

1 **Dear Trevor Keenan (editor),**

2 Thank you for taking the time to evaluate our paper based on the reviewer comments
3 and for the positive response to accept the manuscript with minor revisions. We have
4 prepared a new version of the paper that has been thoroughly revised. The relevant
5 changes we made are:

- 6 1) A section in the introduction describing in detail the particular characteristics of
7 the country (as suggested by reviewer 2).
- 8 2) A section in the methodology that explains the limitations of the data we used
9 (accompanied by a new table and a supplementary table which links to the
10 freely available data we used) (as strongly suggested by both reviewers).
- 11 3) A section on the discussion of limitations and considerations of the study (as
12 suggested by both reviewers).
- 13 4) A more detailed description of the datasets used and updated references.
- 14 5) Additional supplementary information regarding LULCC for the country, how Rh
15 is calculated in the models and its impact on the MRT of C in the soil.
- 16 6) An updated review of literature for measurements of NPP in Mexico.

17 We also made all other smaller changes (e.g. grammatical and syntactical
18 suggestions) suggested by the reviewers as we stated in our response.

19 Please find next the document with the changes tracked using the review tools
20 of Microsoft Office.

21 We look very much forward to your comments and hope this should suffice to
22 accept our paper.

23

24 **Your truly,**

25 **Guillermo Murray-Tortarolo on behalf of all co-authors.**

26 |

1 The Carbon Cycle in Mexico: past, present and future of C
2 stocks and fluxes.

3

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23

24 **Abstract**

25 We modelled the carbon (C) cycle in Mexico with a process-based approach. We used
26 different available products (satellite data, field measurements, models and flux towers) to
27 estimate C stocks and fluxes in the country at three different time frames: present (defined as
28 the period 2000-2005), the past century (1901-2000) and the remainder of this century (2010-
29 2100). Our estimate of the gross primary productivity (GPP) for the country was 2137 ± 1023
30 TgC yr^{-1} and a total C stock of $34,506 \pm 7483 \text{ TgC}$, with $20,347 \pm 4622 \text{ PgC}$ in vegetation and
31 $14,159 \pm 3861$ in the soil.

1 Contrary to other current estimates for recent decades, our results showed that Mexico
2 was a C sink over the period 1990-2009 ($+31 \text{ TgC yr}^{-1}$) and that C accumulation over the last
3 century amounted to $1210 \pm 1040 \text{ TgC}$. We attributed this sink to the CO_2 fertilization effect
4 on GPP, which led to an increase of $3408 \pm 1060 \text{ TgC}$, while both climate and land use
5 reduced the country C stocks by -458 ± 1001 and $-1740 \pm 878 \text{ TgC}$, respectively. Under
6 different future scenarios the C sink will likely continue over the 21st century, with decreasing
7 C uptake as the climate forcing becomes more extreme. Our work provides valuable insights
8 on relevant driving processes of the C cycle such as the role of drought in drylands (e.g.
9 grasslands and shrublands) and the impact of climate change on the mean residence time of
10 soil C in tropical ecosystems.

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1 **1 Introduction**

2 The global carbon (C) cycle has been altered by anthropogenic activity with the release of
3 CO₂ into the atmosphere through fossil fuel burning and land use and land cover changes
4 since the industrial revolution (Keeling et al., 1995). As a consequence C stocks have
5 increased in the atmosphere, land and oceans. About 50% of the annual anthropogenic
6 emissions are sequestered in the marine and terrestrial ecosystems (Le Quéré et al., 2014). In
7 the latter, the atmospheric CO₂ increase has led to greater gross primary productivity (GPP),
8 as a result of the fertilization effect on the plants' photosynthetic machinery, hence leading to
9 higher C storage (Norby et al., 2005). However GPP and the net biome productivity (NBP)
10 display high interannual variability due to the effect of climate variability on vegetation
11 processes (e.g. plant production and water use, growing season extension, fire, drought
12 induced mortality) (Sitch et al., 2015).

13 The interaction among climatic forcing, atmospheric CO₂ and terrestrial C remains
14 one of the main uncertainties in our understanding of the global C cycle and in our ability to
15 model it, particularly concerning future projections. Different authors have documented
16 contrasting qualitative and quantitative results regarding the future evolution of the land C
17 cycle. These range from a strong future C sink due to a longer growing season in the Northern
18 Hemisphere and the CO₂ fertilization effect, to C sources from drought-induced tropical forest
19 dieback and temperature-induced enhancements in mid-latitude soil respiration (Friedlingstein
20 et al., 2006; Cox et al., 2000; Friedlingstein et al., 2013).

21 These differences in the future of land C arise from two sources: the strength of the
22 carbon cycle feedbacks (driven by the sensitivity of land C to atmospheric CO₂ increase and
23 climate change) and the poor representation of smaller-scale processes (e.g. disturbance) in
24 the models (Ciais et al., 2013). Thus, regional studies are growing in importance to close the
25 gap in our knowledge. These use finer resolution climate information and other data sources
26 from the field (e.g. site-level carbon stocks), from satellites, and ecosystem-level information
27 for particular regions. An example is the Regional Carbon Cycle Assessment and Processes
28 (RECCAP) initiative, which has promoted studies on drivers of the land C cycle in different
29 regions worldwide (e.g. Dolman et al., 2012; Gloor et al., 2012; King et al., 2015; Piao et al.,
30 2012; Valentini et al., 2014), but further work is needed at finer scales (e.g. country level)
31 (Enting et al., 2012).

1 In this context, we centred our investigation on Mexico's C cycle. Until now, studies
 2 on the C stocks or fluxes at the country level have been estimated from changes in vegetation
 3 C due to land use change (Masera et al. 1997; Cairns et al. 2003) and ~~more recently less~~
 4 ~~frequently~~ soil C has been incorporated in the calculations (de Jong et al. 2010). While these
 5 studies provide important insights on the processes driving the C cycle (e.g. ~~LULCC~~), they
 6 place Mexico as a source of C (Pacala et al. 2007), which may be an ~~incomplete~~ conclusion
 7 derived from estimating C fluxes from biomass change only (Table 1). This approach results
 8 in that important ecological processes are not taken into account, ~~such as~~ the effect of CO₂
 9 fertilization on GPP ~~and~~ the impacts of climate change ~~or ommiting soil C dynamics~~. In
 10 contrast, results from global models and atmospheric CO₂ inversions place the country as a C
 11 ~~sink~~ (Hayes et al., 2012; King et al., 2012), but they lack a representation of the driving
 12 mechanisms of change. Hence, a ~~study based on multiple sources of evidence, that takes into~~
 13 ~~account the g of the C balance in multiple various driving processes of the land C in Mexico~~
 14 ~~is needed~~ ~~is needed~~, ~~particularly~~ to aid in policy formulation and to identify regions that may
 15 provide important ecosystem services like C sequestration.

16 In this study, we provide a country level perspective of the C cycle in Mexico and use
 17 different products and complementary approaches to estimate C stocks and fluxes over three
 18 different time frames: the present (2005-2009), the last century (1901-2000) and the
 19 remainder of this century (2010-2100). ~~Mexico represents a unique opportunity to compare~~
 20 ~~the different approaches for several reasons. The country includes four main mountain ranges,~~
 21 ~~three of them along the Gulf of Mexico and the Pacific coasts and a volcanic belt, which cuts~~
 22 ~~across the middle of the country from east to west (Challenger 1998). It also comprises a large~~
 23 ~~high central plateau, smaller scale depressions, large alluvial plains and two topographically~~
 24 ~~contrasting peninsulas. Thus, the topography in Mexico is among the most heterogeneous in~~
 25 ~~the world. The funnel shape of the country (wide in the north and narrow to the south), along~~
 26 ~~with the mountain ranges, the prevailing winds and the oscillations of the high pressure~~
 27 ~~subtropical belt contribute to a very high diversity of climates, with four of the five major~~
 28 ~~climate types described by Koeppen represented in the country (Challenger 1998; Espinosa et~~
 29 ~~al. 2008). With few exceptions, most of the country shows a summer precipitation pattern.~~
 30 ~~Climate types vary from very dry in the north to sub-humid and very humid in the south,~~
 31 ~~which reflect a high variety of land cover types (Figure 1, supplementary 1) and soils, as well,~~
 32 ~~The high environmental heterogeneity also allows that multiple processes that drive the C~~

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monanous ranges and it is divided in by the transverse neovolcanic belt, this creates a plethora of small-scale climates. Additionally, the country faces remarkable precipitation and temperature heterogeneity, with high interannual variability driven by the effects of increase precipitaion as a consequence of hurracaines. The result is a high floristic and faunistic diversity.

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opportunity to compare the different approaches, due to the high variety of climates, topography and vegetation (Challenger, 1998), which includes a wide range of land cover types (Figure 1, supplementary 1).

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country level analysis, we can compare estimates and products by land cover typebroad

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1 | cycle globally can be identified, at an intermediate, spatial scale (e.g. fire, drought, tropical
2 | deforestation); thus, providing insights on the global drivers of the land C.

3 | We address the following research questions for the different time periods under
4 | consideration:

- 5 | 1. Present-day: What are the magnitudes of C stocks and fluxes at the country level?
6 | How do they vary geographically and by land cover type? How do the estimates with
7 | the different approaches compare?
- 8 | 2. Past: How have C stocks and fluxes changed over the last century? How do these
9 | relate to changes in atmospheric CO₂, precipitation, temperature and land use?
- 10 | 3. Future: How are C stocks and fluxes projected to change over the 21st century under
11 | different climate-change scenarios?

12 |

13 | 2 Methods

14 | 2.1 Datasets

15 | Climate: We used observed temperature and precipitation data from CRU v3.1 (Harris et
16 | al., 2013) (???. We expressed the change over time as the total for the last century. These
17 | data, among other climatic drivers, were also used to force the Dynamic Global Vegetation
18 | Models (DGVMs) (Figure 1).

19 | Present-day land cover: we used the observed vegetation dataset by Ramankutty and
20 | Foley (1999). This was derived from satellite data and contains 18 different categories (Figure
21 | 1). Ten categories were present in Mexico (Sup. 1). In order to simplify the analysis due to the
22 | spatial scale involved, we aggregated the vegetation into five broad categories: broadleaf
23 | evergreen forest, broadleaf deciduous forest, needleleaf evergreen forest, grassland/shrubland
24 | and croplands (Figure 1d).

25 | Past Land Use Land Cover Change (LULCC): We used data for the agricultural
26 | fraction from Hyde et al. (2013), which was also used to force the DGVMs. LULCC
27 | emissions were obtained from the DGVMs. These datasets use a mixture of process-based and
28 | FAO country statistics to calculate the transformation of forest, agricultural areas, pastures
29 | and natural grasslands to other categories.

30 | DGVMs: We used vegetation C, soil C, heterotrophic respiration (Rh), GPP and the net
31 | biome productivity (NBP) from an ensemble of 9 DGVMs (Sup. 2) from the TRENDY v2

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1 | project (Le Quéré et al., 2014; Sitch et al., 2015). All models were forced with the same input
2 | data and spin-up protocol. To attribute the relevant driver (CO₂ fertilization, climate or
3 | LULCC) of past change a set of factorial experiments was conducted over the period 1901-
4 | 2012, where the effect of individual drivers and their combinations were analysed. The runs
5 | were:

- 6 | • Simulation 1 (S1): rising CO₂ through the century with constant climate and no
7 | LULCC; hence the CO₂ effect only.
- 8 | • Simulation 2 (S2): rising CO₂ through the century with real climate and no
9 | LULCC; hence the CO₂ + climate effect.
- 10 | • Simulation (S3): all drivers included, (rising CO₂, observed climate and land use
11 | change).

12 | The attribution of the drivers was calculated as: S1: CO₂ effect only; S2 minus S1: climate
13 | effect only; S3 minus S2: LULCC effect only, and S3: the combined effect of all drivers and
14 | their interactions. A full description of the experiment can be found in Sitch et al. (2015).

15 | Earth System Models (ESMs): We used NBP, precipitation and temperature for four
16 | IPCC Representative Concentration Pathways or RCPs (2.6, 4.5, 6.0 and 8.5) based on an
17 | ensemble of 9 CMIP5 models common to all RCPs (Sup. 2) (Taylor et al., 2011). A full
18 | description of the models can be found in Anav et al. (2013).

19 | Model Tree Ensemble (MTE): This is a data-driven model of gross primary
20 | productivity (GPP) based on flux tower observations, the satellite fraction of the active
21 | photosynthetic active radiation (fAPAR) and climate fields. It uses a Model Tree Ensemble
22 | (MTE) which is a machine learning system based on the data structure (Jung et al., 2011,
23 | 2009). We separated GPP from NEE with the methodology from Reichstein et al. (2012).
24 | Although the MTE has been widely used, it is important to note that there are only a few flux
25 | towers in Mexico and only four of those are included into the algorithm. In recent years, more
26 | data have been incorporated to FLUXNET, and results may vary when these are considered.

27 | Satellite: To estimate aboveground biomass we used annual passive microwave
28 | satellite-based vegetation optical depth (VOD). VOD is an indicator of vegetation water
29 | content of aboveground biomass and can be approximated to mean biomass (Liu et al., 2011,
30 | 2013). We approximated the vegetation C from VOD using a linear coefficient for each cover
31 | type, derived from the best fit to the modeled aboveground biomass. To estimate GPP we
32 | used data derived from MODIS v17 f. The MODIS GPP algorithm is described in Running et
33 | al. (2004). A simple light use efficiency model (MOD17) is at the core of the GPP algorithm

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1 and it requires daily inputs of incoming photosynthetically active radiation (PAR) and
2 climatic variables.

3 Field data: To estimate vegetation C we used the data from the REDD-Mexico
4 initiative, which contains extensive field measurements from the National Forestry
5 Commission (Alianza MREDD+, 2013), for the year 2004 (Sup. 3). For soil C, we used the
6 topsoil C concentrations (0-20 cm depth) from 4000 sampling sites ([Segura-Castruita et al.,
7 2005](#)) covering most of the country; soil sampling was conducted between 2000 and 2006. An
8 alternative source for soil C was the harmonized soil database from FAO v1.2
9 (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). We multiplied C concentrations by the reference
10 bulk density and the soil depth from the same database to estimate soil C stocks.

11 Atmospheric inversions: for the analysis on the land C flux for the present-day we
12 used the mean annual CO₂ posterior flux from atmospheric CO₂ inversion from 10 different
13 products from Peylin et al. (2013) for the period 1990-2005. The uncertainty was calculated
14 as the standard deviation across products. Due to the broad scale of the product (5x5 degrees)
15 we only **provide** the national average and not the gridded means.

16 All datasets were re-gridded to a common 1°x1° grid.

18 2.2 Data limitations

19 Although we tried to use datasets that represent the state-of-the-art to our knowledge,
20 the satellite retrievals, models (both DGVMs and ESMs), atmospheric inversions, flux tower
21 data, and field inventories contain different caveats that must be brought forward. We have
22 summarized the advantages and limitations of each dataset in Table 2. This implies that some
23 results could potentially change in the light of new and better constrained data in the future. In
24 addition, we provide the link for all freely available datasets (Table S4).

26 2.3 Data analysis

27 For the present-day analysis, we first we computed the gridded mean GPP (satellite,
28 MTE and DGVMs), soil C (field data, DGVMs and FAO) and aboveground vegetation C
29 (field data, satellite and DGVMs) for the period 2000-2005. Then, we calculated those values
30 for each land cover type and the total for the country for same time period, which was

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1 common to all datasets. We also computed the mean NBP from all DGVMs, but for an
2 extended time period (1990-2009), as this flux is strongly affected by the interannual
3 variability of the Earth system. Our 'best estimate' for each C pool or flux was the mean
4 across all products (i.e. the contribution of each product was equally weighted). The error was
5 computed as the standard deviation for all years for all products pooled together. We also
6 computed a spatially weighted correlation across products.

7 For the analysis on past changes, we calculated cumulative NBP from the DGVMs
8 ensemble for the period 1901-2000 (100 years) for the three different runs. We then attributed
9 to environmental drivers (change in NBP for the run S1:CO₂, S2 minus, S1: climate and S3
10 minus, S2: LULCC). We calculated the gridded linear change for each run and each driving
11 factor (i.e. change in stored C by climate vs. precipitation and temperature trend). The mean
12 residence time of C in the soil (MRT) was calculated by dividing the linear change of soil C
13 by the change in soil heterotrophic respiration (Rh).

14 For the analysis on future scenarios, we calculated the change in cumulative NBP for
15 each RCP from the ensemble of ESMs for the 21st century (2010-2100). We did this by grid,
16 by land cover type, and for the whole country. For the gridded plots, we stippled the areas
17 where at least 66% (6) of the models agreed on the sign of change in total stored C.

18

19 3 Results

20 3.1 Present

21 Total GPP for the country was $2137 \pm 1023 \text{ TgCyr}^{-1}$ for the period 2000-2005 (Table 3). In
22 terms of the distribution by land cover type, the forest areas represented 56% of the total GPP
23 and the croplands and grasslands/shrublands most of the rest (44%). The highest GPP per unit
24 area occurred in the broadleaf evergreen forests ($2.2 \pm 0.2 \text{ kgC m}^{-2} \text{ yr}^{-1}$) and the lowest in the
25 grasslands and shrublands ($0.6 \pm 0.1 \text{ kgC m}^{-2} \text{ yr}^{-1}$; Table 3). In terms of the country's
26 geography, we found the highest GPP in the South and Southeast with a steep decrease to the
27 North; the lowest GPP occurred in north-central region (Figure 2a). The three different
28 products (i.e. satellite, flux towers (MTE) and DGVMs) displayed similar GPP distributions
29 (Figure 2b, c, d), with DGVMs estimating higher values over the mountainous ranges in the
30 East and the West of the country and part of the central plateau. The spatial correlations

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1 between products were very high: satellite-MTE=0.97, satellite-DGVMs=0.92, and MTE-
2 DGVMs=0.91 (see also Sup. 4).

3 | Our estimate for the total C stock in Mexico was $34,506 \pm 7843$ TgC (Table 4), of
4 | which $20,347 \pm 4,622$ TgC (59%) was stored in the vegetation and $14,159 \pm 3,861$ TgC (41%)
5 | was stored in the soil (Table 4). Similar to GPP, the forested areas accounted for 60% of the
6 | total stored C, with 40% in grasslands/shrublands and croplands. The broadleaf evergreen
7 | forest showed the highest C stock per unit area in the vegetation (22.9 kgC m^{-2}) and soil (12.1
8 | kgC m^{-2}), whereas the grassland/shrubland the smallest (6.0 and 4.7 kgC m^{-2} , respectively)
9 | (Table 4, Figure 3, Sup. 5).

10 | Vegetation C estimates from the three products (DGVMs, satellite and field data) were
11 | in broad agreement at the country level and by land-cover type (Figure 4; Sup. 5). The largest
12 | differences among products were evident in the grassland/shrubland, with both DGVMs and
13 | satellite-based estimates 15-24% higher than those obtained from field measurements, which
14 | was evident in the geographical distribution of C stocks (Figure 4a, b, c; Sup. 5). The spatial
15 | correlations between products were lower than for GPP: field-DGVMs=0.79, field-
16 | satellite=0.84, and DGVMs-satellite=0.74.

17 | The differences among products were greater for soil C. The field data estimates were
18 | on average 15% higher than with the other two products. In particular, the DGVMs and the
19 | FAO database appeared to underestimate soil C in the grasslands and shrublands in Northern
20 | Mexico, with a value 27% lower than the field data (Figure 4d, e, f; Sup. 5). Nonetheless,
21 | there were similarities in the geographical patterns across products, which depicted generally
22 | higher soil C towards the South and lower towards the North, particularly in the central
23 | region. The spatial correlations between products were generally lower than for vegetation C
24 | stocks: field-DGVMs=0.68, field-FAO=0.69, and DGVMs-FAO=0.92.

25 | Our results showed that Mexico was a sink of C over recent decades (1990-2009),
26 | gaining 31.4 ± 18.6 TgC yr^{-1} (Table 5). However, the sink was not equally distributed across
27 | land covers, with the broadleaf evergreen forest, the needleleaf evergreen forest and the
28 | grasslands gaining C, but the broadleaf deciduous forest and the croplands losing C. In terms
29 | of the geographical distribution of NBP, most of the country displayed positive values, except
30 | in areas of the Northwest and the central East of the country, which lost C (Figure 5). The
31 | atmospheric inversions also displayed a positive value for the country with a value of $21.4 \pm$
32 | 12.7 TgC yr^{-1} (Table 1).

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1 3.2 Past

2 The model results with the DGVMs showed that Mexico has been a C sink over the
3 last century, during which time there was an overall gain of 1210 ± 1040 TgC.
4 Geographically, NBP was not homogeneously distributed. The South and central regions of
5 the country lost C, while broad regions towards the North and the Yucatan Peninsula
6 represented a C sink (Figure 6). Three drivers of these regional trends could be identified at
7 this scale with the processes included in the DGVMs: a) the rise in atmospheric CO₂, b) long-
8 term climate variability and change, and c) land use change (LULCC).

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9 a) The effect of elevated CO₂ led to enhanced C storage across the whole of Mexico
10 (3408 ± 1060 TgC), with the highest C gain occurring over the forested regions (Figure 7).

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11 b) Climate impacts were highly contrasting across the country. Thus, when accounted
12 nationwide, the positive and negative effects almost counteracted each other, although the
13 negative effect dominated the flux with emissions of -458 ± 1001 TgC. Climate led to a
14 decrease in C storage over most areas of the country, with the exception of the Northeast and
15 the Yucatan Peninsula (Figure 8a). Over the last 100 years, both precipitation and temperature
16 showed an increase in most of the country, except for decreases in precipitation especially in
17 the Baja California Peninsula in the the northwest (Figure 8c). The loss of C over most of the
18 country in spite of generally positive climate trends was driven by a faster increase of
19 heterotrophic respiration (Rh) than GPP, thus leading to a decrease in the mean residence time
20 of soil C (Suppl. 8).

21 c) The negative effect of LULCC on total stored C (-1740 ± 878 TgC) occurred mostly
22 over the South of the country and along the Gulf of Mexico and Pacific coasts (Figure 9a).
23 Carbon emissions from LULCC were apparently related to the distribution of changes in the
24 agricultural fraction over the same time period (Figure 9b). In addition, consistent with
25 historic-estimates and policies for LULCC, the C emissions from LULCC were higher over
26 the period 1950-1960, with a steep decline afterwards (Figure S6).

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27 Thus, when the three drivers were considered simultaneously, we found that the
28 fertilization effect of CO₂ on GPP during those 100 years was greater than the climate and
29 LULCC negative effects, resulting in a positive net C storage at the scale of the country.

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31 3.3 Future

1 In three out of four RCPs scenarios, the Earth System Models predicted Mexico to remain a
2 C sink up to 2100; only in the most extreme scenario (RCP8.5), the country would become a
3 C source. The total amount of stored C decreased as the radiative forcing increased, from
4 3025 TgC in RCP2.6, to 2150 TgC in RCP4.5, to 1578 TgC in RCP6.0 and -762 TgC in
5 RCP8.5.

6 Geographically, Northern Mexico was generally a C source in all RCPs and at least
7 two thirds of the models agreed on this trend (Figure 10). As the radiative force increased,
8 most of the country turned into a C source and model agreement also increased. However,
9 there was a significant uncertainty in the magnitude and even the sign of changes in other
10 parts of the country, especially over the Yucatan Peninsula (Figure 10).

11 Under all RCPs, precipitation decreased (Sup 7) and temperature increased over the
12 21st century in the whole country (Sup 6), with the larger changes occurring with increasing
13 radiative forcing. Under these scenarios, very likely Mexico would face drier conditions, with
14 the North of the country drying faster than the South.

15

16 4 Discussion

17 4.1 Present

18 The GPP (2137 TgC yr⁻¹) estimated in our study for Mexico corresponds to approximately 2%
19 of the global values (Ciais et al. 2013), similar to the fraction of the land area the country
20 represents. As far as we know, this is the first estimate of gross primary productivity at the
21 country level combining different products. There are quite recent estimates of GPP at the site
22 and regional levels determined from flux tower measurements of tropical dry forest in the
23 northern range of its distribution (Verduzco et al. 2015; see Fig. S1) and from fPAR as a
24 proxy of GPP for the Baja California Peninsula (Reimer et al. 2015). Tropical dry forest GPP
25 was estimated at 831-1099 gC m² yr⁻¹ (Verduzco et al. 2015), which is comparable to our
26 mean estimate of 1200 gC m² yr⁻¹ for broadleaf deciduous forest and to the range of GPP
27 values estimated for that NW region of the country. Also, GPP estimates for the Baja
28 California Peninsula (700-960 gC m² yr⁻¹; Reimer et al. 2015) are comparable to the range of
29 GPP values estimated in the peninsula from our study, especially to the satellite derived
30 estimates.

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1 ~~T~~here are a few site estimates of net primary productivity (NPP) in Mexican
2 ecosystems, ~~since most studies use litterfall as a proxy for NPP (see for example the literature~~
3 ~~revision by Escobar et al., 2008).~~ ~~We~~ can compare them by assuming NPP to be 0.5 of GPP
4 ~~(Farquhar and Sharkey, 1982).~~ Among those, Martínez-Yrizar et al. (1996) estimated an
5 aboveground NPP of 0.6-0.8 kgC m⁻² yr⁻¹ in the tropical dry forest of Chamela, Mexico,
6 similar to our findings of 0.6 ± 0.2 kgC m⁻² yr⁻¹ for broadleaf deciduous forest. García-Moya
7 and Montanés-Castro (1992) estimated NPP in a semiarid grassland in central Mexico
8 between 0.3 and 0.6 kgC m⁻² yr⁻¹, similar to our finding of 0.3 ± 0.2 kgCm⁻²yr⁻¹ for
9 grasslands/shrublands. Such overall agreement of GPP and NPP provides elements to
10 constrain C fluxes, although more field measurements are needed to provide better
11 comparisons at the country scale.

12 The total C stock (vegetation and soil) for the country of 34,506 ± 7483 TgC,
13 estimated with different products (field data, DGVMS and satellite), differs from the 24000
14 TgC estimated by Masera et al. (2001) with a C accounting model. More recent and
15 comprehensive estimates put the total C stock for Mexico at around 33000 TgC (Pacala et al.,
16 2007), which is similar to our value. Interestingly, the baseline estimate of 19,000 TgC for the
17 total C stock in forests by Masera et al. (2001) compares to our 20,347 TgC for forest
18 vegetation. This means that the highest source of discrepancy across estimates concerns soil
19 C, with our estimate of 14,159 TgC almost three times higher than Masera et al. (2001) of
20 5,000 TgC.

21 Total aboveground biomass C for Mexico represents ~4% of the global biomass stocks
22 (Ciais et al., 2013). Our estimates for land cover types are difficult to compare to field-based
23 studies because of the coarse scale of resolution used in our study, which provides large-scale
24 averages and does not capture the heterogeneity of land cover at the local scale. Also,
25 difficulties arise when comparing with other modelling approaches because of differences in
26 criteria to establish land cover classes and in the methods for calculation. Nevertheless, it is
27 interesting that our mean estimate of 22.9 ± 0.9 kgC m⁻² in the broadleaf evergreen forest is
28 similar to the mean value of 20.5 kgC m⁻² from Masera et al. (2001) for the same land cover,
29 with a different modelling approach, and even to the 19.5 kgC m⁻² reported for the Los
30 Tuxtlas region from field measurements (Hughes et al., 1999). Also, our estimate for the
31 needleleaf evergreen forest of 15.1 ± 0.9 kgC m⁻² compares to the mean temperate forest C
32 stock of 12.6 kgCm⁻² of Masera et al. (2001). However, it is important to note that field

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1 measurements by Jasso (2014) showed a range from 2.1 to 20.8 kgC m⁻² for pine and fir
2 dominated forests depending on altitude, which indicates the high degree of variability for this
3 land cover type. Important discrepancies were found over the grasslands/shrublands for which
4 we estimated a mean vegetation C of 6.1 ± 0.7 kgC m⁻², while field studies (e.g. Búrquez et
5 al., 2010; Navar et al., 2014) estimated 1.6-4.4 kgCm⁻² in the deserts over the North of the
6 country. Broadleaf deciduous forest C is more difficult to compare to field-based estimates,
7 since for the purposes of our study this land cover type combined oak and tropical dry forest.

8 Total soil C storage in the country is ~0.6% of the global stock (Ciais et al., 2013
9 IPCC Chapter 6). This represents a smaller percentage than the other stocks and fluxes,
10 because the FAO and field data used in this study included only the top 20 cm of soil; thus,
11 the size of the soil C stock is underestimated. Batjes (1996) showed that, on average, topsoil
12 (20 cm) represents a third of the global soil C stock. A field study in the dry tropics of Mexico
13 (Jaramillo et al., 2003) showed that 37-59% of the soil C stock was in the top 20 cm of soil in
14 land covers which comprised dry and floodplain forest and pasture. In the tropical evergreen
15 forest of Los Tuxtlas (Hughes et al., 2000), soil C in the top 30 cm of soil represented 46% of
16 the soil C stock to a 1 m depth. Thus, the amount of C stored in soil at the country scale is
17 likely to be at least twice as high as estimated here and further work is needed to better
18 constrain this calculation. Nevertheless, our estimate for the 20 cm soil depth of 14.2 Pg C for
19 the country compares to the 15.3 PgC calculated by de Jong et al. (2010) in a study of the
20 impact of LULCC on C stocks in Mexico. A more recent estimate based on extensive field
21 measurements of soil organic C for the top 30 cm of soil (Cruz-Gaistardo and Paz-Pellat
22 2014) provides 9.2 Pg C for the country. This implies, that if soil inorganic C is accounted
23 for, soil C stocks would be higher and likely similar to the estimates above. In fact, maximum
24 soil C stocks occur in the Yucatan Peninsula, with soils rich in calcium carbonate, and in the
25 southern edge of the eastern Sierra (Etchevers et al. 2014), which is consistent with the
26 geographical distribution of soil C depicted in our study, especially as estimated from the
27 field data set.

28 If we compare the estimates among products and consider the high correlations among
29 them, it seems that the C stocks in the vegetation and the GPP fluxes are remarkably well
30 constrained and compare favourably against field data and findings by other authors (Pacala
31 et al. 2007). However, model development and improvement, particularly over non-forested
32 areas, is needed, where the DGVM estimates showed the highest differences compared to

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1 field values. This is particularly important, because in spite of the fact that drylands only
2 represent 25% of the GPP and C stocks, they account for nearly half the area of the country.
3 This means that error propagation in this particular land cover may lead to changes in the
4 estimations of the C cycle.

5 Our results showed that Mexico was a C sink over recent decades (1990-2009),
6 gaining $31.4 \pm 18.6 \text{ TgC yr}^{-1}$. This is similar to recent calculations by Hayes et al. (2012)
7 using inverse ($+8.7 \text{ TgC yr}^{-1}$) and forward models (29.0 TgC yr^{-1}) and to the result from
8 atmospheric CO_2 inversions (21.4 TgC yr^{-1}). Also, recent flux tower estimates of net
9 ecosystem production (NEP) in tropical dry forest at the site scale (Verduzco et al. 2015) have
10 shown a predominant local C sink. Our results are in disagreement with inventory based
11 calculations (Masera et al., 1997; Cairns et al., 2000; de Jong et al., 2010) that place Mexico
12 as source of C (Table 1). The discrepancy may arise because the latter estimates are based on
13 changes in vegetation stocks as fixed covers, which do not take into account other C fluxes
14 and important ecosystem processes such as the effect of CO_2 fertilization and the impact of
15 climatic variables. In other words, those estimates are closer to the LULCC C-flux than to
16 NBP (see Table 1). Based on our estimates and the recent literature, we argue that it is likely
17 that Mexico is currently a sink and not a source of C, if we disregard emissions from fossil
18 fuels. The definition of Mexico as a C sink is consistent with the overall role of North
19 America (USA and Canada; Hayes et al. 2012) and would place the North American C sink at
20 approximately 377 TgC yr^{-1} .

21 22 4.2 Past

23 Similar to the present-day, our results indicated that the terrestrial ecosystems in the country
24 were a C sink over the last 100 years, gaining $1,210 \pm 1040 \text{ TgC}$ in total. Such increment was
25 driven by the CO_2 fertilization effect on vegetation ($3408 \pm 1060 \text{ TgCyr}^{-1}$), which enhanced
26 GPP and subsequently biomass and possibly soil C to different degrees. Both the climate ($-$
27 $458 \pm 1001 \text{ TgCyr}^{-1}$) and the land use ($-1740 \pm 878 \text{ TgCyr}^{-1}$) drivers showed a generalized
28 negative effect on C storage. Our estimates are highly consistent with those derived from
29 global models for Latin America, which show these land ecosystems as C sinks (Pan et al.
30 2011). However, during the period 1901-2000 the country's emissions from fossil fuels
31 amounted to about $10,600 \text{ TgC}$ (Le Quéré et al., 2014). This suggests that only 11% of the

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1 emissions from fossil fuels were actually captured back into the land and emphasizes the need
2 for more efficient fossil-fuel and [LULCC](#) policies.

3 The loss of C over [NE Mexico](#) is likely driven by climate. A long-term drought
4 identified over [this region](#), and SE USA (Cayan et al., 2010), has led to a reduction in
5 grassland productivity (Grover and Musick, 1990) and the subsequent loss of stored C due to
6 increased dry season intensity and length (Murray-Tortarolo et al., [submitted](#)). However, the
7 overall negative effect of climate on C storage in other regions is likely linked to its impact on
8 soil C mean residence time (MRT; Sup. 8). The increase in temperature leads to a higher
9 respiration rate and soil C loss. As the MRT decreases, it results in certain regions becoming a
10 C source to the atmosphere. This source, nevertheless, is apparently overridden by the impact
11 of higher precipitation on plant productivity in many regions of Mexico. In this sense, MRT is
12 one of the main sources of uncertainty for the future of global soil C (Carvalhais et al., 2014;
13 Friend et al., 2014) and a more comprehensive analysis over the country, based on observed
14 data, is lacking.

15 Other regions which experienced C loss are linked to the impact of [LULCC](#). [LULCC](#)
16 accounted for a loss of 1740 TgC over this period, with most of the emissions (60%)
17 occurring in forested regions and 32% in the broadleaf forests over the South. Interestingly,
18 about a third of the emissions (34%) were accounted for in croplands. Country-level estimates
19 by Masera et al. (1997) calculated the flux at 61 TgC yr⁻¹ based on changes only in vegetation
20 stocks for their baseline year in the 1980s. More comprehensive analyses including C
21 emissions from the soil C, estimated net emissions of 23.7 TgC yr⁻¹ from [LULCC](#) in forests of
22 Mexico for the period 1993-2002 (de Jong et al., 2010; Hayes et al. 2012). Despite the
23 different methodologies, all approaches establish that the highest [LULCC](#) emissions fluxes
24 have occurred mostly over [Southern](#) Mexico.

25 When the effects of all drivers were considered, the models showed that changes in
26 climatic variables had a smaller impact on stored C than [LULCC](#) during the period 1901-
27 2009. This was due to the fact that the impacts of [LULCC](#) were consistently negative on all
28 land cover types, whereas climatic variables showed a heterogeneous effect (i.e., positive and
29 negative) on the land cover types, which are differentially distributed over the country.
30 Notably, climate trends have promoted C capture in broadleaf evergreen forests during the
31 past 100 years, but this was overridden by [LULCC](#). However, there is no evidence from field
32 measurements to support or disprove this claim. While there are studies on the consequences

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1 | of [LULCC](#) on C pools at the site and regional levels (Hughes et al. 2000; Jaramillo et al.
2 | 2003; de Jong et al. 2010), there is very little work on the effect of climate change on NBP
3 | over Mexico (e.g. Dai et al., 2014), making [it](#) a fundamental missing piece in our
4 | understanding of [the](#) C cycle at local to regional scales. This is particularly important because
5 | the DGVMs [we](#) used are poorly constrained for their drought response (Morales et al., 2007;
6 | Sitch et al., 2003), a key process for the C balance over the arid regions of Mexico
7 | (grasslands/shrublands), which cover about 40% of the land area.

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9 4.2 Future

10 In three out of four scenarios, Mexico represents a potential C sink in the remaining of
11 this century. It is only in the scenario with the highest temperature and lowest precipitation
12 (RCP8.5) that the country actually turns into a C source. While the CO₂ fertilization
13 dominates the magnitude of the sink across all RCPs, the effect of climate becomes more
14 | negative and predominant as the RCP becomes more extreme (Table [6](#)). Similar modelling
15 | results have been found at the global scale, with an increasing climate-carbon feedback as the
16 | future scenario becomes more extreme (Cox et al., 2000; Friedlingstein et al., 2006).

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17 Important considerations should be taken into account. The CO₂ fertilization effect is
18 likely counterbalanced not only by climate, but also by the effect of limiting nutrients on C
19 | uptake –a process [not](#) considered in many Earth-System-Models (ESMs) (Reich et al., 2014,
20 | 2006; Zaehle et al., 2015) or by more severe fires as a result of more intense and recurrent
21 | ENSO (Yocom et al., 2010). Additionally, as shown by the past trends, a decrease in the
22 | MRT of soil C can change an ecosystem from a C [sink](#) into a source. There is a lack of field
23 | information to estimate MRT and its response to temperature and soil moisture to fully
24 | understand the implications for the future of stored C, especially in tropical and sub-tropical
25 | ecosystems.

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27 [4.3 Limitations and considerations](#)

28 [Although all our calculations are based on state-of-the-art datasets and models, several](#)
29 [limitations must be taken into account. Firstly, our study only comprises data that was either](#)
30 [freely available \(or will be soon\) or published. Several government agencies in Mexico \(e.g.](#)
31 [CONABIO, CONAFOR and INEGI\) have concentrated in producing new, more](#)

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1 comprehensive and updated datasets than those used in this study. This means that our results
2 should be revised in the light of newer data, in particular with the inclusion of additional time-
3 slices in the field data which can facilitate the comparison of modelled and observed changes
4 in the C stocks.

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5 Secondly, most of the datasets we used are improved constantly (e.g. models include
6 additional processes and flux tower data is steadily increasing), therefore, our evaluation of
7 the C cycle in Mexico should improve as these products evolve. Also, and particularly
8 important, models will include additional processes such as fire (although some of the models
9 used already included a fire module), nutrient limitations, a more complex representation of
10 agriculture and finer-scale processes (such as landslides or floods), to mention a few.

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11 Finally, while we tried to tackle the large heterogeneity of the country, it is quite clear
12 that the spatial resolution used cannot provide a detailed analysis. Thus, our results should be
13 used with caution when comparing them with site-level data and are better fit for country-
14 level comparisons. In this sense, additional local/regional modeling studies with appropriate
15 forcing data are a fundamental missing link to compare the different approaches to evaluate
16 the C cycle over complex and dynamic terrains.

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18 5 Final remarks

19 We quantify different aspects of the C cycle for Mexico (GPP and the total land C flux, as
20 well as vegetation and soil C stocks) using different products over three time periods. As far
21 as we know, this is the first time these pools and fluxes have been quantified for the whole
22 country with a process-based approach. It takes into account different drivers (e.g. CO₂,
23 climate and LULCC) and provides a more realistic estimate of the C cycle for the country.
24 Additionally, we quantify fluxes (e.g. GPP and NBP), not previously estimated at the country
25 scale.

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26 Contrary to inventory-based estimates (de Jong et al. 2010; Pacala et al. 2007; Hayes
27 et al. 2012), our analysis shows that over the last 100 years and recent decades the country has
28 been a C sink. Our results suggest this has resulted mainly from the positive effect of CO₂
29 fertilization and to precipitation and temperature changes in some regions. This pattern is
30 likely to persist, although with a diminishing trend, over the remaining part of the century.
31 Such a sink, however, only accounts for 11% of C emissions from fossil fuels during the

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1 period, which clearly points towards the need of more fuel-efficient policies and emissions
2 controls.

3 Our work also identifies the need to study the role of drought in [drylands](#) (e.g.
4 grasslands and shrublands) and to determine soil carbon MRT in tropical ecosystems. Finally,
5 as we used data ~~from global sources~~ (e.g. DGVMs, ESMS, satellite), the methodology
6 proposed here can be used to analyse the full ~~C~~ cycle of regions elsewhere.

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8 Authors Contributions

9 GMT, PF, SS and VJJ designed, executed and wrote the paper. FMF, AA and YL provided
10 and analyzed data. The rest of the authors provided the DGVMs data and ~~provided critical~~
11 ~~comments on the manuscript. ? helped writing the paper.~~

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19 [Murray-Tortarolo](#) and S. Sitch acknowledge the support of the European Commission-funded
20 project [JULCC4C](#) (grant no. 603542).

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- 16

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1 Table 1: Different estimates for the land C-flux of the country. A negative sign indicates a
 2 source to the atmosphere and a positive sign a sink.

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Land C Flux estimates			
Author(s)	Years	Method	Estimate (total) TgC yr⁻¹
Masera et al. 1997	1985-1987	Changes in vegetation cover	-52.6
Cairns et al. 2000	1977-1992	Changes in vegetation cover*	-18.6
De Jong et al. 2010	1993-2002	Inventory-based	-18.4
Haynes et al. 2011	1993-2002	Inventory-based	-18.4
Haynes et al. 2011	2000-2006	Forward models	29.0
Haynes et al. 2011	2000-2006	Inverse models	8.7
This work	1990-2009	DGVMs	31.4
		Atmospheric Inversions	21.4
		LULCC-only	-19.5
This work	1901-2009	DGVMs	12.1

4 *This estimate accounts for only part of the South of Mexico

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1 Table 2: Advantages and limitations of the different datasets used.

Dataset	Advantages	Limitations
Satellite (biomass and GPP)	<ul style="list-style-type: none"> High-resolution Includes all driving mechanisms 	<ul style="list-style-type: none"> Not measured directly but derived from FPAR or VOD. Saturation over highly dense areas. Need for interpolation when clouds present.
Flux towers (MTE) GPP and NBP	<ul style="list-style-type: none"> In-situ measurements Includes all driving mechanisms 	<ul style="list-style-type: none"> Few sites in Mexico (4). But this is increasing rapidly. Uses climatology to interpolate the data (added uncertainty from climate database) Small interannual variability.
DGVMs (GPP, biomass, soil C, NBP)	<ul style="list-style-type: none"> Longer time period of all datasets (full century) Allow testing of individual driving factors to attribute the change in NBP over time. 	<ul style="list-style-type: none"> Do not account for all ecosystem processes (e.g. some models not include plant mortality only few include a representation of fire). Broad uncertainty in the vegetation response to drought.
Biomass field data (National inventory)	<ul style="list-style-type: none"> In-situ measurements "Land-truth" data 	<ul style="list-style-type: none"> Limited to one time-slice. Different sampling methodologies across country
Soil field data (road data)	<ul style="list-style-type: none"> In-situ measurements "Land-truth" data 	<ul style="list-style-type: none"> Point-data that needs to be interpolated Limited to one time-slice. Different sampling methodologies across country. Only accounts for C in the first 20 cm of soil.
Harmonized Soil Dataset (FAO)	<ul style="list-style-type: none"> Standardized global product used in different fields. 	<ul style="list-style-type: none"> Broad approximation to soil C based on type. Only accounts for C in the first 20 cm of soil.
Earth-System-Models	<ul style="list-style-type: none"> Only approach for future changes in land C. Commonly used in policy making (IPCC). 	<ul style="list-style-type: none"> High uncertainty across ESMS, with disagreement of the future change in NBP most of the country. Do not account for all driving factors (changes in the nitrogen cycle).
Atmospheric CO ₂ inversions	<ul style="list-style-type: none"> Includes all driving mechanisms Top-down Approach 	<ul style="list-style-type: none"> Broad-Scale (5°), not suitable for gridded analysis.

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1 Table 3: Mean GPP, total area and total GPP by land cover type for the period 2000-2005.

Gross Primary Productivity for Mexico (2000-2005)			
Land Cover type	Mean kgC m ⁻² yr ⁻¹	Area 10 ⁹ m ²	Total TgC yr ⁻¹
Broadleaf evergreen forest	2.2 ± 0.23	257	553 ± 264
Broadleaf deciduous forest	1.2 ± 0.16	438	519 ± 356
Needleleaf evergreen forest	1.4 ± 0.31	92	134 ± 34
Grassland/Shrubland	0.6 ± 0.12	747	420 ± 260
Croplands	1.2 ± 0.09	423	508 ± 210
TOTAL		1957	2137 ± 1023

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1 | Table 4: Mean (kgC m⁻²) and total (TgC) carbon stored in the vegetation and soil in each land
 2 | cover type for the period 2000-2005.

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TOTAL STORED C	Vegetation C		Soil C		Total	
	Mean kgC m ⁻²	Sum TgC	Mean kgC m ⁻²	Sum TgC	Mean kgC m ⁻²	Sum TgC
Broadleaf evergreen forest	22.9 ± 0.9	5884 ± 1220	12.1 ± 0.4	3100 ± 1167	35.0 ± 1.3	8984 ± 2387
Broadleaf deciduous forest	12.4 ± 0.5	5431 ± 1319	8.9 ± 0.6	3880 ± 1235	21.3 ± 1.1	9311 ± 2554
Needleleaf evergreen forest	15.1 ± 0.9	1385 ± 575	10.9 ± 0.4	1336 ± 586	26.0 ± 1.3	2721 ± 1161
Grassland/Shrubland	6.0 ± 0.7	4482 ± 1556	4.7 ± 0.7	3535 ± 1208	10.7 ± 1.4	8017 ± 2764
Cropland	7.5 ± 0.3	3158 ± 1190	6.2 ± 0.5	2635 ± 790	13.7 ± 0.8	5793 ± 1980
TOTAL		20,347 ± 4622		14,159 ± 3861		34,506 ± 7483

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1 | Table 5: Land C-flux to the atmosphere (NBP) for the period 1990-2009 by land cover type.
2 | For all cases a positive value indicates a sink and vice versa.

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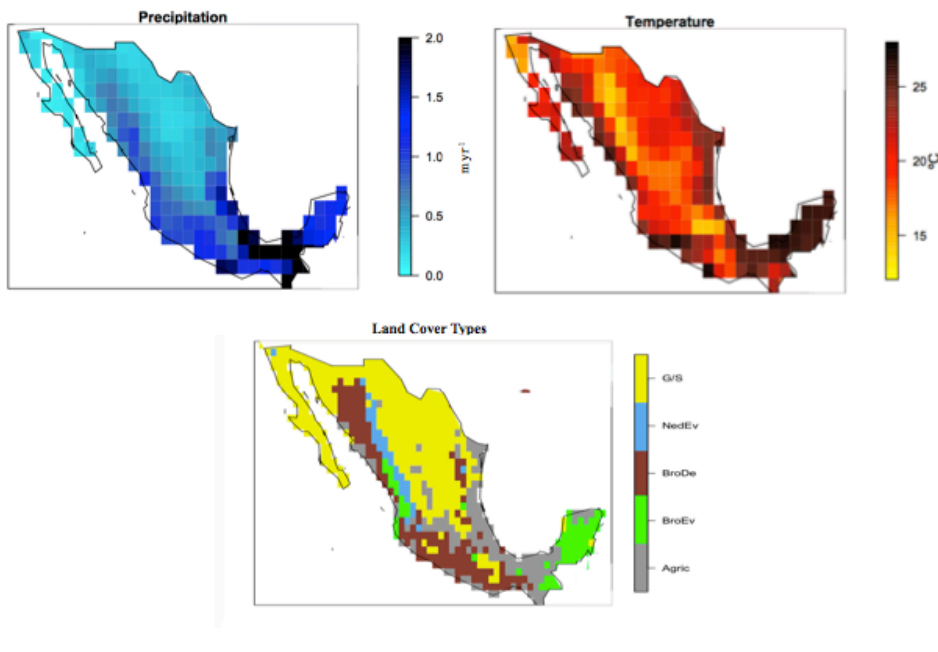
Land-C Flux for Mexico (1990-2009)		
Land Cover type	Mean gC m⁻² yr⁻¹	Total TgC yr⁻¹
Broadleaf evergreen forest	100.8	20.6
Broadleaf deciduous forest	-42.1	-8.9
Needleleaf evergreen forest	22.2	1.5
Grassland/Shrubland	55.2	21.3
Croplands	-52.2	-3.1
TOTAL		31.4 ± 18.6

3

1 | Table 6: Sensitivity of carbon to climate in four RCPs for the whole country. dC: change in
2 | total stored C, dT: change in mean land surface temperature, γ : Change in the Land-C flux
3 | relative to the change in temperature, γ_0 land carbon sensitivity to climate in the past. A
4 | negative $\gamma-\gamma_0$ implicates a detrimental effect of climate in the land-C-flux in the future
5 | compared to the present.

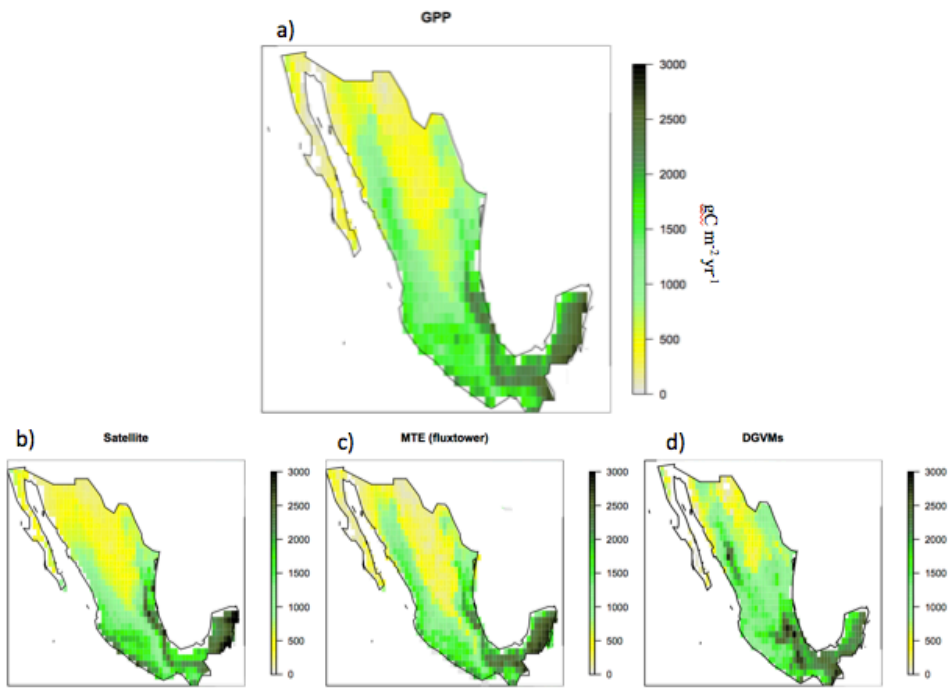
Period/RCP	dC	dT	γ	$\gamma_0-\gamma$
	PgC	°K	PgC/°K	PgC/°K
1901-2000	1.2	0.88	1.36*	
RCP2.6	3.0	2.4	1.25	-0.11
RCP4.5	2.1	3.6	0.58	-0.78
RCP6.0	1.5	4.5	0.33	-1.03
RCP8.5	-0.7	6.1	-0.21	-1.57

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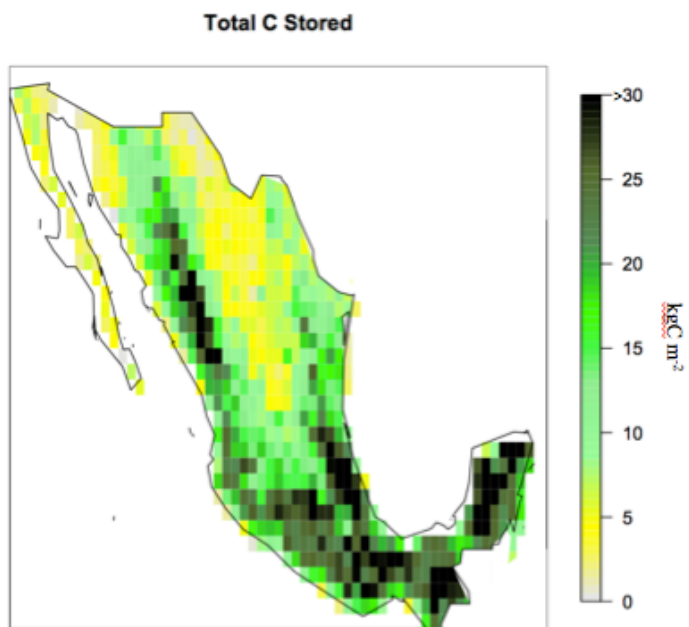


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 2 | Figure 1. Observed precipitation (m yr^{-1}), temperature ($^{\circ}\text{C}$), and land cover types for Mexico
 3 (mean of 2000-2005). Agric: Croplands, BroEv: Broadleaf Evergreen Forest, BroDe:
 4 Broadleaf Deciduous Forest, NedEv: Needleleaf Evergreen Forest, G/S: Grassland/Shrubland.

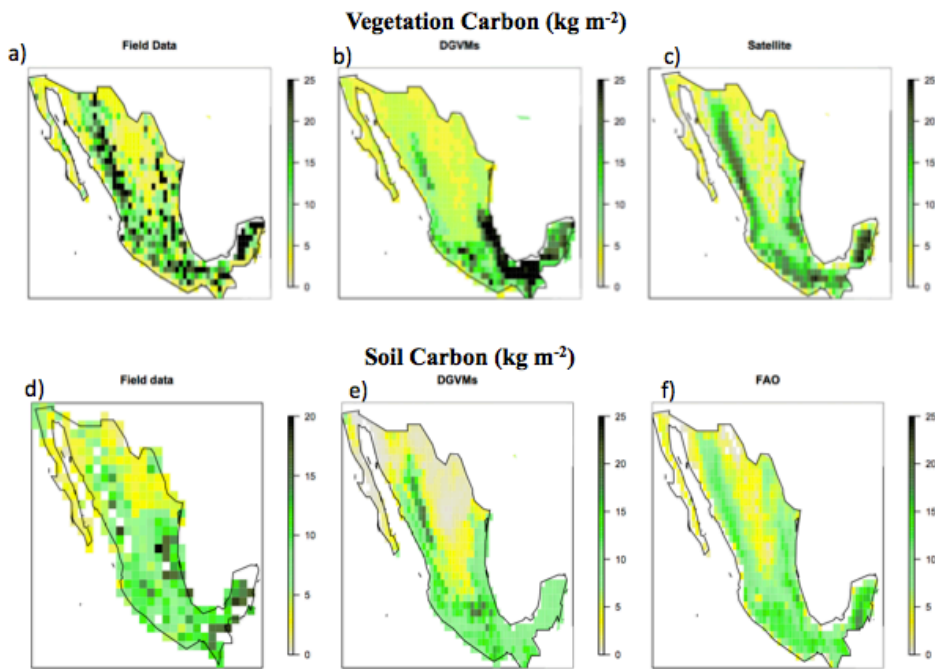
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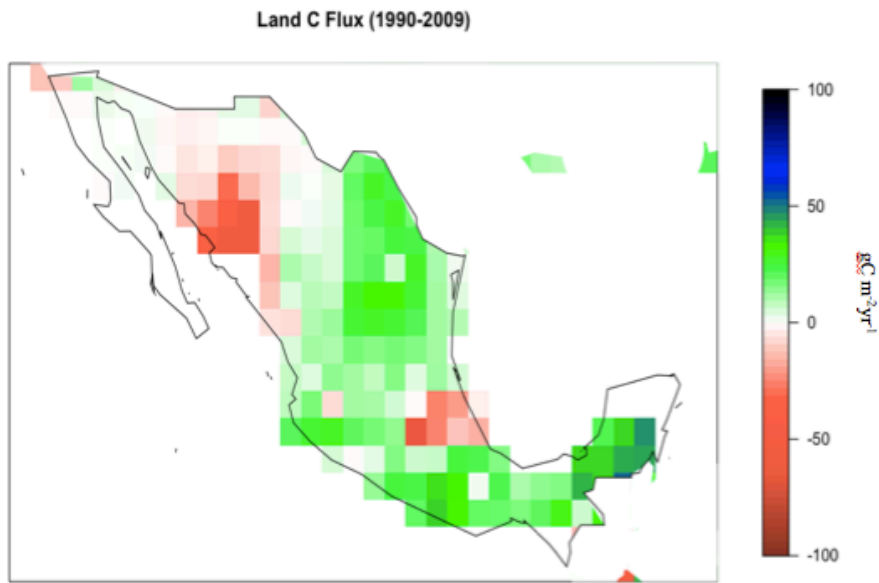
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 2 | Figure 2: Mean GPP ($\text{gC m}^{-2} \text{yr}^{-1}$) for a) ensemble of the three products, b-d) individual
 3 products (Satellite, MTE and DGVMs). All maps correspond to the period 2000-2005.
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2 Figure 3: Total stored C in soil and vegetation (kgC m⁻²), ensemble from all products (6) for
3 | the period 2000-2005. OJO: favor de quitarle "stored" al título de la figura.
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2 Figure 4: Top) Vegetation stored carbon for three products: field data, DGVMs and satellite
3 | (kgC_m⁻²). Bottom) Soil stored carbon for three products: field data, DGVMs and FAO
4 estimates based on multiple datasets (kgC m⁻²). Mean for the time-period 2000-2005.
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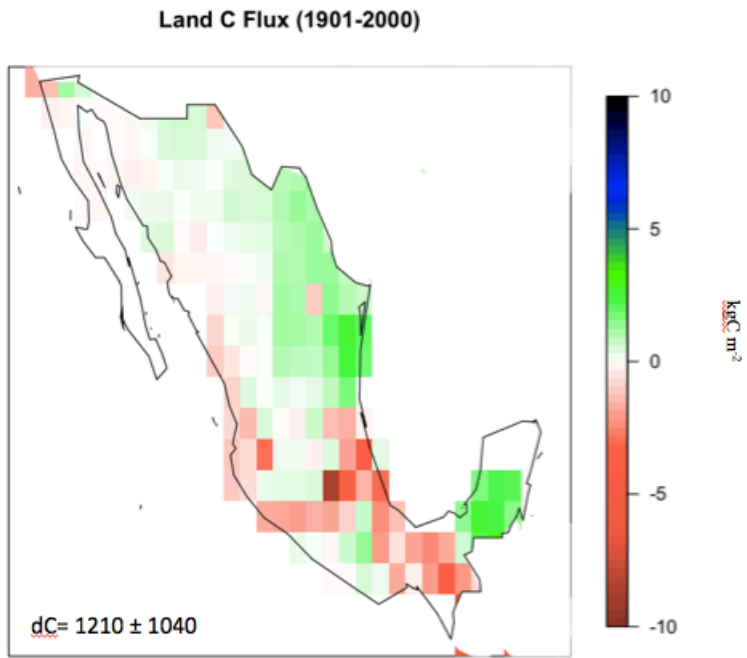
Figure 5: Land-C flux (NBP) for the period 1990-2009 ($\text{gC m}^{-2} \text{yr}^{-1}$). A positive value indicates a C sink and vice versa.

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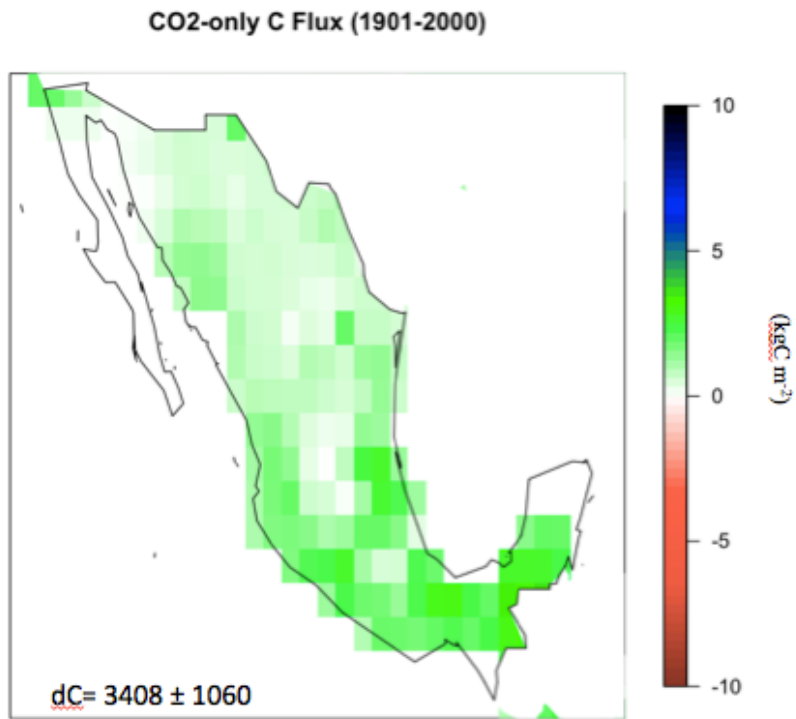
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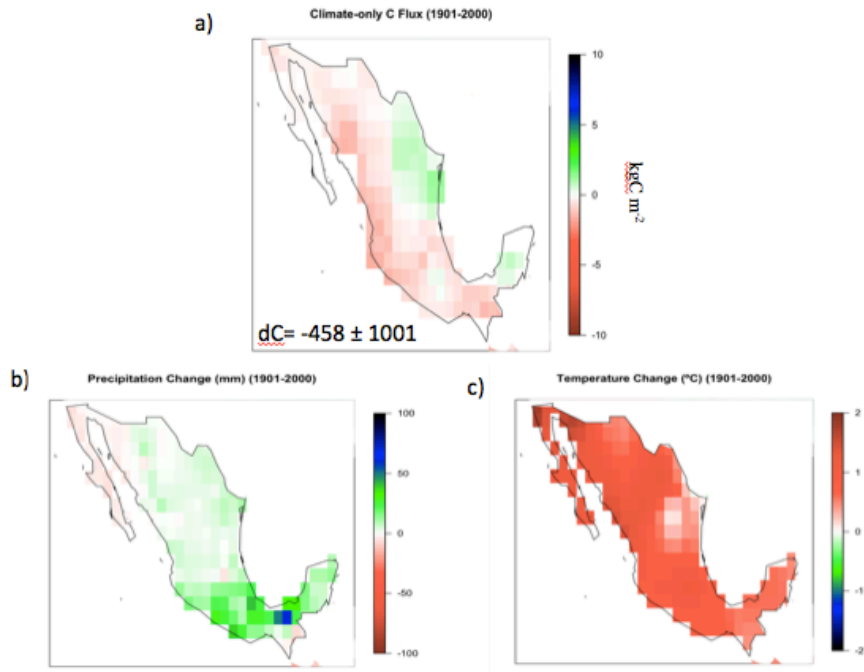


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 2 | Figure 6: Total change in land C during 1901-2000 (kgC m^{-2}). A positive sign indicates C
 3 gain. dC = total change in stored C (TgC).
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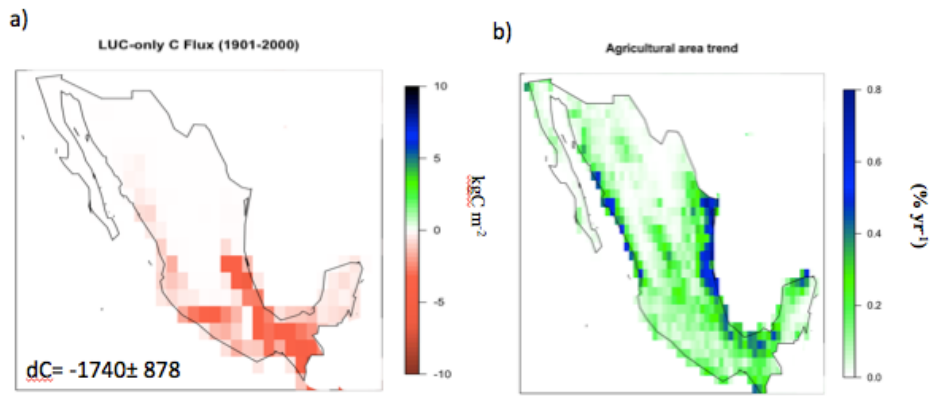
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 2 | Figure 7: Change in total stored C by the effect of CO₂-only over the period 1901-2000 (kgC
 3 m⁻²). A positive sign indicates C gain. dC= total change in stored C (TgC).
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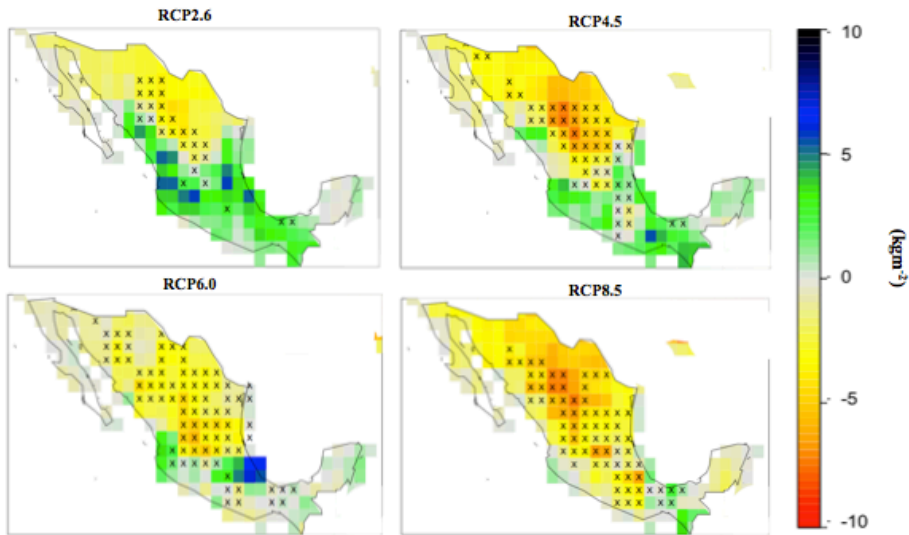
Figure 8: top) Change in stored C by the effect of climate-only for the period 1901-2000 (kgC m⁻²). A positive sign indicates C gain. dC= total change in stored C (TgC). Bottom) change in climate (precipitation and temperature) for the same time-period.



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 2 | Figure 9: a) Change in stored C by the effect of LULCC-only for the period 1901-2000 (kgC
 3 m⁻²). A positive sign indicates C gain. dC= total change in stored C (TgC). b) Agricultural
 4 area change for the same time period.
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Change in future land C (2010-2100)



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2 Figure 10: Gridded future change in total stored C for four RCPs for the period 2010-2100
3 | (kgC m^{-2}). The stippling represents areas where >66% of the ESMs models agree on the sign
4 of the flux.
5