Improving CLM5.0 Biomass and Carbon Exchange across the Western US using Data Assimilation (DART)

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Carbon Monitoring Across Western US

- Vulnerable carbon stocks create drastic change to landscape and ecosystem functioning
- Complex terrain challenges traditional carbon monitoring, flux towers, atmospheric inversions

**Top-Down Modeling**

- Atmospheric CO₂
  - Atm. Transport Model
  - Land carbon exchange

**Bottom-Up Modeling**

- Weather/Climate
  - Land Surface Model (CLM)
  - Land carbon exchange

US Drought Monitor, June 10, 2021
CLM5-DART Overview

CAM4 DART Reanalysis (80 member ensemble)

Observations

Aboveground Biomass (gC m⁻²)
Liu et al., (2015)

Leaf Area (m² m⁻²)
Zhu et al., (2015)

CLM 5 terrestrial biosphere model

Initial Prior State

Fluxes:
NEP + Δ
GPP + Δ
ER + Δ
ET + Δ

Biomass
Leaf Area

Biomass + Δ
Leaf Area + Δ

New Posterior State

Fluxes:
NEP + Δ
GPP + Δ
ER + Δ
ET + Δ

Biomass
Leaf Area

Assimilate

Unobserved Variables

Ensemble estimated Biomass ‘observation’ (prior state)

‘Forward operator’

Live Stem C
Dead Stem C
Leaf C

‘Observed’ Aboveground Biomass (gc m⁻²)

Applies update to PFTs and columns in restart file

Ensemble Adjusted Biomass (posterior state)
Single Instance Spinup Simulation

- Compset CLM5_BGC_Crop
- 200yr AD spin, 1000yr spin, transient (1850)
- Spatial Resolution (0.95°X1.25°)
- Spinup Meteorological Forcing: GRIDMET (Buotte et al., 2019)

Assimilation Run

- 80 ensemble members (CAM4 Reanalysis)
- Assimilation time window: 1998-2011, 3 cycles (looping)
- Adaptive Inflation
CLM5-DART Methods/Terminology

- Remotely Sensed ‘Observations’
  (1.25°x0.95°)

- Observation Rejection Threshold: 3 sigma

- Spatial Localization:
  Horizontal range: ~100 km

- State Space Localization:
  Select most important variables for carbon cycling

Monthly Aboveground Biomass (AGB)

- Global Data Sets of Vegetation Leaf Area Index (LAI)3g and Fraction of Photosynthetically Active Radiation (FPAR)3g Derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) for the Period 1981 to 2011

Monthly Leaf Area Index (LAI)

- Recent reversal in loss of global terrestrial biomass
  Liu et al., (2015) *Nature Climate Change*

‘Standard’ Adjusted State Variables (Biomass C, N)

- Leaf carbon
- Live stem carbon
- Dead stem carbon
- Leaf area index
- Fine root carbon
- Live coarse root carbon
- Dead coarse root carbon

- Leaf nitrogen
- Fine root nitrogen
- Live coarse root nitrogen
- Dead coarse root nitrogen
- Live stem nitrogen
- Dead stem nitrogen
Observations reduce biomass/leaf area, net carbon flux steady

- 31 and 27% reduction in AGB and LAI respectively

<table>
<thead>
<tr>
<th>Simulation Name</th>
<th>AGB (kgC m⁻²)</th>
<th>LAI (m² m⁻²)</th>
<th>GPP (gC m⁻² month⁻¹)</th>
<th>ER (gC m⁻² month⁻¹)</th>
<th>NEP (gC m⁻² month⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free</td>
<td>1.98</td>
<td>1.31</td>
<td>48.18</td>
<td>47.18</td>
<td>1.00</td>
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<td>CLM5-DART</td>
<td>1.36</td>
<td>0.96</td>
<td>38.49</td>
<td>37.21</td>
<td>1.28</td>
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</tbody>
</table>
**LAI**: steady acceptance rate (90%) seasonal dependence, RMSE steady

**AGB**: increasing acceptance rate (75%), decreasing RMSE
Behavior for dominant PFTs within domain

- Crops have much smaller adjustments than natural vegetation
CLM5-DART simulates weak carbon sink compared to FLUXCOM

- CLM5-DART (red) reduces biomass states create offsetting reductions in GPP and ER compared to free run

- Difference due to disturbance history?
- Need more adjusted variables in CLM5-DART?
CLM5-DART simulates weak carbon sink compared to FLUXCOM

1998-2011 Average Fluxes

Weak, neutral uptake

Strong uptake
Water limitation shapes carbon uptake pattern

- Soil moisture limitation and GPP highly correlated (spring: R=0.64; summer: R=0.67)

- Simulated snow has low bias

**Spring (1998-2011)**

**Summer (1998-2011)**

Soil moisture limitation

GPP

Snow water equivalent
Impact of adjusted variables (loop 3 only)

Adjusted variables

- Net land carbon uptake (cumulative NEP) is near neutral for all assimilation runs

Other variables

• Would flux behavior change if soil carbon was directly adjusted?
Key Points

• Assimilating observations of biomass and leaf area reduced simulated biomass and projects a weak land carbon sink across the Western US.

• The estimate of carbon uptake was robust across various assimilation setup settings.

• Our estimate of carbon exchange contrasts with an independent FLUXCOM estimate that shows a significant carbon sink in the Western US.

• Water cycle observations should be used to complement biomass observations to improve the spatial pattern of modeled carbon fluxes.

Improving CLM5.0 Biomass and Carbon Exchange across the Western US Using a Data Assimilation System

Brett Raczka, Tim Hoar, Henrique Duarte, Andy Fox, Jeff Anderson, David Bowling John Lin

**Accepted; JAMES**
Additional data streams help constrain carbon cycling

Using high res land cover maps for improved forward operators (PFT specific).

Finer Spatial Resolution?

Parameter Estimation

Atmosphere:
- CAM4 Reanalysis (~2°)  
  Ds199.1 | DOI: 10.5065/38ED-RZ08
- CAM6 Reanalysis (~1°)  
  Ds345.0 | DOI: 10.5065/JG1E-8525

Land surface:
For more information:

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