slowly start to regrow in this area, following a typical growth curve as in most land-surface models. Regrowth is modelled following process-based plant physiology and usually takes decades to fully recover previous levels of biomass and soil carbon. This is expected to be even slower in fSU, because of the high latitude thus low temperature and short growing seasons. We assigned a forest PFT in one of the scenarios, but in the model it can grow better/bad depending on many aspects. In some regions, even we introduce a forest PFT fraction, the trees will die or result in very low biomass because of e.g. climate anomalies.
Regarding legacy fluxes, following Pongratz et al. (2014):

> *Legacy fluxes include respiration of plant residues (e.g. harvest slash, dead roots) and disturbed soil organic matter, changes in the stocks of products such as paper and timber, and recovery of the living carbon stocks. The legacy flux thus comprises sources and sinks.*

We perform a reference simulation without LU change and use a process-based land surface model that does include part of the legacy effects from LU and does, therefore, simulate the amortization period after land-use change and further accounts for the loss of C-sink capacity (e.g in the case of deforestation). For an overview of the processes included or not in land-surface models (such as ORCHIDEE-MICT) and the type of simulations that allow quantifying these fluxes, please see Pongratz et al. (2014). The simulations we designed in our study follow exactly the protocol used by the LUC community to estimate the legacy fluxes and interaction with climate, by using process-based models like ORCHIDEE-MICT. The referee may note that our simulation using the reference data (S_{Ref}) estimates LUC emissions within the range of ELUC estimates by the TRENDYv4 models (Fig. 4b), which are one of the methods most commonly used to evaluate ELUC, as, for instance, in the Global Carbon Budget and can therefore be used as a reference value. The referee may consult Houghton et al. (2012) for an overview of all methods to estimate LUC emissions. Still, we agree that this may not be fully clear for the readers, and could be improved.

RC5: C) Authors did not describe/ discuss why other socioeconomic shocks, such as the Civil War in Russia (30 Mha land was abandoned) and recent massive long-lasting abandonment after the breakup of the Soviet Union (60 Mha) did not reflect in the plateauing the C emissions. In the end of the abstract authors conclude "Even if land-abandonment during WWII might contribute to a relatively small fraction of the sink required to explain the plateau, it is still non-negligible, especially since such events have likely been registered in other regions". Given

the all caveats with stats and assumption and expected abandonment would result in 6-10% of the gap sink required to explain the plateau (with current data), evidence suggest the role of abandonment was marginal in the plateauing C emissions and overstated. I recommend to carefully evaluate all these caveats and to use a deductive approach to ground the hypothesis about the role of land-use change or simply concentrate on the modeling exercise and leave out interpretation of drivers. I have a feeling, you just made a nice modeling exercise, and try to pin with the war story or better to say, the Soviet development until 1960 (it is also not clear, why until 1960?).You also never reflected on change in economy and industry during the war period and industry decline, which had probably higher contribution to reduction of C during the war in FSU compared to agricultural land use. It is also not clear from the text, if you also look just at the war period and contribution of WWII or the Soviet Union and associated land-use (you talk about war, you talk about soviet period, then about the period during the 20th century, however you tend to reconstruct stats from 190 to 1970?, figure 1), this does not help either to concentrate on your story. Last but least, you need a better structure of the manuscript; there are a lot of inconsistencies with the periods and data you used, the story is not clear, all sections of the manuscript are fuzzy and in the discussion you need to dedicate a fair amount of space to discuss your major findings, comparison with other studies and caveats.

AR5: In reply to the general comment, we provide an overview of the reasoning behind the development of this study. First, we would like to note that the *plateau* is not observed in the anthropogenic emissions, but in the global atmospheric CO2 concentration. The referee suggests declines in industrial production as a possible explanation for reduced CO2 emissions, but as mentioned in page 3, line 15, industrial production in fSU declined only 8% between 1940-1945, also because of the national program of massive displacement of industrial sector eastwards of Ural mountains in Russia, far enough from the area of potential occupation. Moreover, one needs to keep in mind that industrial production actually increased in several countries to support the war effort (e.g. UK, Germany, USA, Harrison 2000a). In fact, emissions from fossil fuel burning and industrial activity are reported to have increased during the period. Since their uncertainty is much smaller than the uncertainty in the other terms of the C-budget, they are not likely to contribute to the *plateau* (please see Bastos et al. (2016) for a discussion on the matter).

In order to explain such stabilization of atmospheric CO2, a strong sink in the terrestrial biosphere is thus required. This may be (i) due to enhanced CO_2 uptake in natural ecosystems or (ii) reduced emissions from LUC. Given that there are, at the moment, no observation-based data that could allow disentangling the natural vs land-use induced increase in the terrestrial sink (cf. Bastos et al. 2016), the only way to try to pin down the individual contribution of each driver is to perform tests using a process-based model.

Therefore, the study was not planned as a nice modelling exercise, but designed specifically to quantify how much could each of these processes contribute to an enhanced biospheric CO_2 uptake during the 1940s, considering that the largest global terrestrial CO2 sink is located in NH forests and that these regions experienced (i) warmer conditions during the period considered and (ii) major socio-economic changes due to war. Given this rationale, the choice of fSU is therefore straightforward: the territory holds a very large fraction of the NH forests and global soil C-stocks, and constitutes a strong share of global CO_2 sink; at the same time, it is well reported that fSU went through dramatic population and economic shocks during the war period; finally, the fSU is unique in the sense that annual statistics about land use were kept in a consistent framework over such a large extent.

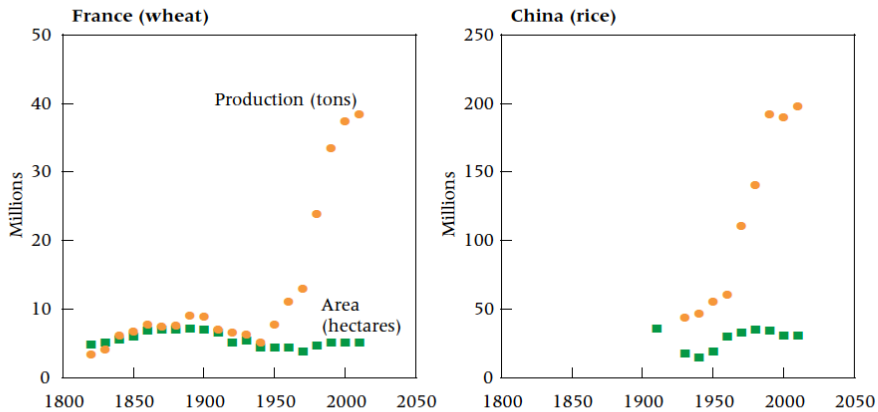
Since it is a comparative study (page 4 lines 25-26), it was important to ensure we were basing our analysis in the same datasets and using a consistent protocol with the model simulations analyzed in Bastos et al. (2016). This implies, thus, that our reference would be the LUH1 dataset, which is based on HYDE 3.1. This dataset, as shown in Figure 1 does not indicate major changes in cropland area during the 1940s, which is inconsistent with studies on the soviet economy during the period (Linz, Nove, Harrison, etc). Initially we made an effort to collect and organize the data available in Russian archives (full list of references in the end of this response and in Supplementary Data). We collected data up until 1961 because it is the period in which LUH1 uses only national population statistics and cropland and grazing land per capita to calculate cropland area, which is not very accurate. Following 1961, the dataset uses FAO data (which in turn relies on national statistics of cropland area directly). Russian data of cropland area for the 20th century period prior to 1913 is, however, not available, to the best of our knowledge.

Our dataset reports strong decreases in cropland extent during the early 1940s (contrary to LUH1), which supports massive land-abandonment during the period reported in economic and historical literature (Linz, Nove, Harrison). Our collected dataset also matches better other relevant socio-economic indicators (RC2 and RC18) and therefore better captures the variations in cropland in fSU during the war period than LUH1 (cf RC2 and RC18, and Section 2.2 for a discussion about the different indicators).

Since we wanted to evaluate separately the effects of LUC and climate on regional land-atmosphere CO_2 exchanges, and to account for two scenarios of natural vegetation regrowth following cropland abandonment, we defined a set of five factorial simulations described in Table 1 (reproduced below).

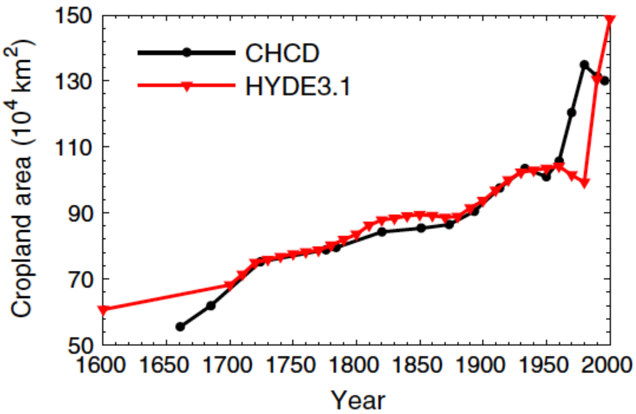
Simulation	Climate	LU map	Test
S_{Ref}	Historical	FSU–REF	-
S_{Clim}	Cyclic	FSU–REF	Climate
S_{noLUC}	Historical	FSU–REF 1860	E_{LUC}
S_{FOR}	Historical	FSU–NEW FOR	FSU–NEW crop $\rightarrow$ Forest
S_{GRA}	Historical	FSU–NEW GRA	FSU–NEW crop $\rightarrow$ Grassland

Because of long-term legacy effects on changes in LU on CO_2 emissions (see reply to RC4), we run model simulations for the full 20^{th} century in order to: (i) account for carry-over effects from previous LUC changes in carbon stocks and fluxes during the 1940s and (ii) evaluate the model ability to correctly simulate the regional carbon stocks and fluxes by covering the observation record period (since 1990s). We hope this explains better the goals and development of this study. We agree that the rationale and flow of the study can be described more clearly in the text and we are willing to fully revise the introduction.
Finally, we find that by using a more detailed dataset of LUC in fSU leads to changes in LUC emissions that could account for 6-10% of the gap sink in Bastos et al (2016). We disagree with the reviewer that this value is negligible, because similar patterns might have occurred in other countries in NH; these could sum up to a non-negligible fraction of the gap sink. Indeed, some works point to decrease in cropland in other countries such as France and China (see figures below).



Extent and production of two cultures in France and China between 1800 and 2010, from Ausubel et al., 2010.

In the case of China, Li et al. (2015) show that there are discrepancies between HYDE3.1 dataset and their historical reconstruction of land-use, even at decadal scale (figure below). Between 1930-1950 HYDE3.1 estimates approximately constant cropland area, while their reconstruction points to a decrease in the 1940s decade. Annual values could potential, as in our work, differ even further.

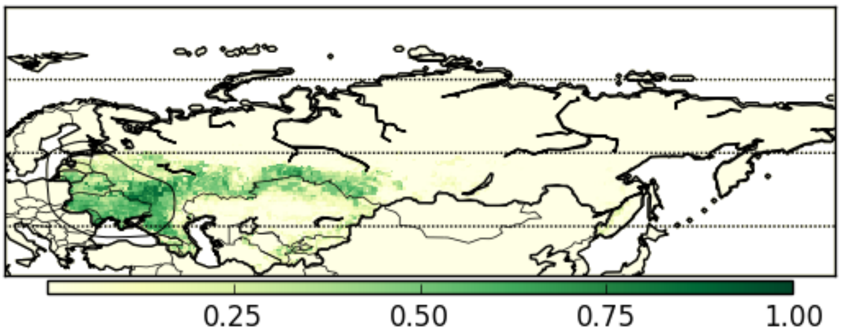


Cropland area comparison between the reconstruction Chinese Historical Cropland Dataset (CHCD) and HYDE 3.1 dataset from Li et al. (2015).

Therefore, our results support the hypothesis proposed in Bastos et al. (2016), that part of the gap sink in the 1940s may be partly explained by the failure in the LUC reconstructions used to account for post-war agricultural abandonment. The global carbon cycle and modelling community relies extensively on LUH1 data and basically all LUC emission estimates up until recently were based on or related to the LUC values in this dataset. The revision of LUC areas in fSU in this study shows that incorporating annual information about LUC may lead to important differences in estimated ELUC (45%-78% during the 1940s decade in fSU), which, for instance, indirectly affects the estimates of IAV in the residual terrestrial sink.

RC6: Major issues/ caveats in more details. 1. Authors state from 1941 to 1943 abandonment comprised 64 Mha of croplands of the Soviet Union, which is one/ third of cultivated croplands in 1940, a pre-war year (they simply perform the subtraction of the numbers before and after the major peak of the Great Patriotic War in 1943 (name, which is common across the Soviet Union for the WWII activities at the Eastern Front) However, evidences suggest Nazi maintained agricultural production and reorganized kolhozes and sovkhoses to feed the Third Reich (12% of consumed food to Nazi Germany was coming from fSU), they had to feed Wehrmacht at the Eastern front (3 -4mln people annually), plus to maintain remaining population on occupied lands (60% from total fSU's population, if i am not mistaken, were living on occupied lands). While the infrastructure has been deteriorated (50%-60% of agricultural equipment was not functioning by the end of 1941), deeply behind the Red's lines, particularly on Chernozem lands, the agriculture has been restored and even equipment was brought from Nazi Germany (this was also a part of Nazi's program to further expand at the expense of best endowed soils in Russia and Ukraine and resettle land poor Germans). So, despite cleansing, massive deaths and destruction of equipment, Nazis still had to maintain agriculture to feed above-mentioned groups on occupied territories. I am not a big expert on the state of land use on occupied lands during WWII, but this has to be discussed and additional evidences are needed to estimate, which portion of occupied agricultural lands was truly abandoned. At the same time, a loss of agro-environmentally endowed lands forced Soviet Union partially expand production in Siberia and Kazakhstan- land use displacement (to capture such displacement you need to look at the oblast level statistics if such displacement occurred). Last but not least here, Soviet Union received technology and food support via lend-lease program from the States, thus causing via teleconnection additional cropland expansion in North America (please take a look at the agricultural statistics of the US). This has not been discussed and accounted in the C estimates, which makes me feeling, the contribution of Soviet Union in C savings is oversimplified.

AR6: This number (64Mha) is not stated in the manuscript. It should read 62Mha and the decrease is from 1940 to 1942 instead as shown in Supplementary Data for total fSU. As already discussed in reply to RC1, we do not assume that all occupied cropland was abandoned. In addition to the supplementary data which provides values for non-occupied and occupied regions, we show below the distribution of cropland area (in fraction of pixel) in fSU between 1940 and 1950.



Fraction of cropland per pixel in fSU between 1940-1949 in our reconstruction (FSU-NEW). The contour indicates approximately the occupied regions.

As the referee may note, even if we did indeed reduce cropland area (compared to the LUH1 dataset), the occupied areas still present high fractional cover of cropland PFTs (1940-1949 average). Even if agricultural fields were displaced to the east (Linz), they were not massive as reflected in our country level data. This is mainly due to unfavorable climatic conditions in Siberia and lack of fertile lands in general (huge forest and wetland areas, not suitable for agriculture). As shown in Figure A3 (Supplement), national statistics show little increase of total agriculture land in Kazakhstan, which had the potential of use fertile lands, in the period 1941-1943. There is also dramatic decrease in 1944 with numbers even below pre-war period.

Figure A2 (Supplement) compares the data collected in this work for each of the former republics composing fSU with LUH1 and our updated LUC data, used to force the land-surface model. Also, even if still there are some regional discrepancies, our maps reconstructed from the national totals (following the method described in Sec. 3.1) do capture the regional differences better than LUH1(keeping in mind this is our reference dataset) as mentioned in page 8, line 21-22.

RC7: 2. Continuing here the discussion about the caveats, authors assume, a bulk of abandoned lands just in three years has reverted into shrubs and trees. First, depending on site condition, even in temperate Russia, it may take even up to 20 years for the field to be encroached by shrubs. At the same time, a bulk of potentially abandoned lands (occupied by Nazis) was located in the central and southern Russia and Ukraine (authors did not show an area of potentially occupied by Nazis). If Nazis would not maintain farming (which was not the case) in the Black soil region, first we would observe a grassland restoration, but not shrubs and trees.

AR7: We do not assume that abandoned land was immediately replaced by trees (see reply to RC4). The referee has focused only on the first part of our sentence and omitted our subsequent discussion (page 12 lines 16-21):

> *Considering average reference values of CO_2 uptake by different forest types (Luyssaert et al., 2007) and assuming that the decrease in cropland extent between 1940 and 1942 was replaced by young growing trees proportionally for each PFT, the estimated net CO_2 uptake resulting from forest expansion over abandoned cropland would be of about 0.09PgC.$^{yr-1}$. This value is consistent with the differences in net CO_2 uptake relative to the reference simulation in the FOR scenario of 0.07PgC.yr^{-1}. The difference for the grassland scenario is higher, ca. 0.12 PgC.yr^{-1}, since grasslands are more productive than forests in the model (Table A1) and grasses allocate more carbon to belowground biomass.*

<u>The first value from Luyssaert et al. (2007) is used as a comparison, and is not the core of our analysis</u>. The referee may note that we designed <u>two scenarios to force the DGVM</u>, one in which forests slowly regrow in abandoned areas (FOR), and another where cropland is replaced by grasslands (GRA). This is clearly indicated in Table 1 (factorial simulations) and <u>results are presented for both scenarios</u> in Figures 2, 3, 4 and A2, A4, A5. Furthermore, throughout the text <u>we always discuss comparatively the results for the two scenarios.</u> In line with the referee's comment, we even mention that the scenario where grassland tends to replace cropland in abandoned areas matches observation-based data better (page 11 lines 26-28):

> *Overall, the simulations using the maps derived from FSU–NEW cropland data provide a better agreement with observed carbon fluxes and stocks in the late 20th century, especially SGRA.*

RC8: I also did not find how did you account where abandonment would occur (I see only stats at country level).

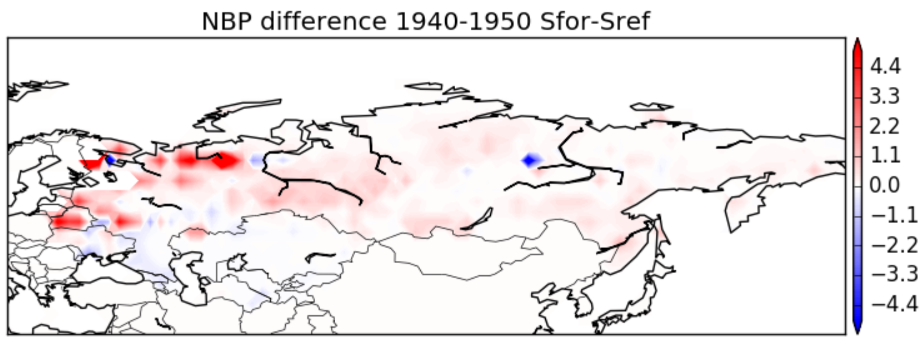
AC8: In Section 3.1 we present the description of how we produce spatially-explicit maps of land-use using the national and country level statistics (page 6 lines 25-30):

> *Based on FSU–NEW data for total crop area in FSU (subsection 2.1.1, Figure 1), we produced new spatially explicit maps used to force ORCHIDEE-MICT by combining patterns from FSU–REF and statistics from FSU over administrative units. First we fill the two missing years (1918 and 1919) using a linear adjustment. Since FSU–NEW data always estimate lower cropland area than FSU–REF, in each pixel the crop area was reduced proportionally to the corresponding contribution to the overall FSU crop area (i.e. more crop area is reduced in pixels with high cropland area in FSU–REF) at each time-step to match the FSU statistics in each administrative unit.*

I.e. the difference between the two datasets is distributed over all pixels, proportionally to the fraction of cropland in each pixel, which is a common method to allocate LUC into PFT maps in land surface models (Peng et al., 2017).

RC9: 3. Studies confirm, during the first three years after the abandonment, there might be even C losses and largest C sequestration, particularly in the above ground biomass and in soil will start after 10 years after abandonment in European Russia and Ukraine (for further details please see Quandary over Soviet croplands http://www.nature.com/doifinder/10.1038/504342a and Schierhorn et al. 2013 http://dx.doi.org/10.1002/2013GB004654). In this regard, it is not clear how C gain just in three years has been assessed. Here I also provide a criticism; you also did not validate your modeling results on C uptake on abandoned lands, to reflect if your estimates are plausible (no any soil chronosequences were used for the contrast and I did not see your C sequestration map for WWI period).

AC9: Please see our response to RC4 and RC7. As shown in reply to Referee #1 (published in 24 July 2017), <u>there is actually carbon loss in the full decade in some of the regions with higher land abandonment</u> (blue shades in the figure below).



Difference in NBP in 1940-1950 between the two factorial simulations S_{FOR} and S_{Ref}. Values correspond to g.m^2.decade^{-1}

RC10: 4. There have been similar massive LUC processes/ shocks-the Civil War in Russia (roughly 30 Mha were abandoned over similar period), post-Soviet transition from state-command to market driven economy (60 Mha from 1990 to 2010), Virgin Lands Campaign cropland expansion (just from 1953 to 1964-40 Mha on new

croplands), recent massive afforestation in China. Why these processes did not yield to plateau or toward a rapid increase of C emissions? Reflection on that is necessary.

AR10: The period of Civil War in Russia (1918 to 1923) is missing (to the best of our knowledge) in National statistics for this period and fSU total are also missing for 1918 and 1919, as mentioned in the manuscript. Still, fSU totals show a decrease in cropland extent during this period and, in our simulations, the Civil War does lead to an increased sink in the two simulations using FSU-NEW. This is clearly presented in Figure 2 (yellow shades and explained in the caption) and discussed in the manuscript, for example (page 9 lines 15-17):

> *Generally, the ORCHIDEE-MICT simulations forced by new LUC maps with lower cropland area estimate lower LUC emissions and, in some cases even a LUC-related sink, as during period between 1913 and the early 1920s (coincident with decreasing cropland area during the WWI and the Russian Civil War* […]

Nevertheless, it is unlikely that legacy effects persisted until the 1940s (as discussed in Page 10, lines 1-6).

As for the other periods and regions mentioned, Bastos et al. (2016) Figure 2 (reproduced below) does indeed show that LUC reconstructions indicate strong increase in ELUC during the 1950s-1960s, and also a strong gap sink. This issue is discussed in the original paper and is beyond the scope of this study. Other regions are also beyond the scope of this study (cf reply to RC5).

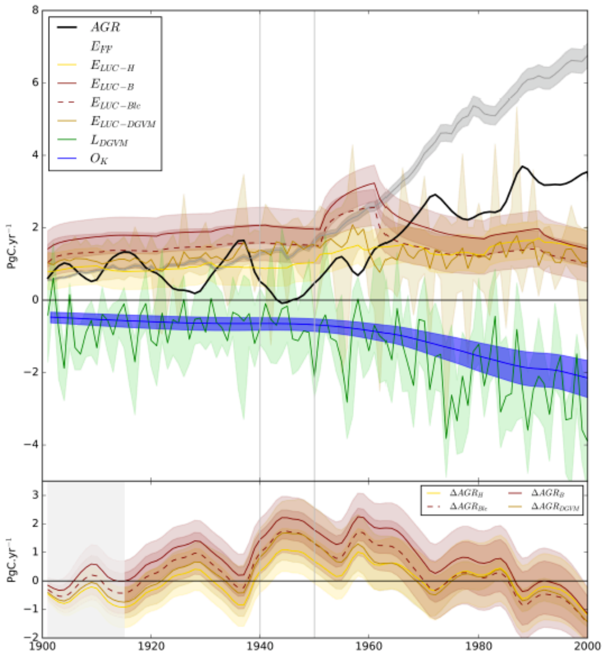


Figure 2 in Bastos et al. (2016) reconstructions of sources and sinks of CO2 (top) and gap sink (bottom) during the 20th century.

RC11: Additional comments. It would be best if you would provide line numbering to make the comments. The abstract can be condensed.

AR11: The lines were numbered in steps of 5.

RC12: It is not clear if data has been assembled at provincial (gubernya or oblast like level) or national level (one number per year for entire country). For instance, if we talk about the former Soviet Union, do you use only one value for Russia without further disaggregation for oblast (s) provinces? How then did you track, where did cropland expansion occur and where was an influence of WWII? Country-level data is not sufficient for such analysis, especially if you talk about land-use displacement (mentioned in the work of Linz).

AR12: The data was summarized at country level, but **we produced spatially explicit datasets**. Cf. reply to RC8 about spatially-explicit information and RC14 about more detailed statistics.

RC13: Block 15. P 3 the Soviet Union is one of the well documented countries regarding the agricultural statistics (for instance, explicit statistics exists on crops and yields back to 1913). LUH1 report and Luyri et al. have different numbers, simply they use different assumptions about LUC. If statistics is scarce and contradictory to your opinion, why do you use the sources of contradictory statistics?

AR13: During 1940-1945 several different estimates of agricultural area are reported in the literature and LUH1, which is what we meant with contradictory. As mentioned previously, the goal of this paper is to provide an estimate of how much could uncertainty in LUC estimates contribute to differences in emissions from LUC, using fSU as an example, particularly because it is a country with well documented data over most of the 20th century. Cf. reply to RC5.

RC14: Block 20 p 3 "the new farmland created likely did not compensate land abandonment in the affected war territories". I am questioning here, likely or did not? I would recommend by using a deductive method to further explore, how much, in fact, land was actually abandoned with account for land-use displacement. You use just one number per country, without any account for land use displacement (you need to go down to oblast level data, which is available for FSU)

AR14: This was meant as an introductory sentence. Our collected data shows that it did not compensate. As for more detailed data, our records did not include oblast-level data for the period analyzed. Therefore, to preserve consistency of the data, we focused on fSU and country-level totals.

RC15: block 30 p. 3 not clear the objectives, if you talk about Soviet Union, or 20th century or WWII period if you reconstruct what happened during 20th century, then you need stats by 2000 (I see some simulations by 2000 and in figure 1 stats is between 1910 and 1970, but in the text you state,1913-1916).

AR15: We agree that Figure 1 should show data up to 2000, since it was the period used to perform the model simulations. The choice of period has already been explain in reply to RC5: to account for long-term legacy effects on changes in LU on CO_2 emissions (mentioned by the reviewer further on), we run model simulations for the full 20th century in order to: (i) account for carry over effects from previous LUC changes in C-stocks and fluxes during the 1940s and (ii) evaluate the model ability to correctly simulate the regional C-stocks and fluxes by covering the observation record period.

We believe this can be made clearer in a future revision of the manuscript.

RC16: block 10 p.4 Lyuri et al. (2010) is a book in Russian, which chapter, or dataset did you use? How well Lyuri et al. data match Nove and which parameter did you use as a proxy for abandonment (arable land or sown areas?). I am a bit surprised you rely on assumptions from the book of Nove (1982) another edition is from 1990, which is a rough book for a broader audience. You need to disentangle land use and rely on studies on economic performance on occupied lands. There has been plenty of studies by Russian historians and former Generals of Wehrmacht (testimonies).

AR16: Lyuri et al. (2010) does not provide any dataset, but includes one figure (2.28) showing the evolution of cropland in the fSU (shown below). As mentioned before, we do not rely on Nove (1982) nor Harrison (2000a) nor Sapir (1989) numbers to produce our LU maps, simply as a reference for comparison. Our data was collected from **national statistics** (full list of references in the end of the document) and is, to the best of our knowledge, which are the most reliable and consistent sources of information about cropland evolution in fSU.

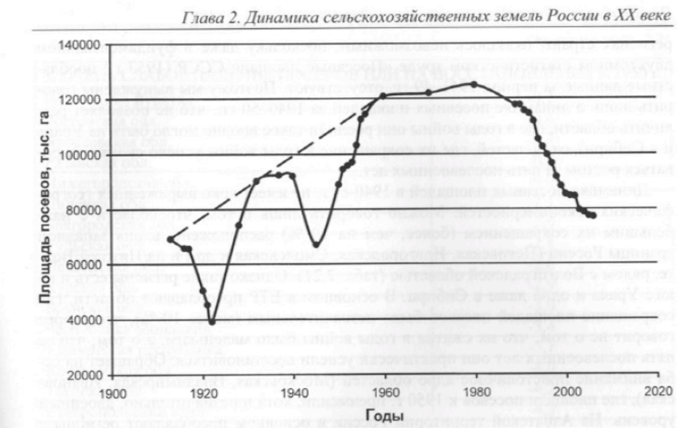


Figure 2.28 in Lyuri et al. (2010). Cropland in fSU during the 20th century and early 21st century.

The sentence in Sec. 2.1.1 should, in fact read (Page 4 lines 9-11):

> *The new dataset of FSU agriculture area comprises the data collected from official national statistics ~~from Lyuri et al. (2010). National statistics were~~ provided for the Former Soviet Union (FSU) during the period 1917-1961, and the Russian Empire during the pre-Soviet period starting from 1913 (dataset and full list of references in Supplementary Data).*

This will be corrected in a revised version of the manuscript.

RC17: block 25 p. 4 how well LUH1 matches selected statistics from Lyuri and Nove ? it is not clear from the text why do you use Hurtt data jointly with HYDE 3.1. Plus earlier in the text you criticized HYDE data and then you use HYDE, I assume, to disaggregate your statistics at the national level.

AR17: The manuscript explains how LUH1 is based on HYDE 3.1 in Page 4 line 26 to Page 5 line 2:

> *The LUH1 provides annual values at half-degree from 1500 until 2100 of fractional data on cropland, pasture, primary vegetation, and secondary vegetation, as well as the underlying transitions between land-use states. In this dataset cropland, pasture, urban, and ice/water fractions between 1500 and 2005 are calculated*

based on the HYDE 3.1 database (Klein Goldewijk et al., 2011) that provides gridded time series of historical population and land-use data for the Holocene. The HYDE 3.1 database relies on U.N. Food and Agricultural Organisation data (FAO, 2008) national statistics of agricultural areas from 1961 onwards, and extrapolates these country-level estimates backwards in time using population dynamics, with cropland and pasture values per capita allowed to change only slightly prior to 1961(Klein Goldewijk et al., 2011).

RC18: Socio-economic statistics Why do you need population and GDP, how does this related to land-use demand and land abandonment. It would be best to explain in the introduction. How GDP for fSU is reliable? Block 10 p.5 "The relationship between population and economic output with total crop area likely changed over the 20th century due to agricultural mechanization and fertilization or to rural exodus. Nevertheless, they provide reasonable proxies to evaluate the variability of crop area reconstructed by FSU–REF and the FSU–NEW statistics." Did you use linear relationship in the end between population and land-use demand? I fully agree, by the end of XIXth century, such linear relationship is not valid for Russia and fSU.

AR18: The socio-economic statistics are presented to support the discussion that total population numbers may not directly translate into cropland area variations. The GDP data used was all published in economic literature and is, to the best of our knowledge, a reliable source of information. As mentioned previously, we did not use the social statistics to calculate cropland area. Our dataset was collected from national statistics (references in the end of this response), as mentioned in the manuscript and throughout this response.

RC19: 2.3 ORCHIDEE-MICT Why did you use this model not any other process-based dynamic vegetation models(e.g., LPJ–GUESS? How did you (if you) validate your model, particularly, it was not designed to model C sequestration on abandonment. I assume, this model does not have agricultural component, such as LPJmL. "The new soil carbon module was shown to reproduce the amount of soil carbon in the high latitudes and the seasonal exchange of CO2 resulting from the seasonal imbalance between gross primary productivity (GPP) and total ecosystem respiration (TER). Fire occurrence is simulated using the SPITFIRE fire model as described in Yue et al. (2014), which is well calibrated to simulate boreal fires". This all interesting, but how did you account for agriculture? It is not clear, how did you parametrize your model and what were inputs (e.g., crop rotation, mechanization, fertilizers, land use)? There is nothing sad if you validated your model, particularly on C stocks on abandoned lands.

AR19: ORCHIDEE-MICT was chosen, as described in Section 3.2, because it was specifically developed to improve the representation of high-latitude processes, as mentioned in the manuscript (Page 6 lines 4-9):

Here we use the updated version of the land surface model ORCHIDEE which is specifically developed for high-latitude processes: ORCHIDEE-MICT (Zhu et al., 2015; Guimberteau et al., 2017). The model includes an enhanced description of high latitude land surface processes such as an enhanced hydrological balance, the effect of snowpack insulation in winter and its coupling with soil temperature, and an improved description of soil carbon interactions between soil freeze, soil water holding capacity and thermic conductivity. The new soil carbon module was shown to reproduce the amount of soil carbon in the high latitudes and the seasonal exchange of CO2 resulting from the seasonal imbalance between gross primary productivity (GPP) and total ecosystem respiration (TER).

We stress that, as the title and abstract state clearly (and see reply to RC5), we want to disentangle the possible contributions of both LU and climate variability to a potential increased sink in the northern high-latitudes. The model ORCHIDEE-MICT relies on the same agricultural module as the main version of ORCHIDEE (Krinner et al., 2005; Piao et al., 2009), which is regularly used in model inter-comparisons and contributes to the Global Carbon Budget (LeQuéré et al., 2016), including LUC emission estimates. Each model has strengths and caveats, but we believe that our choice of model is as valid as any of the other models proposed by the referee.

RC20: 3.1 Updated gridded LUC data. How did you account or simulate abandonment-prone area in the occupied zone? I do not see any reconstruction of land-use. Did you distribute evenly abandoned lands across fSU?

AR20: Cf. Section 3.1 and reply to RC8.

RC21: 4.2 Carbon fluxes during the 20th century you tried to reconstruct land use from 1910 until 1960,right? How does this come to entire 20th century?

AR21: We reconstruct the LU maps from 1913 to 1961. We prolonged the simulations up until 2000 in order to be able to evaluate our simulated C-stocks and fluxes by comparing with observation-based estimates, as shown in Table 2. Also see reply to RC5 and RC19.

RC22: Block 10 p. 8 you use the references to almost yellow literature Linz and Nove, no any studies by the Russian historians or any other historians who worked on reconstruction of land use on occupied lands. Again, a subtraction of two numbers, before and after main venue of war, when a large portion of agricultural land was

occupied, does not mean a complete termination of land use (since for Nazis it was a task and doctrine to obtain these fertile soils).

AR22: We are surprised by the referee's comment that we did not rely on Russian data, since we state clearly in Section 2.1.1 that our dataset is based on Russian official statistics and provide references:

> *The new dataset of FSU agriculture area comprises the data collected from official national statistics ~~from Lyuri et al. (2010). National statistics were~~ provided for the Former Soviet Union (FSU) during the period 1917-1961, and the Russian Empire during the pre-Soviet period starting from 1913 (dataset and full list of references in Supplementary Data). The data for Russian Empire is presented in its actual borders, i.e. not conform to FSU borders, and originally derived in obsolete Russian units of land area (dessiatina, 1 Des=1.09 ha). At the time of the Soviet Union, the statistics provided total cropland area (Mio ha), and cropland area in each of the 15 Federal Republics (thousands ha). Even though the borders of the Russian Empire and FSU were different, both covered the areas which account for most of the cropland area (Russia, Ukraine, Kazakhstan, see Figure A2) and therefore we aggregate both datasets.*
>
> *The total agricultural area is divided into regional values when available and includes winter and spring crops, industrial crops and sown area for fodder. We placed special focus on collecting data for the area of cropland land on occupied and nonoccupied territories made in a subset of the data during the World War II (1941-1945, Supplementary Data). Total cropland area for the FSU aggregated for all types of agriculture products (hereafter referred to simply as FSU–NEW)*

The text should be corrected, as the references used are the ones provided in Supplementary Data and in the end of this reply (not simply Lyuri (2010)). Furthermore, in the previous comments the referee acknowledges we also discuss Lyuri (2010) work.

As replied previously, we do not simply subtract two numbers before and after the war. We perform different model simulations that account for different LU trajectories both before and after the war using a reconstructed dataset that we are confident that better reproduces the variations in agricultural land in fSU during the study period.

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