Studying land-atmosphere feedbacks via coupling of the global carbon cycle

Eunjee Lee

with Randal Koster, Fanwei Zeng, Lesley Ott, Sarith Mahanama, Brad Weir, Benjamin Poulter

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Overview

1. NASA GMAO
2. Impact of atmospheric CO_2 variability on the global land carbon fluxes
3. AGCM study with fully coupled carbon-water-energy cycles between land and the atmosphere

Satellites Support Earth System Science

https://svs.gsfc.nasa.gov/30701

Themes of GMAO’s Research and Products

Weather Analysis and Prediction

Seasonal-to-Decadal Prediction

Reanalysis

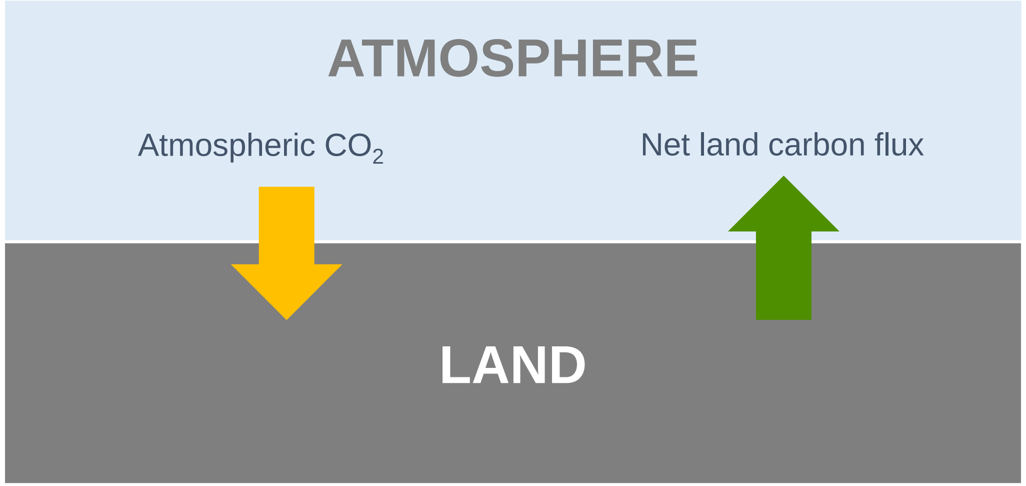
Multi-Scale Modeling

Observing System Science

- Central theme is to use, support, and plan for NASA’s Earth Observations
- Goddard Earth Observing System (GEOS) model and data assimilation system central to all components
- Modular system is highly flexible, can be configured to increase complexity depending on application
- Aerosol, carbon, and composition cut across, represented in each theme

Courtesy of Lesley Ott

Connecting the land and atmospheric branches of the carbon cycle
Simulating land-atmosphere feedback



A new capability in the NASA GEOS system:

(i) allows modeled atmospheric CO_2 to affect land surface carbon uptake, and

(ii) uses modeled net CO_2 uptake at the land surface as a source or sink for the atmospheric CO_2,

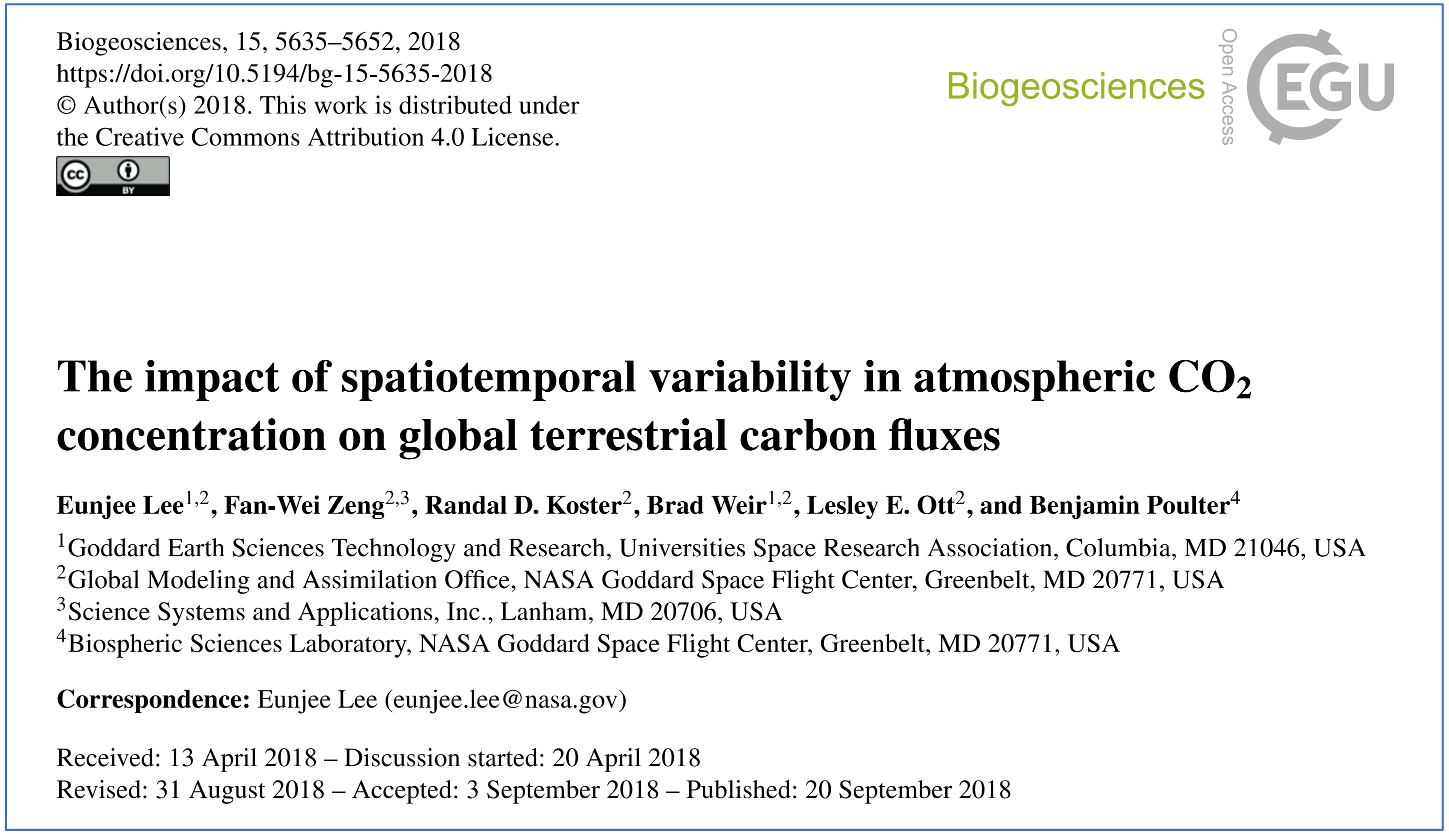
(iii) thus enables **carbon cycle feedbacks** alongside **water & energy cycle feedbacks**

Offline study

A part of special issue, The 10th International Carbon Dioxide Conference (ICDC10)

How sensitive are the land carbon fluxes to the atmospheric CO_2 variability?

- Is the common practice of using annually increasing global CO_2 in the offline LSM/TBM studies good enough?
- The sensitivity of terrestrial carbon cycle fluxes to multiple facets of the spatiotemporal variability in atmospheric CO_2 is quantified.
- Model: Offline Catchment-CN model
- Meteorological forcing: MERRA-2
- CO_2 forcing: NOAA CarbonTracker



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The impact of spatiotemporal variability in atmospheric CO_2 concentration on global terrestrial carbon fluxes

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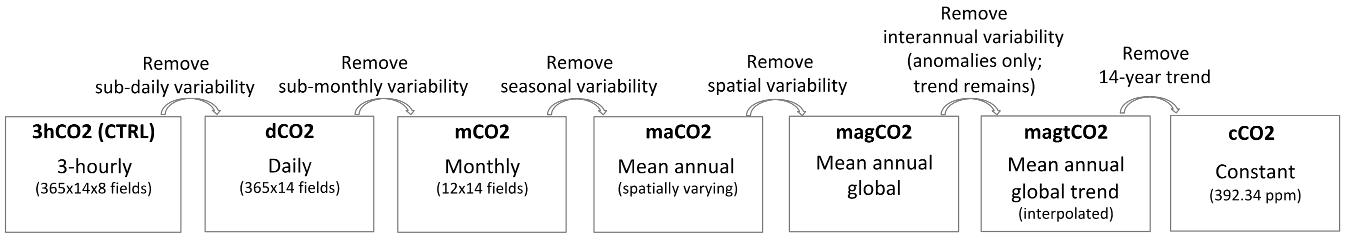


3hCO2 (CTRL)
3-hourly
(365x14x8 fields)

Remove
sub-daily variability

dCO2
Daily
(365x14 fields)

Remove
sub-monthly variability

mCO2
Monthly
(12x14 fields)

Remove
seasonal variability

maCO2
Mean annual
(spatially varying)

Remove
spatial variability

magCO2
Mean annual
global

Remove
interannual variability
(anomalies only;
trend remains)

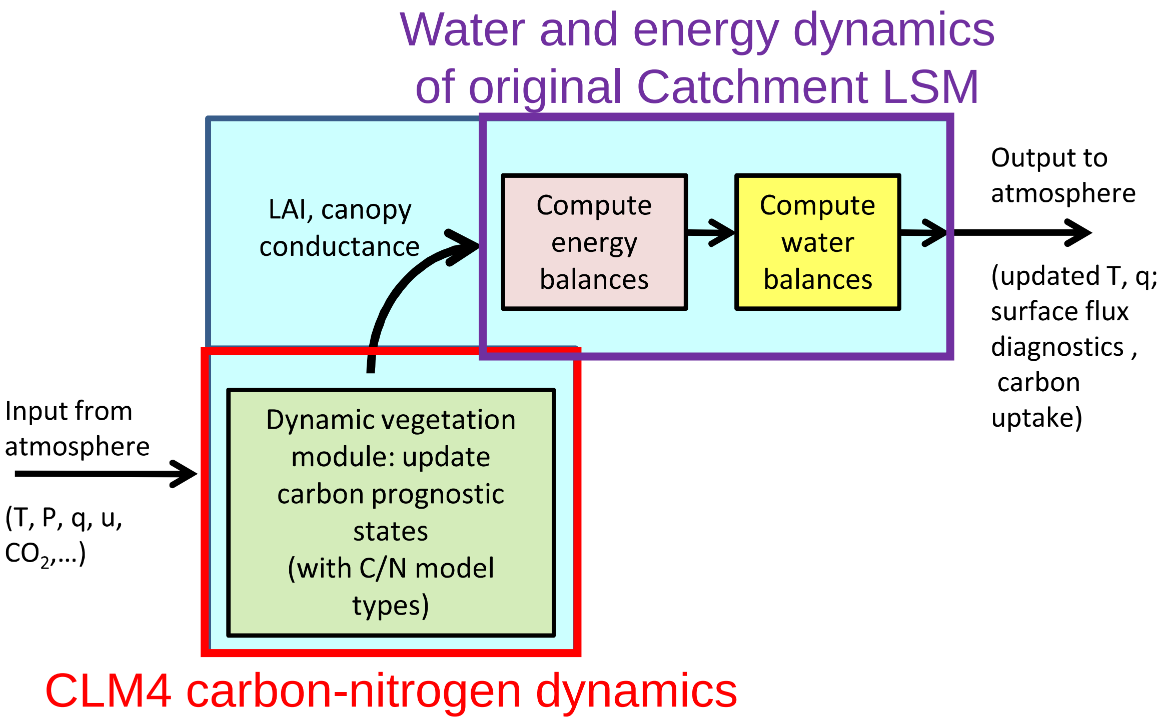
magtCO2
Mean annual
global trend
(interpolated)

Remove
14-year trend

cCO2
Constant
(392.34 ppm)

Catchment-CN model

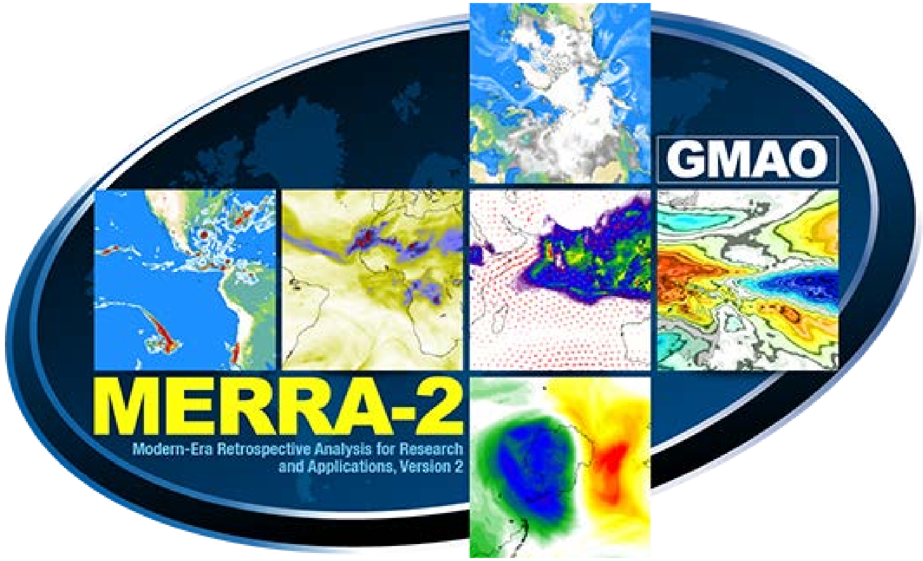
- Land component in NASA GEOS system
- Merger of Catchment LSM & CLM4 CN dynamics
- Based-on tiles (subsets of catchments)
- Each land surface element (i.e., tile) is subdivided into three static vegetation zones (valley bottoms, lower hill slopes, and upper hill slopes)
- Soil moisture and temperature information from the dynamically varying hydrological zones are area-weighted for the fixed vegetation zones
- References
  - Model description: Koster et al. (2014), *J Clim*
  - GPP, NBP validations: Lee et al. (2018), *Biogeosciences*



Koster et al. (2014)

Meteorological forcing: MERRA-2

- NASA GMAO reanalysis product
- Available for 1980-present
- 0.5º x 0.625º
- Hourly
- https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/



Diurnal variation in atmospheric CO_2 forcing

- The temporal variability in CO_2 compensates for mean global GPP increase due to the spatial variability, reducing overall global GPP.
- Consideration of the **diurnal** variability in atmospheric CO_2 reduces mean global annual GPP by 0.5 PgC/yr and net land carbon uptake by 0.1 PgC/yr.

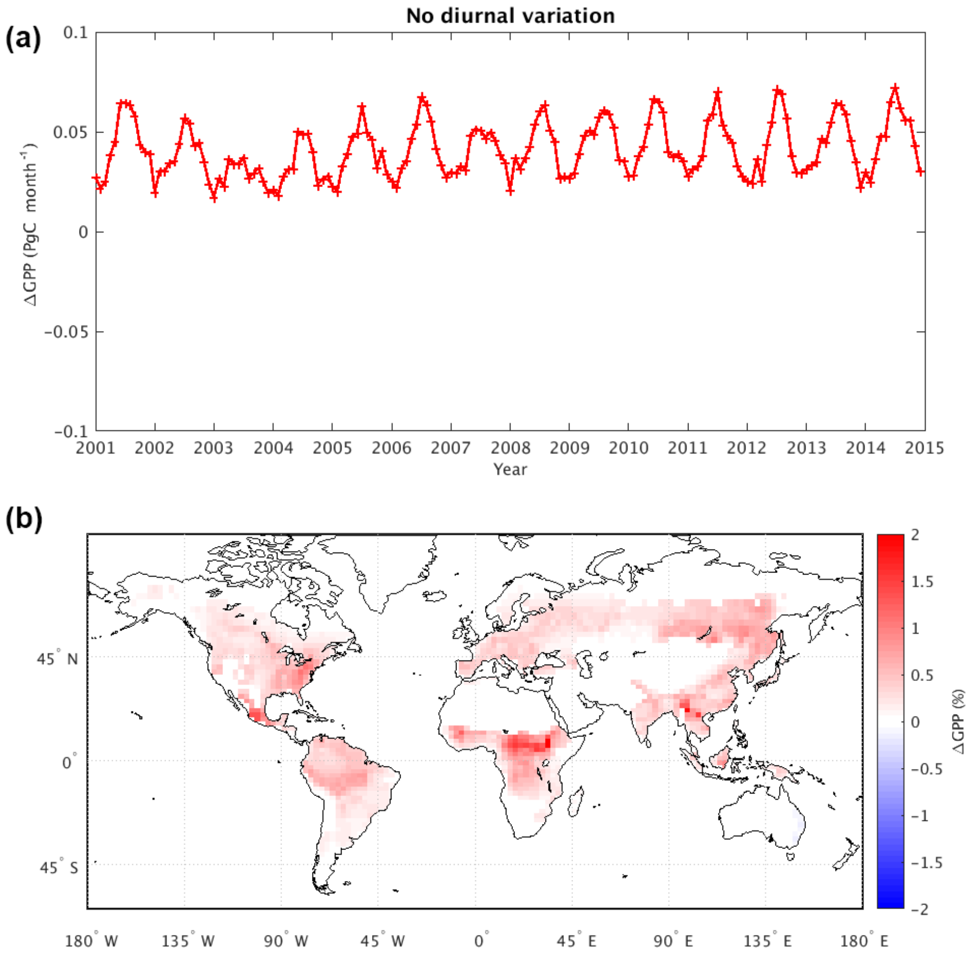


Figure 4. (a) Change in mean global GPP (Pg C month^{-1}) due to removal of diurnal variability in atmospheric CO_2 concentration (i.e., GPP from the dCO2 experiment minus that from the control). **(b)** Map of time-averaged GPP changes as a percentage (%). The tile-based model GPP values were aggregated to 2° × 2.5° for visualization purposes.

Lee et al. (2018)

Offline study

Contribution of each variability in atmospheric CO_2 may differ seasonally and regionally

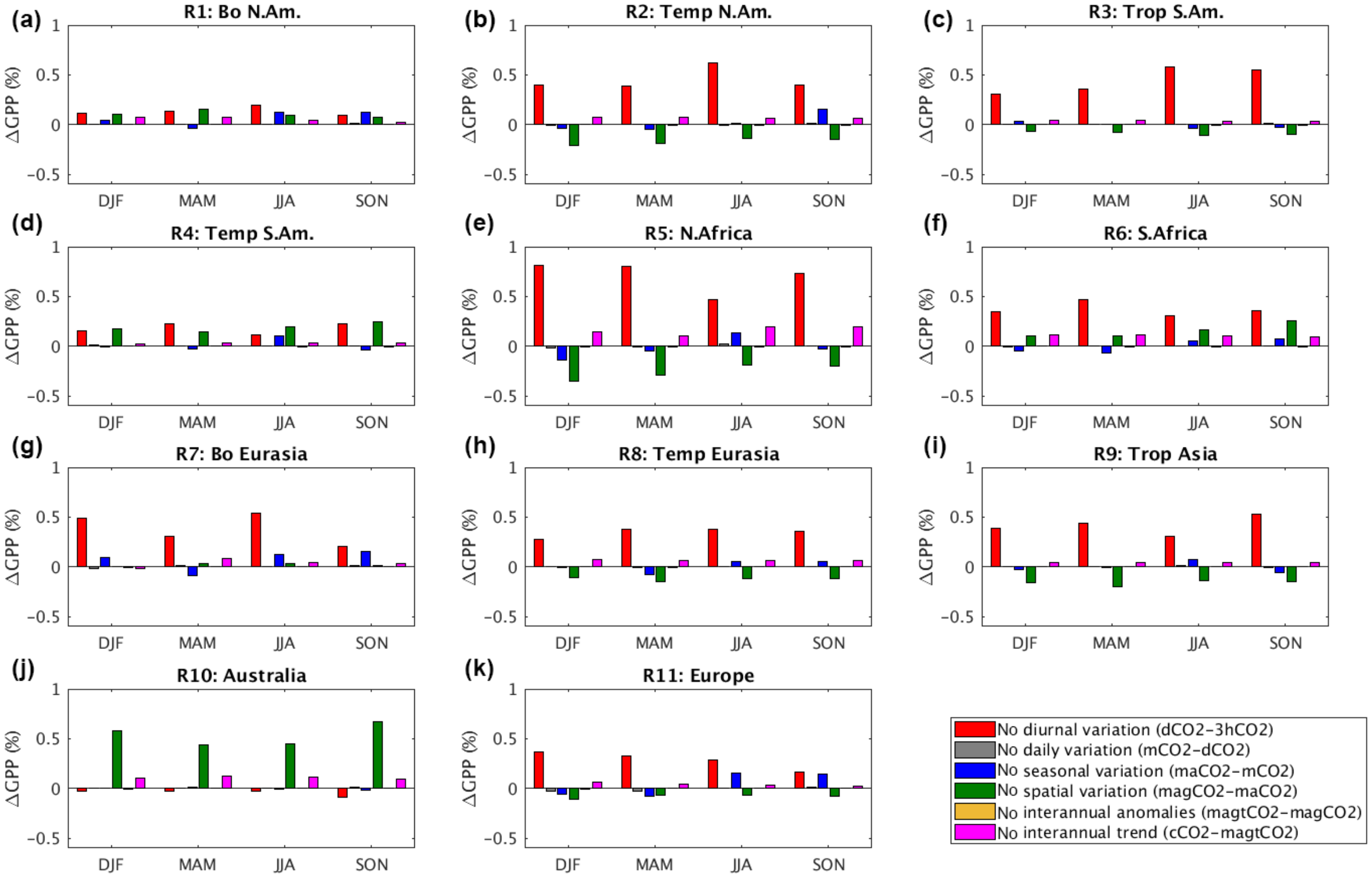


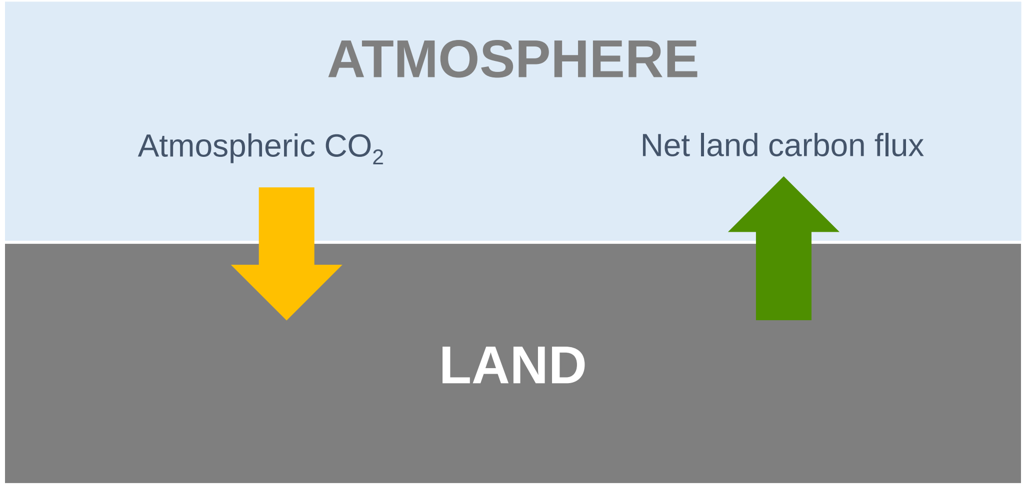
Figure 8. Regional- and seasonal-scale impacts of spatiotemporal CO_2 variabilities on GPP. Incremental change in GPP associated with each added facet of CO_2 variability is shown as a percentage of the previous experiment's regional GPP. The map in **(l)** shows the regional boundaries of TransCom land regions (reconstructed from the basis function map in http://transcom.project.asu.edu/transcom03_protocol_basisMap.php, last access: November 2017).

Lee et al. (2018)

Summary and implication to the land-atmospheric feedback studies

1. The Coupled Model Intercomparison Project Phase 6 (CMIP6) has recently proposed increased spatial and temporal resolutions for the surface CO_2 concentrations used to calculate GPP, and this study offers a full set of evaluation of the consequences of the increased resolution for carbon cycle dynamics.
2. In terms of estimating global GPP, the magnitudes of the sensitivities are minor, indicating that the common practice of applying spatially uniform and annually increasing CO_2 (without higher-frequency temporal variability) in offline studies is a reasonable approach.
3. For certain regional and seasonal-scale GPP estimations, the proper treatment of spatiotemporal CO_2 variability appears important.

Connecting the land and atmospheric branches of the carbon cycle
Simulating land-atmosphere feedback



A new capability in the NASA GEOS system:

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(ii) uses modeled net CO_2 uptake at the land surface as a source or sink for the atmospheric CO_2,

(iii) thus enables **carbon cycle feedbacks** alongside **water & energy cycle feedbacks**

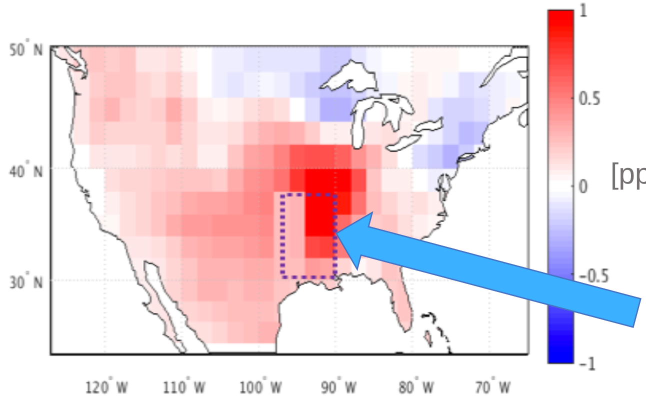
L-A coupling study

Impact of a regional drought on local and proximate C exchange and atmospheric CO_2 via the water-carbon feedback processes

To what extent do changes in T, P and CO_2 driven by a regional Spring drought affect land carbon fluxes and productivity?

- Two sets of 80-member ensembles of free running GEOS AGCM simulations
- Control ensemble vs. DryS ensemble
  - Control ensemble is with no imposed artificial drought
  - DryS ensemble is with an artificially imposed drought on Region S (boxed region) from April to June, followed by a 3-month recovery period
  - 2012 SST was applied for all members

Δ mean model surface CO_2 during recovery period (JAS)
(anomaly relative to no drought ensemble suite)



In GEOS ensemble runs, imposing a drought here during April to June…

…leads to lower soil water and leaf area index (LAI) during April to September

➪ Reduced GPP and net carbon uptake by land

➪ Increased atmospheric CO_2 across the US.

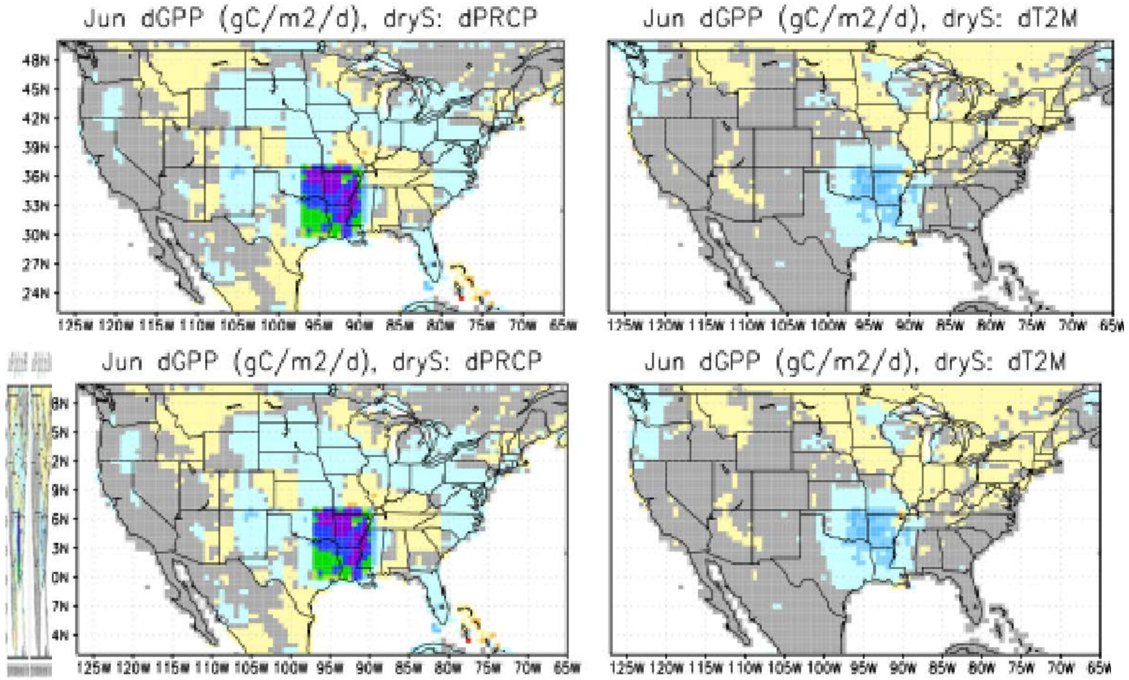
L-A coupling study

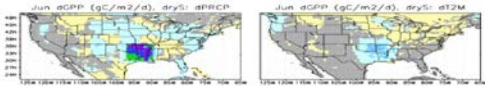
Impact of a regional drought on local and proximate C exchange and atmospheric CO_2 via the water-carbon feedback processes

To what extent do changes in T, P and CO_2 driven by a regional Spring drought affect land carbon fluxes and productivity?

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

Δ GPP from offline model driven by anomalies from AGCM





Eco-climate teleconnection (magnitudes, temporal scale of disturbance/drought)?

Ongoing work
Land carbon flux vs. atmospheric transport

What are the relative contributions of land carbon fluxes and atmospheric transport to spatiotemporal variations in atmospheric CO_2?

- GEOS AGCM simulations in replay mode
    - Forces the model to reproduce the weather systems captured by the MERRA-2 reanalysis
- In the control AGCM simulation, the land carbon fluxes and the atmospheric CO_2 concentrations, as well as the meteorology, are simulated over 2001-2015.
- In the experiment AGCM simulation, the climatological seasonal cycles of net land carbon production from the control simulation are prescribed in the same replay mode.
- Difference is the contribution of the variability associated with land carbon fluxes.

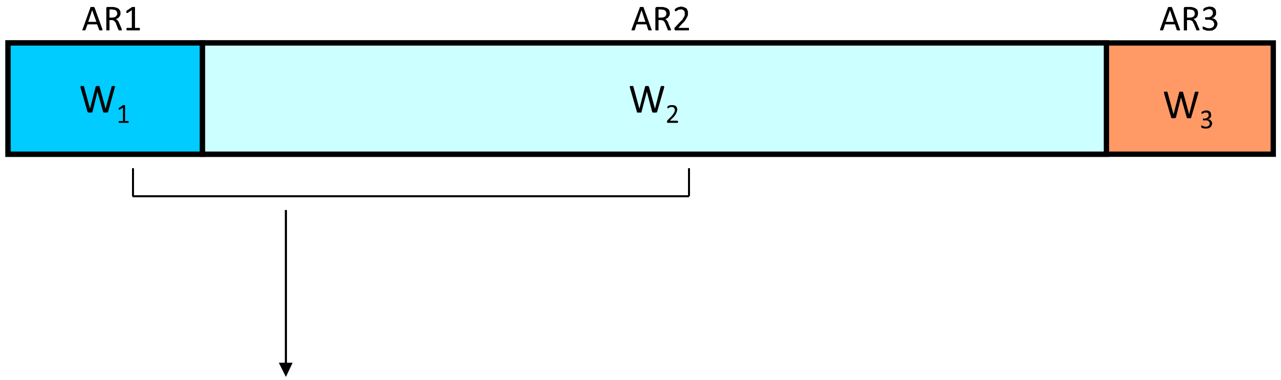
Another on-going work is to co-investigate the NASA Interdisciplinary science project “Integrating remote sensing observations with NASA’s GEOS-5 modeling framework in support of retrospective analyses and seasonal prediction” led by Lesley Ott (collaboration among GMAO, UMD and UCI).

Extra slides

Catchment-CN model

Dynamic hydrological zones

Areas (AR1, AR2 and AR3) change with time, so as the soil moisture states (W1, W2, and W3)



Static carbon zones

Areas (10%, 45%, and 45%) are fixed

Each zone allows up to 4 PFTs that compute photosynthesis physics and update carbon states

getation zones. Weighted averages of vegetation zone quantities (e.g., canopy conductance) are similarly passed back to the hydrological zones.

Koster et al. (2014), J Clim

Offline study

Evaluation of carbon fluxes

(Catchment-CN model driven by MERRA-2)

GPP

2002-2011 mean

Catchment-CN

MTE-GPP

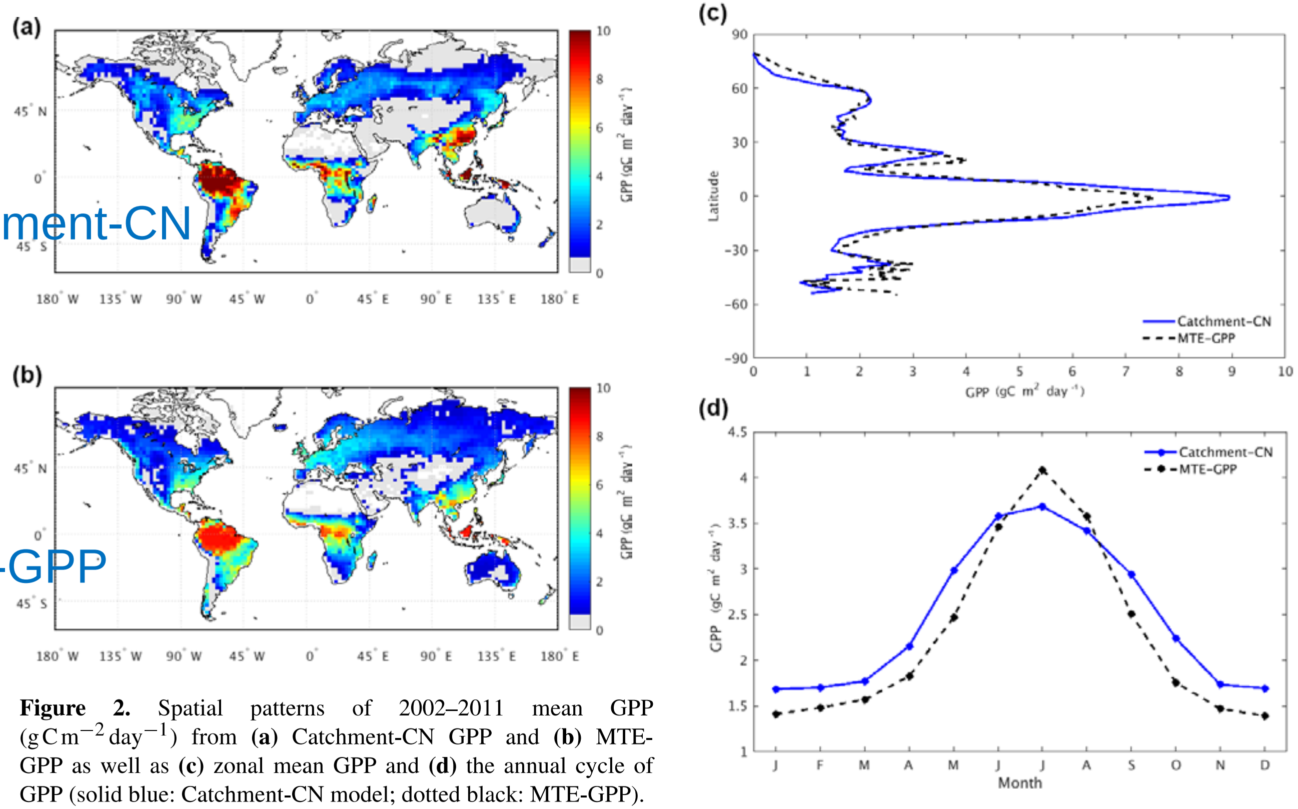


Figure 2. Spatial patterns of 2002–2011 mean GPP ($\mathrm{g\,C\,m^{-2}\,day^{-1}}$) from **(a)** Catchment-CN GPP and **(b)** MTE-GPP as well as **(c)** zonal mean GPP and **(d)** the annual cycle of GPP (solid blue: Catchment-CN model; dotted black: MTE-GPP).

NBP

2004-2014 mean

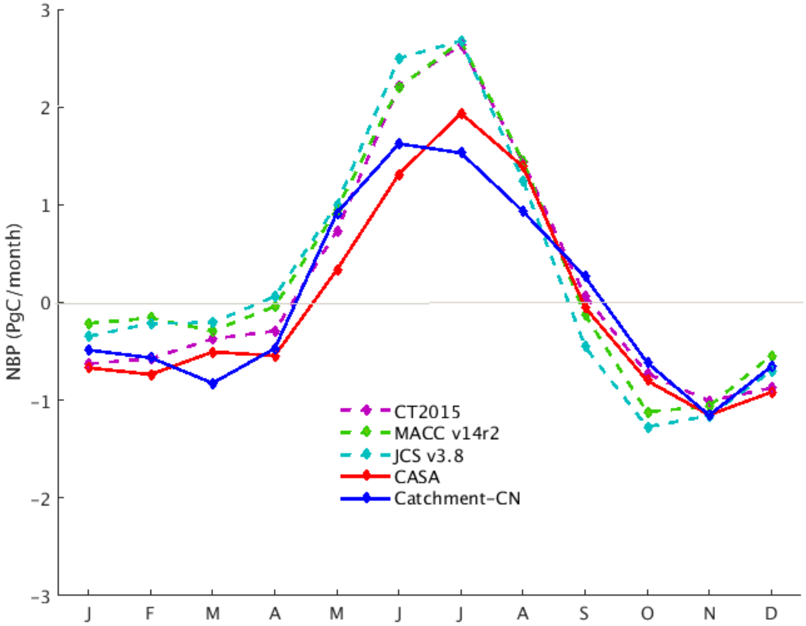


Figure 3. Monthly mean of terrestrial NBP of the Catchment-CN model (blue), of the CASA GFED3 model (red) and of three atmospheric inversions (dotted lines), for the period of 2004–2014. Positive (negative) NBP values indicate that land is a carbon sink (source).

Lee et al. (2018)