Joint assimilation of leaf area index and aboveground biomass into CLM significantly reduces carbon uptake and storage in the Arctic and Boreal Region.

Xueli Huo[1], Andrew Fox[2], Alistair Rogers[3], Hamid Dashti[4], Charles Devine[1], Brett Raczka[5], William Kolby Smith[1], & David Moore[1]

1. University of Arizona 2. Joint Center for Satellite Data Assimilation 3. Brookhaven Natl Lab 4. University of Wisconsin-Madison 5. National Center for Atmospheric Research

NASA ABoVE 18-TE18-0002

Introduction

Carbon storage in the Arctic and Boreal zone is a key control of the global carbon cycle. Future projections of carbon uptake and storage are strongly controlled by model estimates of current leaf area index (LAI) and vegetation biomass. The Community Land Model (CLM) over-estimates both LAI and aboveground biomass in the Arctic and Boreal (ABoVE) region. We assimilated the LAI (MODIS) and annual aboveground biomass (Wang et al 2021) into CLM using an Ensemble Adjustment Kalman Filter (EAKF) implemented by the Data Assimilation Research Testbed (DART). This resulted in significant decreases in above ground carbon stock estimates by CLM.

Model set up and Data Assimilation

Preparation

1. Generate surface dataset and domain dataset at the resolution 0.25ox0.25o.
2. Spin up model for 1080 years and check the equilibrium with one ensemble forcing.
3. Generate ensemble spread. Cycle CLM for three times with 80 CAM6 ensemble forcing over period from 2011 to 2019.

DART-CLM

CLM: PPE.n01_ctsm5.1.dev012
Resolution: 0.25ox0.25o
Forcing Data: CAM6 reanalysis ensemble (0.9degx1.25deg)
Number of Ensembles: 40
Time: 2011 Jan 1st to 2019 December 31st

DART (Data Assimilation Research Testbed)

Observation

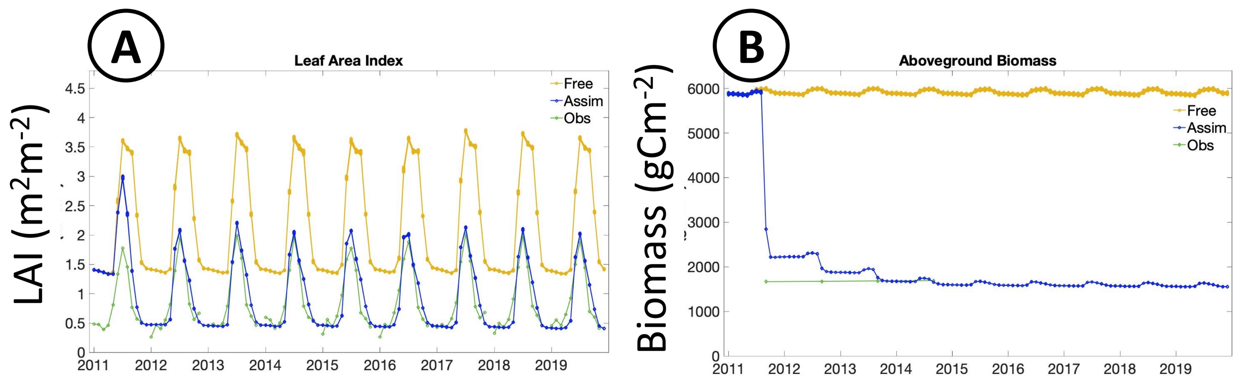
1. NASA MODIS leaf area index (LAI) which is an 8-day 500m satellite data product from 2011 to 2019.
2. Aboveground biomass (annual) from 2011 to 2014 (Wang et al 2021).

Assimilation

Apply a large inflation value in summer and a small inflation value in other seasons to avoid a high spatial heterogeneity of LAI occurring due to the uneven spatial availability of LAI observation with time.
Set the assimilation time step to be the same as that of LAI, 8-day, and assign the date of the annual biomass to be Sep 5 in 2012 and Sep 6 in 2011, 2013, and 2014 to enable the biomass observation assimilated on assimilation date.
Update displayed carbon pools (leaf, livestemc, deadstemc and root) and vertical decomposition pools (coarse wood debris, litter and soil carbon) when assimilating biomass, and only update leaf carbon when assimilating LAI.
Turn off outlier threshold when assimilating biomass to assimilate all the biomass observations and turn on outlier threshold when assimilating LAI.

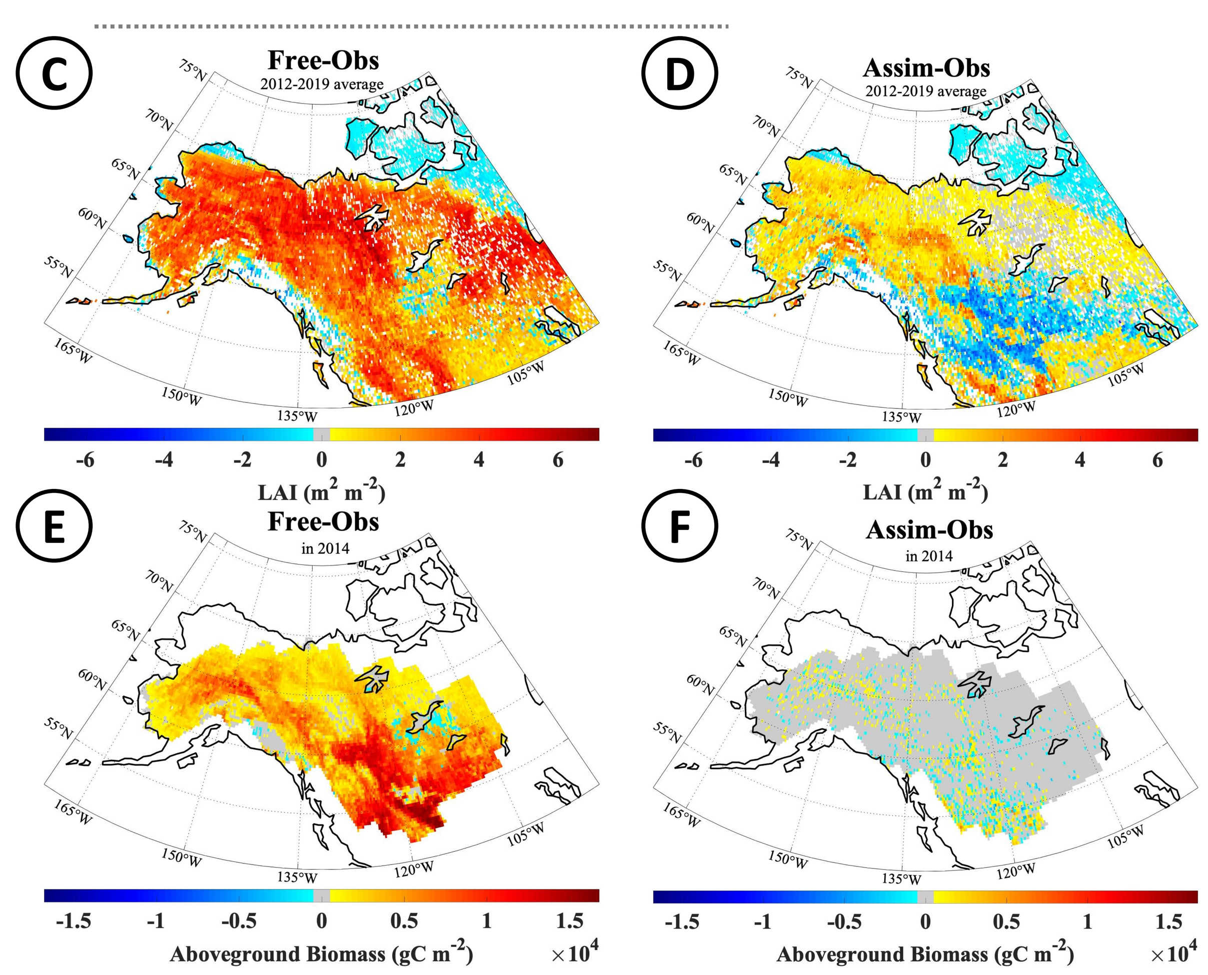
Results

LAI and above ground biomass decrease



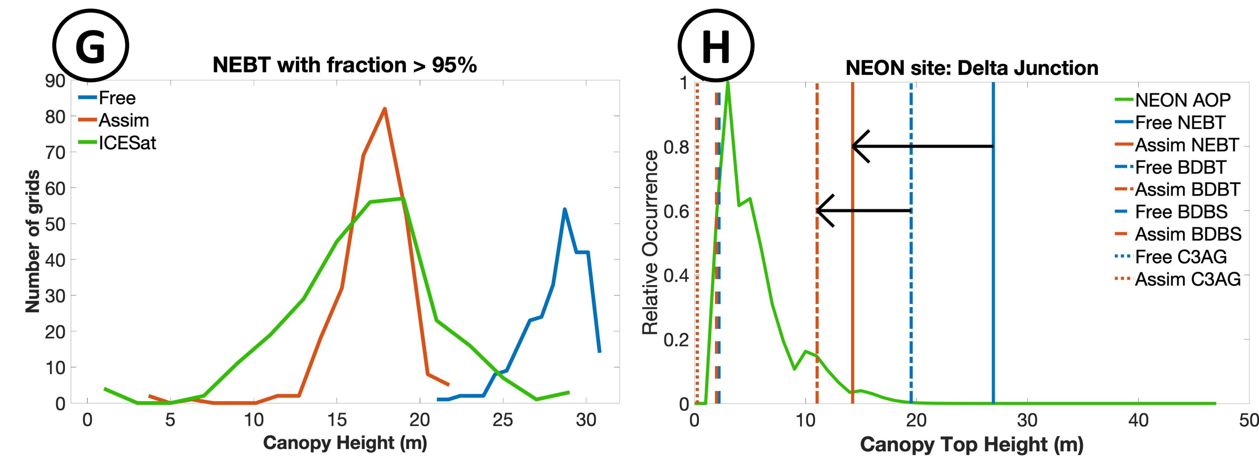
Time series of (A) monthly LAI and (B) aboveground biomass from the free run (orange line), assimilation run (blue line) and the observation (green line). LAI is averaged over the ABoVE region and aboveground biomass is averaged over the ABoVE core domain to be consistent with the spatial coverage of aboveground biomass observation. The 8-day MODIS LAI observation is averaged to the monthly time scale, and the aboveground biomass observation is annual.

- **Errors in LAI and Biomass in the free run are very large. LAI is decreased by 58.8% (A), and biomass is decreased by 71.8% (B) in the assimilation run compared with the free run.**



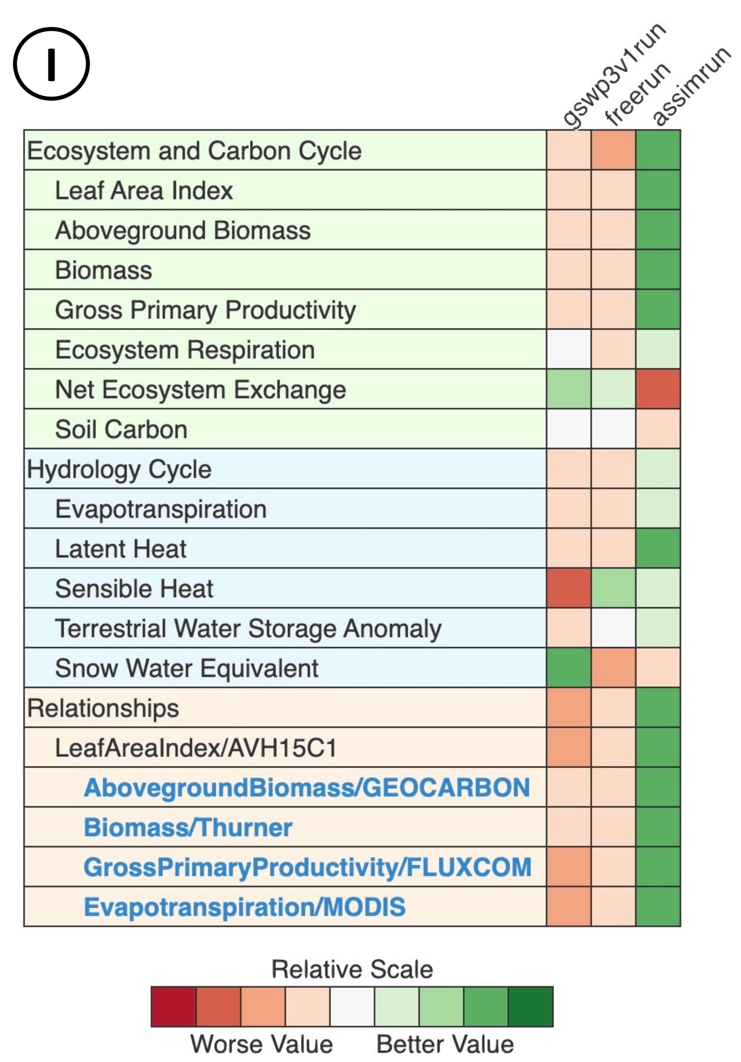
Spatial maps of the difference between modeled LAI and MODIS LAI observation averaged over July and August from 2012 to 2019: (C) free run; (D) assimilation run. Spatial maps of the difference between modeled aboveground biomass and aboveground biomass observation in 2014 using annual values: (E) free run; (F) assimilation run.

Widespread model benchmark improvement



Across the ABOVE domain we compared CLM canopy height to canopy height derived from the Geoscience Laser Altimeter System (GLAS) aboard ICESat (Ice, Cloud, and land Elevation Satellite) regridded to ~25km x ~25km for grid cells dominated by NEBT. For two grid cells (Healy and Delta Junction research sites) we compared the model with airborne lidar based estimates of canopy top height (National Ecological Observatory Network, release-2022).

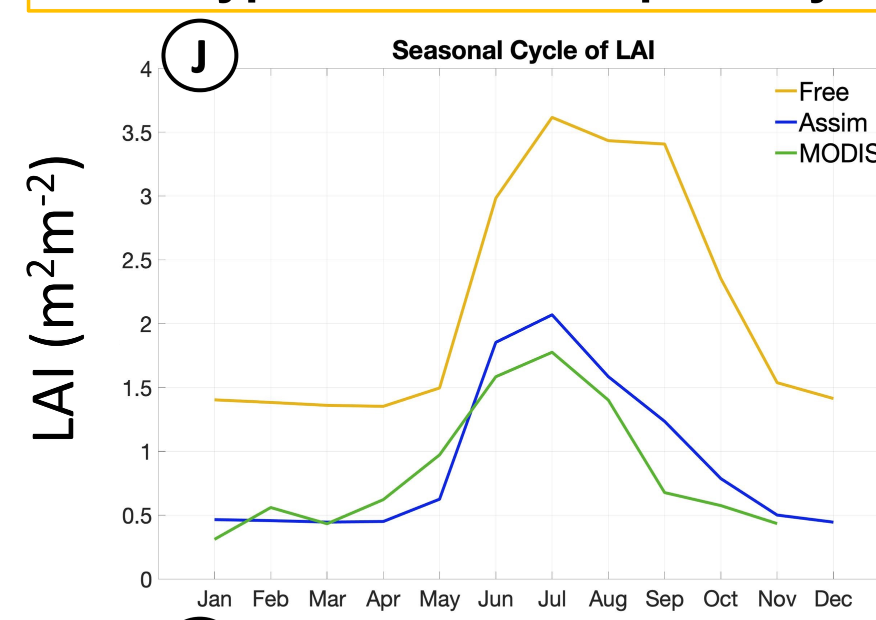
- **Errors in canopy height in the free run are very large (G & H)**
- **DA caused improved canopy height across the domain.**
- **DA caused improved performance against most of the iLAMB benchmarks (I)**
- **Soil C and NEE were not improved using this approach.**

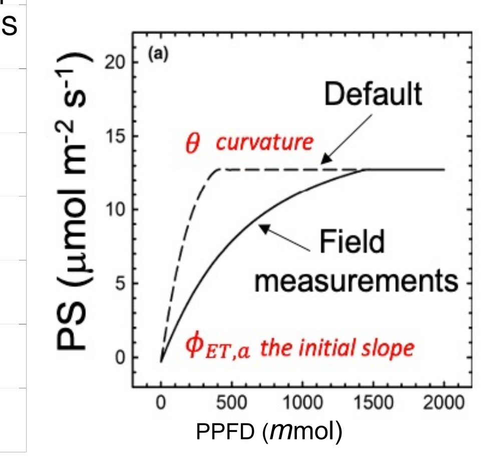


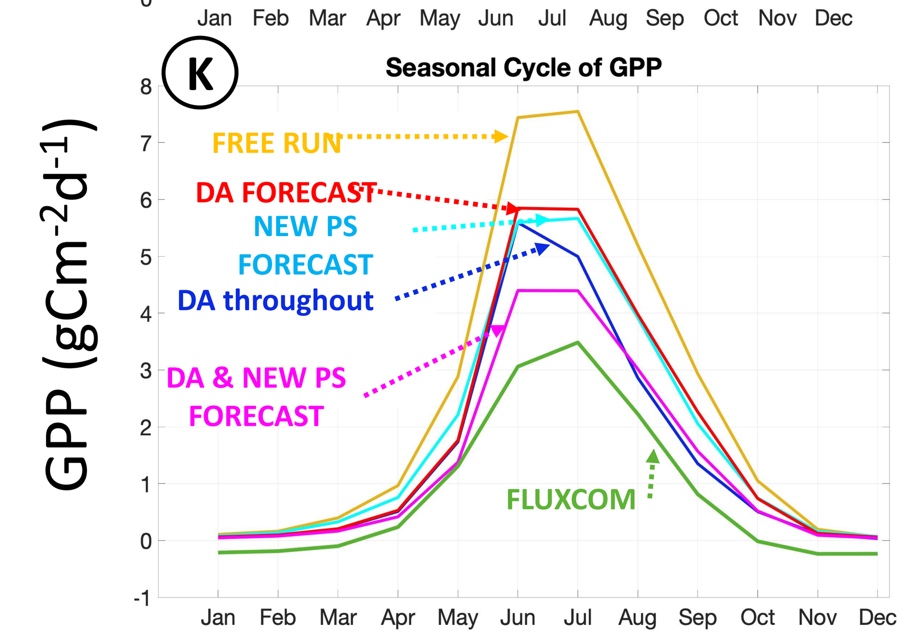
ILAMBv2.6 was used to assess the impact of assimilating LAI and aboveground biomass observations into CLM on the terrestrial carbon and water cycles in the ABoVE region. The assessment integrated analysis for 12 variables in the carbon and water cycles utilizing 22 benchmark datasets.

Improvements in GPP was greater than in TER. Bias remains in these two key variables. The differential improvement results in "poorer" NEE performance. **GPP remains 50% higher than FLUXCOM after assimilation of carbon stocks.**

Test hypothesized new photosynthesis processes







Field estimates of photosynthetic quantum yield and the curvature of that response were strongly depressed in low temperature and low light conditions. (Rogers et al., 2019). We reparametrized the photosynthetic processes (PS) to include new photosynthetic parameters and temperature sensitivity from Rogers' findings.

- **Assimilating C stocks (DA Forecast) and reparametrizing photosynthesis (PS Forecast) had a similar effect on GPP across the ABOVE domain.**
- **A significant bias from in GPP relative to the FLUXCOM GPP benchmark remained after correcting LAI (DA throughout).**
- **The combination of corrected LAI and the revised PS parameterization more closely matched FLUXCOM GPP (DA and PS forecast).**

Conclusion

Errors in carbon stocks cannot be addressed by reparametrizing short term controls of carbon fluxes. Here we overcame errors in phenology, allocation and tissue turnover through data assimilation. This allowed investigation of photosynthetic processes without biased LAI. Methods using accelerated updates of soil carbon may improve estimation of these long-term soil stocks.

Contact: davidjpmoore@arizona.edu

References
- Rogers, A., Serbin, S. P., Ely, K. S., & Wullschleger, S. D. (2019). Terrestrial biosphere models may overestimate Arctic CO_2 assimilation if they do not account for decreased quantum yield and convexity at low temperature. New Phytologist, 223(1), 167-179.
- Wang, J. A., Baccini, A., Farina, M., Randerson, J. T., & Friedl, M. A. (2021). Disturbance suppresses the aboveground carbon sink in North American boreal forests. Nature Climate Change, 11(5), 435-441.