Impact of a regional drought on terrestrial carbon fluxes and atmospheric carbon: Results from a coupled carbon cycle model

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Global Modeling & Assimilation Office

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GC21C-0958, 2017 AGU Fall Meeting

INTRODUCTION

Understanding the underlying processes that control the carbon cycle is key to predicting future global change. Much of the uncertainty in the magnitude and variability of the atmospheric carbon dioxide (CO_2) stems from uncertainty in terrestrial carbon fluxes, and the relative impacts of temperature and moisture variations on regional and global scales are poorly understood. Here we investigate the impact of a regional drought on terrestrial carbon fluxes and CO_2 mixing ratios over North America using the NASA Goddard Earth Observing System (GEOS) Model. Results show a sequence of changes in carbon fluxes and atmospheric CO_2, induced by the drought. The relative contributions of meteorological changes to the neighboring carbon dynamics are also presented. The coupled modeling approach allows a direct quantification of the impact of the regional drought on local and proximate carbon exchange at the land surface via the carbon-water feedback processes.

RESEARCH QUESTIONS

- To what extent do changes in temperature, rainfall and CO_2 driven by a regional Spring drought affect land carbon fluxes and productivity?
- Does interactive phenology help to lengthen or shorten an agricultural drought?

METHODS

- Models: GEOS-5 AGCM with a newly instituted land-atmosphere CO_2 coupling; additional offline land only (Catchment-CN) simulations
- The 80-member ensembles of GEOS-5 simulations:
  i) CTRL: a control ensemble
  ii) DryS (or DryL): an ensemble with an artificially imposed drought on Region S (or Region L) from APR to JUN, followed by a 3-month recovery period.

Two Regions of Imposed Spring Drought

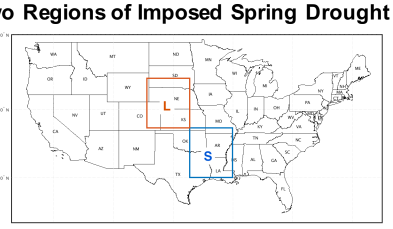

Figure 1: "L" represents a region of lower productivity with frequent droughts, and "S" a region of higher productivity with less frequent droughts. Definitions of the regions are as denoted in Koster et al. (2016).

Simulating Land-Atmosphere Feedback with CO_2 coupling

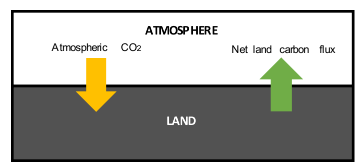

Figure 2: Schematic figure of GEOS-5 AGCM with interactive carbon coupling.

In the interactive CO_2 coupling, the land component (i.e., Catchment-CN) uses the atmospheric CO_2 generated by AGCM, and provides net land carbon flux to the atmosphere.

RESULTS

1. A Spring drought has a footprint on land carbon dynamics that persists during the recovery period, and affects the carbon productivity in neighboring areas mostly due to remote changes in temperature and water availability.
2. The carbon flux change due to the induced CO_2 fertilization effect acts only slightly to mitigate the meteorology effects.

Induced Changes by a Spring Drought (DryS example)

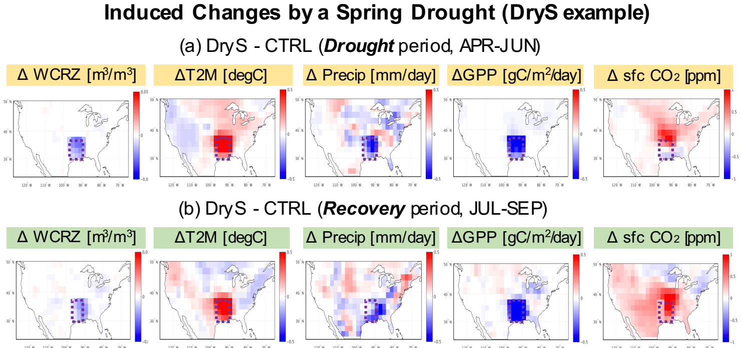

Figure 3: Changes in root-zone water content (WCRZ), 2m air temperature (T2M), Precipitation, Gross Primary Production (GPP), and atmospheric CO_2 concentration at the land surface during (a) drought period and (b) recovery period. All changes are DryS minus CTRL.

Impact on a Remote Area (Eastern Side of the Region S example)

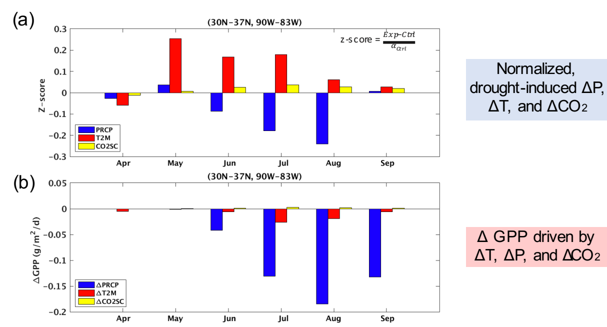

Figure 5: (a) Normalized anomalies of precipitation, temperature, and CO_2, which are caused by drought (from Fig. 3) and (b) the changes in GPP associated with the forcing anomalies (from Fig. 4) of the east side of the Region S. The GPP reduction is predominantly caused by ΔP.

Relative Contributions of Isolated Drivers to GPP (DryS example)

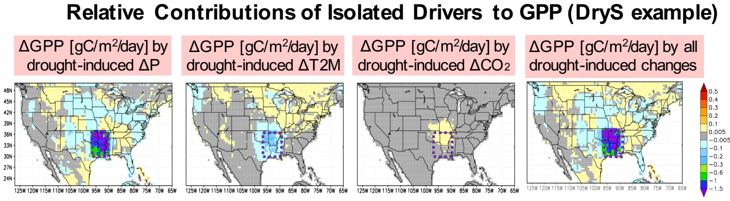

Figure 4: June ΔGPP (local and remote) from isolated and combined contributions of precipitation, temperature, and CO_2 anomalies that are caused by the drought imposed in the Region S. The offline Catchment-CN model was used to isolate the induced changes in the meteorological drivers by the coupled model (from Fig. 3).

[Ongoing work] Effect of C Status on Soil Moisture Recovery

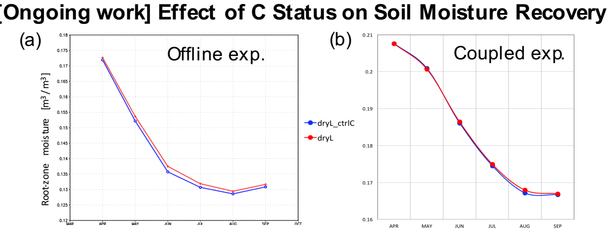

Figure 6: Responses of the root-zone soil moisture [m^3/m^3] in the *Region L* to the drought-free LAI and carbon status: (a) Offline Catchment-CN and (b) Coupled Catchment-CN to the atmosphere in GEOS-5.

[Reference] Koster, R. D., Chang, Y., Wang, H., & Schubert, S. D. (2016). Impacts of Local Soil Moisture Anomalies on the Atmospheric Circulation and on Remote Surface Meteorological Fields during Boreal Summer: A Comprehensive Analysis over North America. *Journal of Climate*, 29(20), 7345–7364. https://doi.org/10.1175/JCLI-D-16-0192.1

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