The contribution of aerosol cooling to historical land carbon uptake

Rachel Law, Tilo Ziehn, Peter Vohrallik and Xingjie Lu*

CSIRO OCEANS AND ATMOSPHERE
www.csiro.au

Over recent decades the land biosphere has been a net carbon sink and it is important to understand what is driving that uptake. An Earth System Model, ACCESS-ESM1, has been used to test the sensitivity of land carbon uptake to the inclusion of anthropogenic aerosols over the period from 1850-2020. The simulations show a large reduction in land carbon uptake if aerosol cooling is not considered.

ACCESS-ESM1

The Australian Community Climate and Earth System Simulator (ACCESS) contributed to the Coupled Model Intercomparison Project (CMIP5) (Bi et al., 2013) and has since been extended to include the carbon cycle (Law et al., 2017). For land carbon, the model includes both nitrogen and phosphorus limitation but does not include land use change. Analysis of a historical simulation (Ziehn et al., 2017) showed the model compared reasonably with observations and other CMIP5 models.

Model simulations

Three sets of experiments have been performed:

1. 1850-2005, prescribed atmospheric CO_2, with (control) and without (noAA) anthropogenic aerosols. Three ensemble members for each.
2. Offline simulations of the land surface component of ACCESS (CABLE) for 1850-2012 with CRU-NCEP (Viovy 2009) meteorological forcing (control) and with a global temperature perturbation added to the forcing ('warmer'). The perturbation was the global ensemble mean land temperature difference between noAA and the control from Experiment 1, with 10 year smoothing applied (Figure 2, top).
3. 1850-2005, emissions driven simulation with interactive CO_2 and with (control) or without (noAA) anthropogenic aerosols.

Experiment 1 results

- noAA simulations (red) are warmer and wetter over land.
- Gross primary production (GPP) is smaller, as is leaf area index (LAI).
- Cumulative land carbon uptake since 1850 is reduced to less than 50 Pg C compared to around 150 Pg C in the control case. Control land carbon uptake is comparable to Global Carbon Budget estimates (Le Quéré et al., 2015).

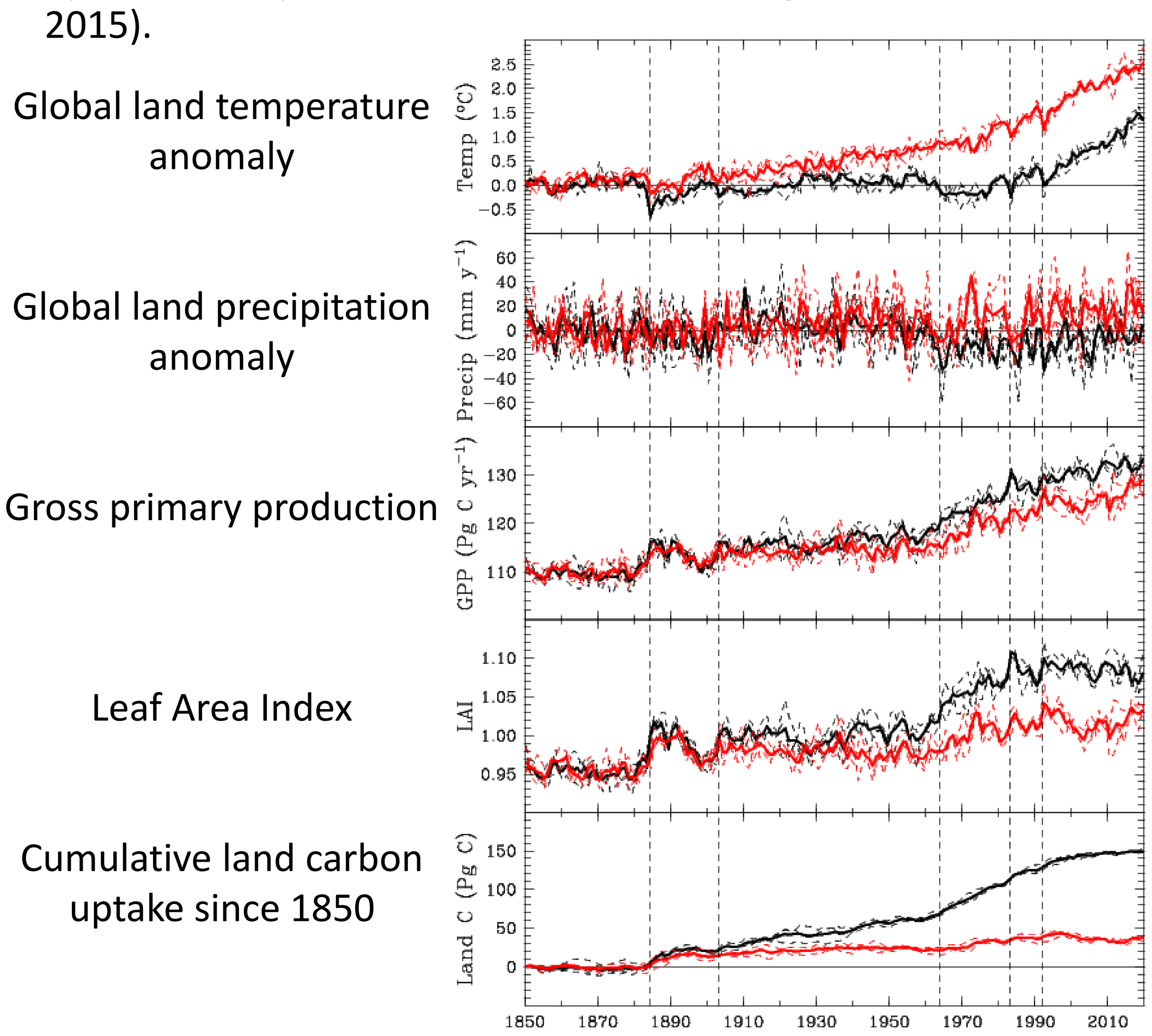

Figure 1: noAA (red) and control (black) for (top-bottom) global near-surface land temperature anomaly, global land precipitation anomaly, gross primary production, leaf area index and cumulative land carbon uptake from 1850. Temperatue and precipitation anomalies are relative to 1850-1859.

Experiment 2 results

- The reduction in land carbon uptake due to the warm temperature anomaly in the offline simulation (red) is similar to that produced in ACCESS when it is run with no anthropogenic aerosols (blue).
- This suggests that for the ACCESS model, temperature is the main driver of the reduction in land carbon uptake.

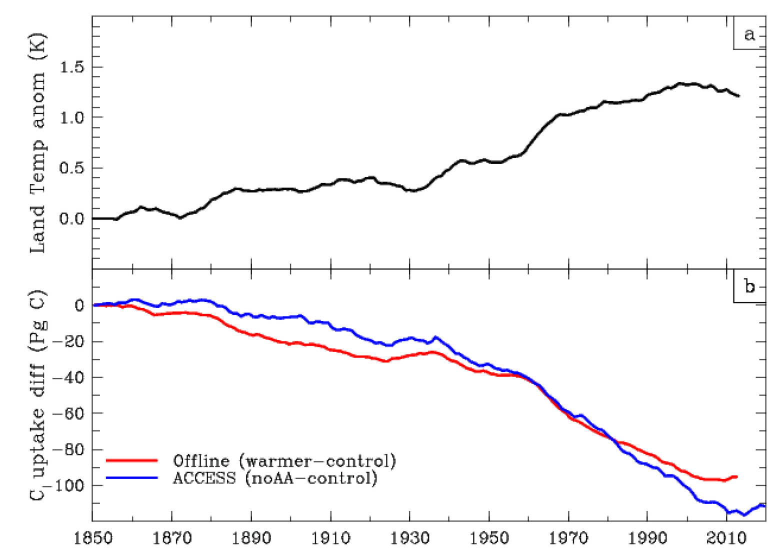

Figure 2: Global land temperature anomaly applied in the offline CABLE experiment 2 (top) and (bottom) the difference in cumulative land carbon uptake since 1850 from the ACCESS-ESM simulations (blue) and the offline CABLE simulations (red).

Experiment 3 results

- The emissions-driven control simulation (black, dotted) reproduces the prescribed atmospheric CO_2 (black, solid) and hence land temperature and land carbon uptake are similar.
- In the emissions-driven noAA simulation the smaller land carbon uptake due to warmer temperatures leads to increased atmospheric CO_2 compared to the prescribed CO_2 case. The increased atmospheric CO_2 moderates the reduction in land carbon uptake despite slightly enhancing temperature.

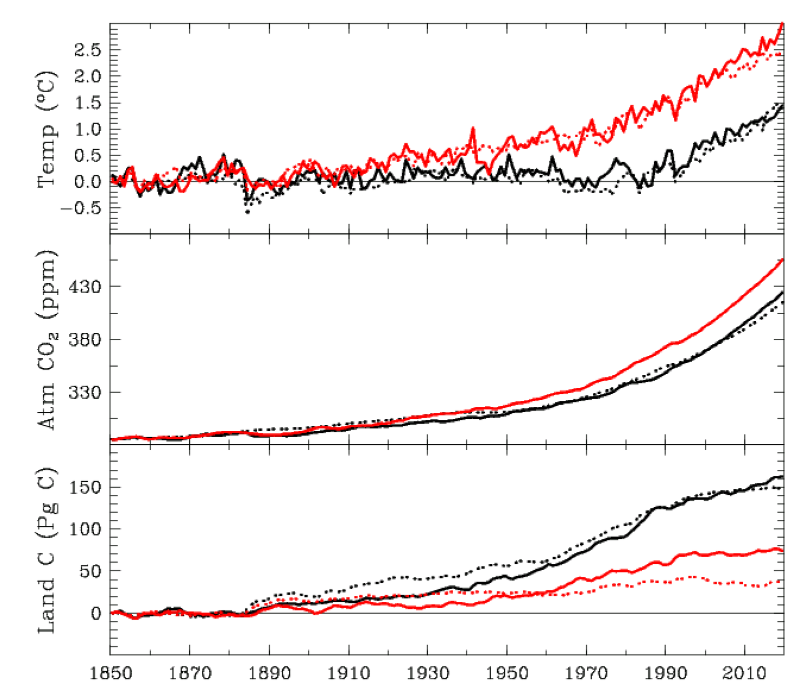

Figure 3: Global land temperature anomaly (top), atmospheric CO_2 from lowest model level (middle) and cumulative land carbon uptake from 1850 (bottom) for noAA (red) and control (black) emissions-driven simulations (solid) and prescribed CO_2 simulations (dashed).

Discussion

These model simulations suggest that the cooling caused by increased anthropogenic aerosols from 1950 onwards has also had a substantial impact on land carbon uptake. Land carbon uptake is influenced by atmospheric CO_2 concentration and by climate. If the planet had experienced greenhouse warming alone, our simulations suggest that increased carbon sinks due to increased atmospheric CO_2 would have been largely offset by changes in the carbon flux due to increased temperature. Including feedbacks between carbon and climate in the model simulation moderated that offset.

Anthropogenic aerosols are expected to decrease over coming decades. Our simulations would suggest that this could lead to enhanced warming and a relative reduction in land carbon uptake. This would leave more carbon in the atmosphere and provide a positive feedback on warming.

FOR FURTHER INFORMATION
Rachel Law
e rachel.law@csiro.au

* Now at Department of Microbiology and Plant Biology, University of Oklahoma, USA

REFERENCES

Bi, D., et al.: The ACCESS coupled model: description, control climate and evaluation, Aust. Meteor. Oceanogr. J., 63, 41–64, 2013b.
Law, R. M., et al.: The carbon cycle in the Australian Community Climate and Earth System Simulator (ACCESS-ESM1) – Part 1: Model description and pre-industrial simulation, Geosci. Model Dev., 10, 2567-2590, https://doi.org/10.5194/gmd-10-2567-2017, 2017.
Le Quéré et al.: Global Carbon Budget 2015, Earth System Science Data, 7, 349-396, doi:10.5194/essd-7-349-2015, 2015.
Viovy, N.,ftp://nacp.ornl.gov/synthesis/2009/frescati/temp/land_use_change/original/readme.htm, 2009.
Ziehn, T., et al.: The carbon cycle in the Australian Community Climate and Earth System Simulator (ACCESS-ESM1) – Part 2: Historical simulations, Geosci. Model Dev., 10, 2591-2614, https://doi.org/10.5194/gmd-10-2591-2017, 2017

ACKNOWLEDGEMENTS
This research was supported in part by the Australian Climate Change Science Programme and undertaken on the NCI National Facility in Canberra, which is supported by the Australian Commonwealth Government.