Applying the Data Assimilation Research Testbed towards improved simulations of Earth System Carbon, Water and Energy Cycling

Brett Raczka[1], Jeffrey L. Anderson[1], Andrew M. Fox[2], Xueli Huo[3], Daniel Hagan[4], Moha Gharamti[1], Kevin Raeder[1], Helen Kershaw[1], Ben Johnson[1]

[1]National Center for Atmospheric Research, Boulder, CO, [2]Joint Center for Satellite Data Assimilation, Boulder, CO, [3]University of Arizona, Tuscon, Az, [4]Nanjing University of Information Science & Technology, Nanjing, China

Contact: bmraczka@ucar.edu

Data Assimilation Research Testbed (DART)

DART is an open-source ensemble DA software system developed by the National Center for Atmospheric Research (Anderson et al., 2009). The DART system has been previously coupled with many geophysical and theoretical models. Here we focus on applications of the ensemble Kalman Filter within DART to the Community Land Model (CLM; Lawrence et al., 2019).

To generate ensemble spread CLM-DART relies on atmospheric reanalysis data (Raeder et al., 2012, Fig. 1, 2). DART includes important features such as a time and space varying 'inflation' which adjusted ensemble spread to account for sampling uncertainty and systemic biases. It also includes space and state based 'localization' to isolate the influence of observations upon the most correlated portions of the model state. See https://dart.ucar.edu/ **for more information.**

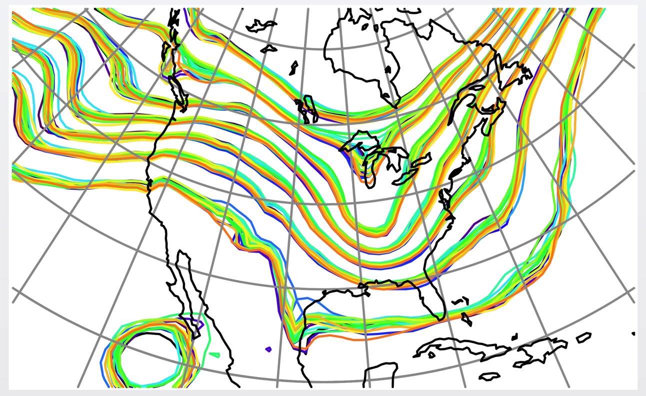


Figure 1. Example of an atmospheric reanalysis that samples uncertainty in atmospheric state. This serves as a boundary condition for CLM-DART.

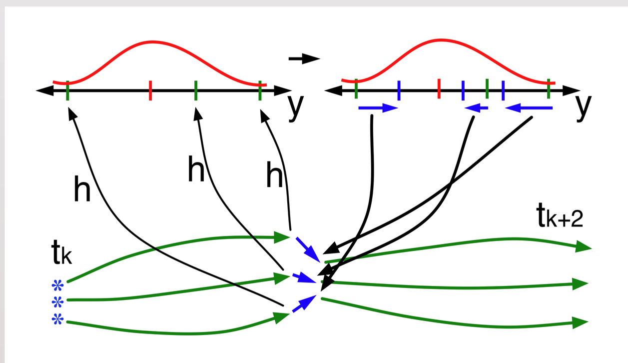


Figure 2. A schematic of a DART assimilation time step which adjusts the ensemble model forecast (green) to better match observations (red).

Carbon and Water Cycling Analyses (CLM5-DART) for Western United States

Remotely sensed observations of aboveground biomass and leaf area were used to adjust simulations of the Community Land Model (CLM5-DART) for the Western United States (Fig. 3), the Arctic-Boreal Vulnerability Experiment (ABoVE; Fig. 4, 5) and global domains (Fig 6,7).

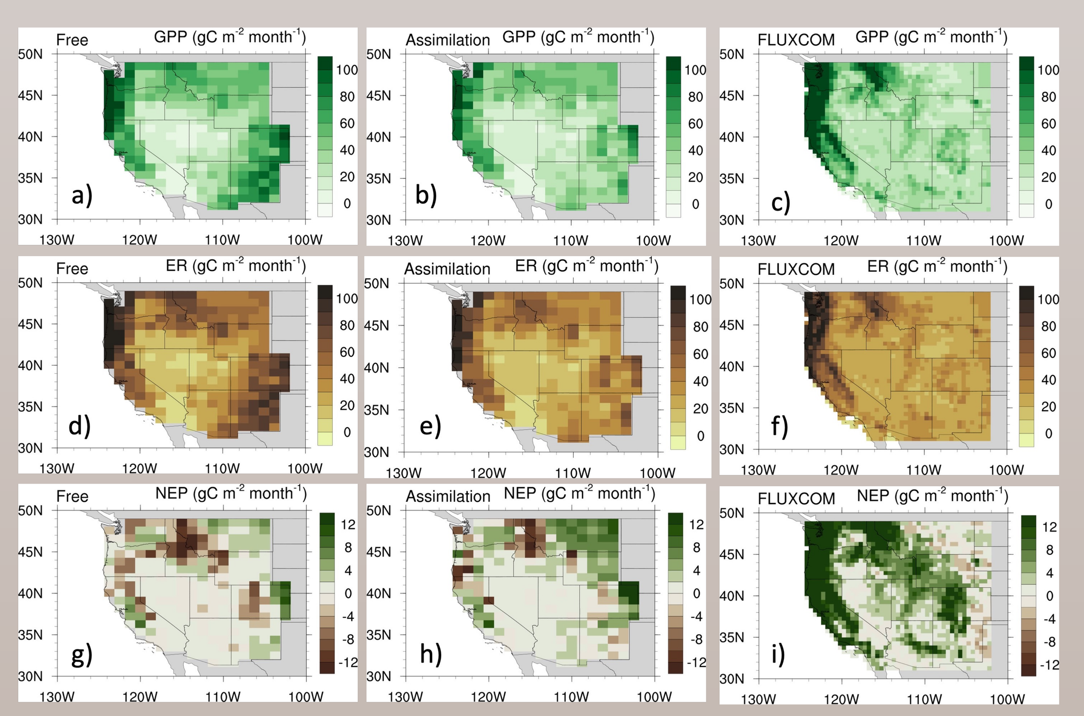


Figure 3. The ensemble average carbon fluxes (2001-2010) for a-c) GPP, d-f) ER, and g-i) NEP for the free simulation (left column), CLM5-DART assimilation (middle column) and FLUXCOM.

Raczka et al., (2021); JAMES

The (CLM5-DART) adjusted assimilation decreases biomass (31%) and LAI (27%) compared to the free run (Fig. 3). This decreases both GPP (20%) and ER (21%) carbon fluxes such that the NEP remains nearly identical between the free and assimilation run. This estimate of a weak carbon sink contrasts with FLUXCOM (Jung et al., 2020) which suggests a strong carbon sink, especially across the high elevation terrain.

Carbon, Water, Energy Cycling Analyses for Arctic-Boreal and Global Domains

Simulations of CLM5 across the Arctic-Boreal domain (2011-2019) overpredicts the leaf area (LAI; Fig. 4). By constraining the CLM simulations with observations of leaf area (MODIS) and aboveground biomass (Wang et al., 2021) simulations of carbon and hydrological cycling improve based on the International Land Model Benchmarking (ILAMB; Collier et al., 2018) criteria (Fig. 5).

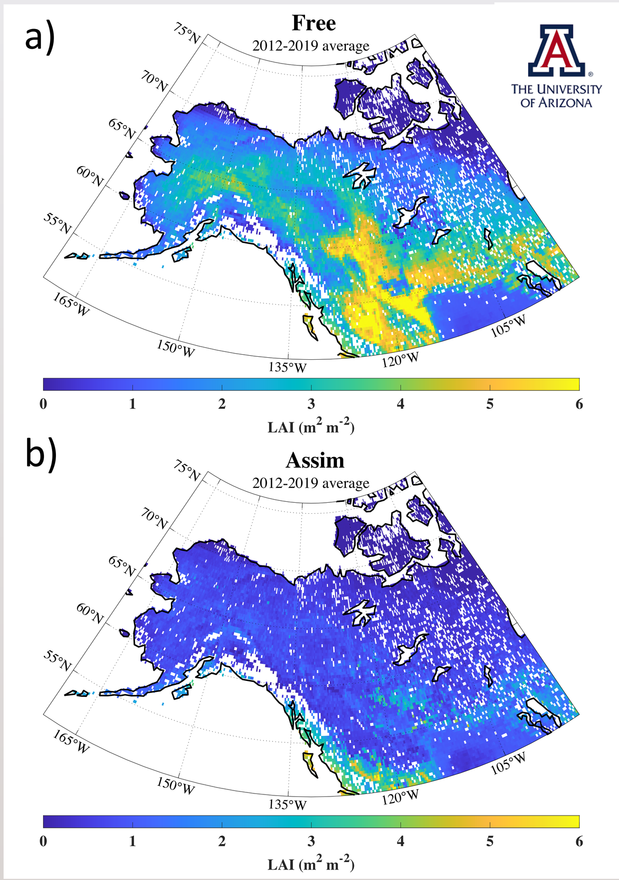


Figure 4. Comparison in LAI spatial patterns for (a) free and (b) assimilated CLM5 simulations.

Xueli Huo et al, (in prep)

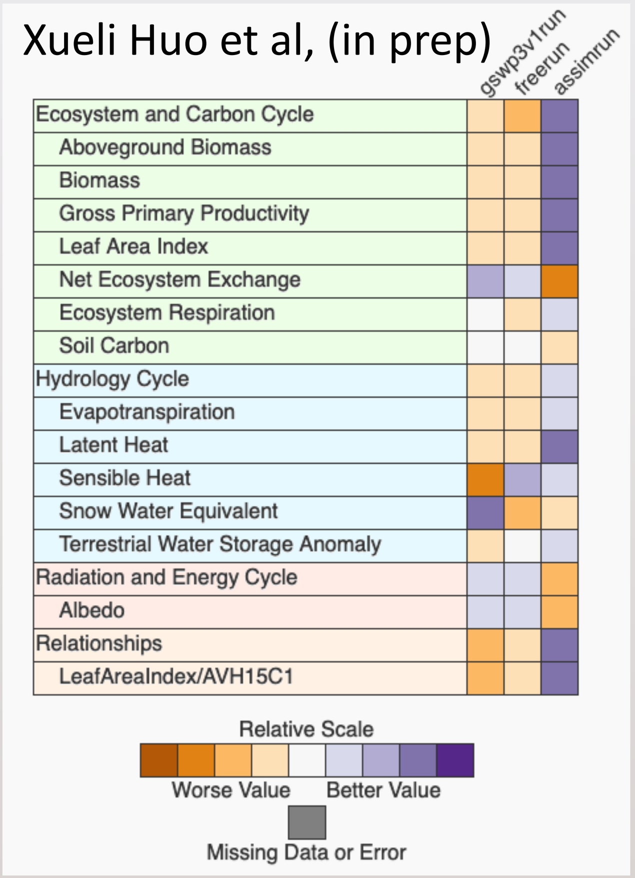


Figure 5. Statistical comparison between free and assimilated CLM5 simulations against ILAMB criteria (e.g. bias, RMSE).

A. Fox et al, (in revision); JGR-Biogeosciences

Assimilating Global leaf area observations reduced CLM 5 estimates of leaf area (TLAI) by 26%, leading to an 18% and 6% reduction in GPP and latent heat (LE) respectively.

CLM5 shows large positive biases across much of the Northern Hemisphere and low latitudes of the Southern Hemisphere (Fig. 6). The simulated positive bias in TLAI is consistent across the season cycle (Fig. 7). The forecast run at 2006 departs from the assimilation run (Fig. 7), indicating model parameters (e.g. allocation, phenology) and or atmospheric forcing contribute to the differences.

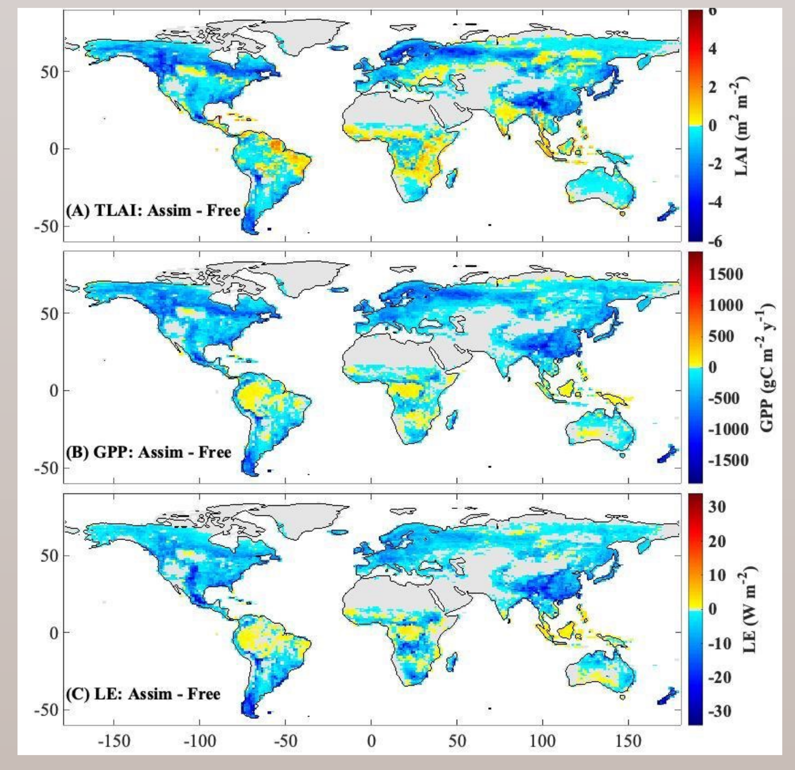


Figure 6. Decreases in (a) TLAI imposed by the assimilation also lead to decreases in (b) GPP and (c) LE (years: 2006-2010).

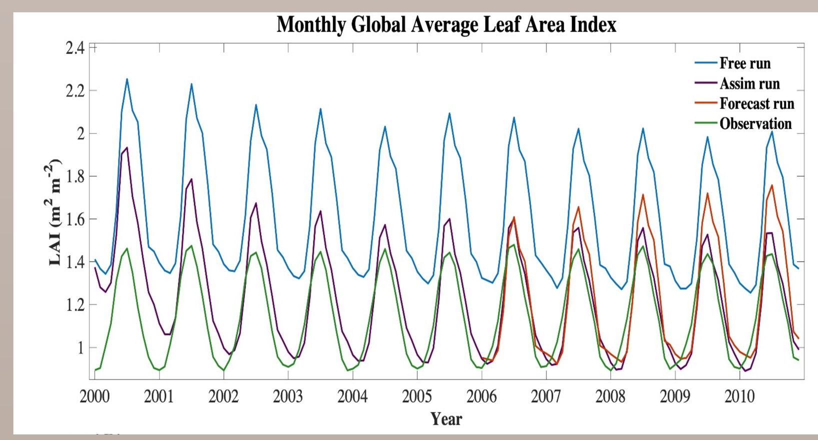


Figure 7. The TLAI free, assimilation and forecast runs compared against the TLAI 3g observations (Zhu et al., 2013) (2000-2010).

Improving water cycling through soil moisture satellite DA

Soil Moisture observations (ECV-CCI) have been assimilated into CLM4.5 w/ satellite phenology (SP) to create a reanalysis data product across China that closely matches the behavior of the benchmark ERA-5 soil moisture product (Fig. 8). Significant improvement is also demonstrated against surface and subsurface in-situ site level observations of soil moisture (Fig. 9).

Daniel Hagan et al, (in prep)

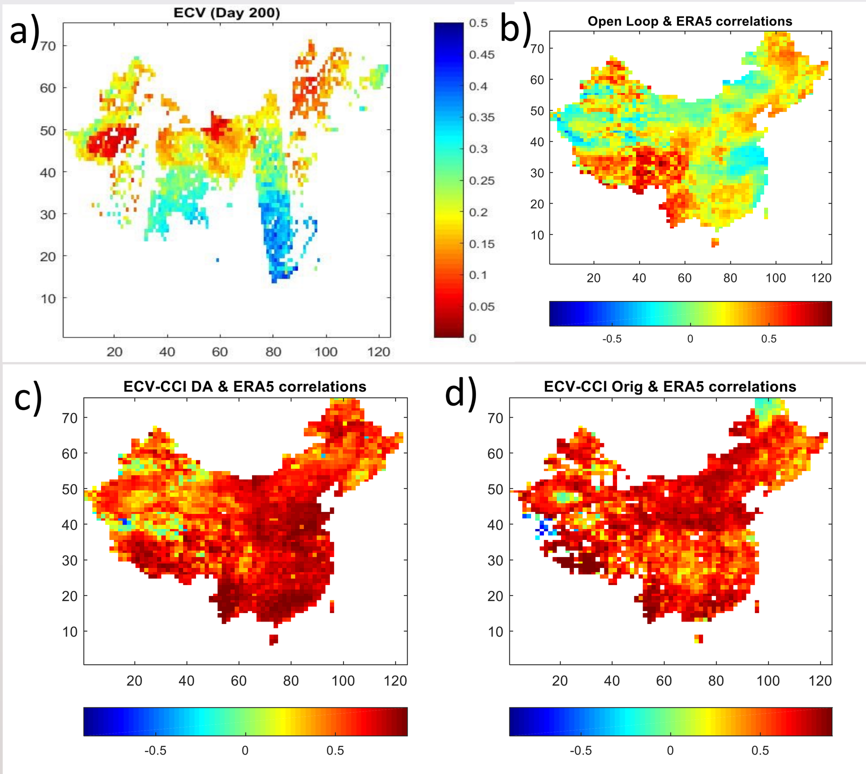
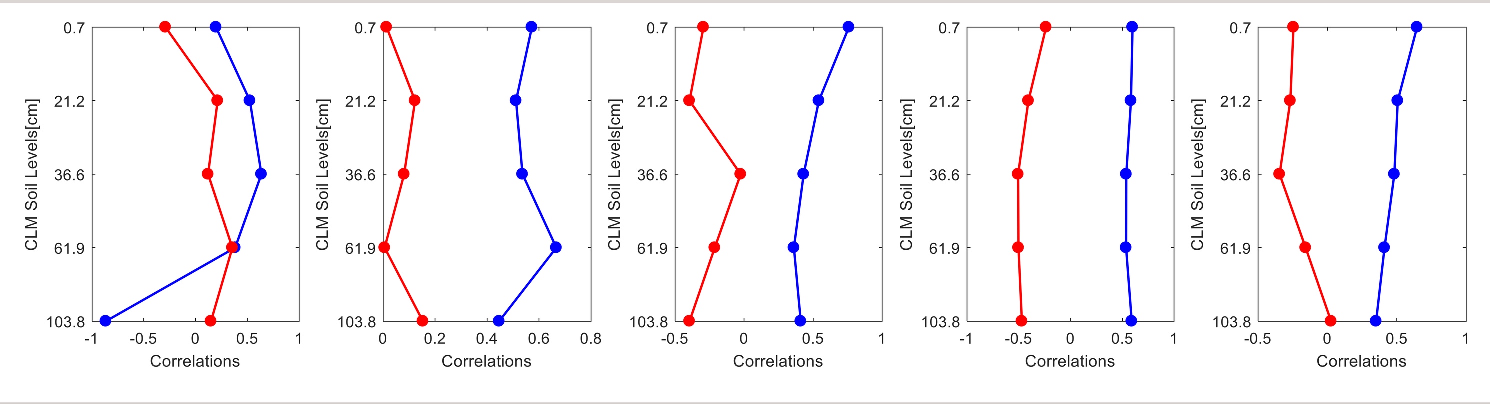


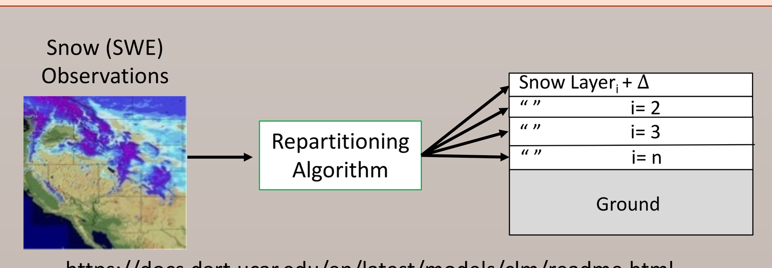
Figure 8. An example of (a) an ECV-CCI daily satellite retrieval and comparison of ERA-5 soil moisture correlations with (b) CLM4.5-SP, (c) CLM4.5-SP w/ assimilation, and (d) the ECV-CCI observations. Data is for year 2010.

Figure 9. Correlation comparison between the CLM4.5-SP (red) and CLM4.5-SP w/ assimilation (blue) soil moisture with site level soil moisture observations. Observations shown between 0-100 cm. in depth.

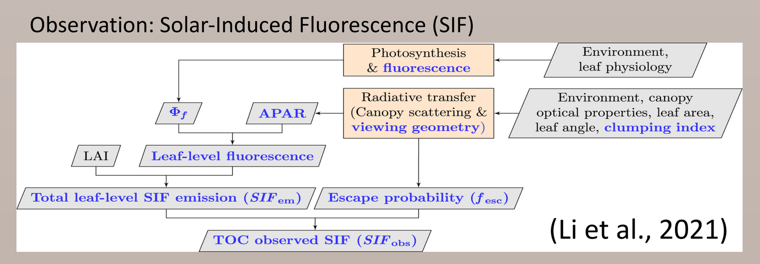


New Developments in CLM-DART

Recently, software capabilities have been added to DART allowing for the assimilation of observations of snow water equivalent (SWE) and Solar-Induced Fluorescence (SIF). A CLM5-DART tutorial has been created to familiarize new users with important DART assimilation steps specifically related to CLM.

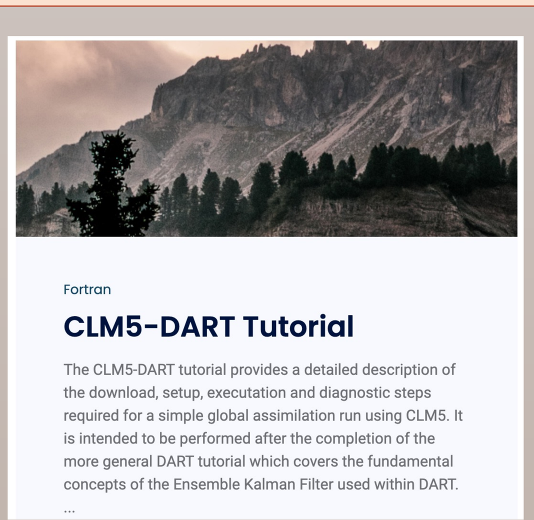


https://docs.dart.ucar.edu/en/latest/models/clm/readme.html



(Li et al., 2021)

https://docs.dart.ucar.edu/en/latest/observations/obs_converters/SIF/SIF_to_obs_netcdf.html



https://dart.ucar.edu/tutorials/clm-dart/

CITATIONS

Fox et al., (in revision); Assimilation of global satellite leaf area estimates reduces modeled global carbon uptake and energy loss by terrestrial ecosystems, JGR-Biogeosciences.

Jung et al., 2020; Scaling carbon fluxes from eddy covariance sites to globe: Synthesis and evaluation of the FLUXCOM approach. *Biogeosciences*

Li et al., (2021) Representation of Leaf-to-Canopy Radiative Transfer Processes Improves Simulation of Far-Red Solar-Induced Chlorophyll Fluorescence in the Community Land Model Version 5; JGR Biogeosciences

Raczka et al., (2021); Improving CLM5.0 Biomass and Carbon Exchange Across the Western United States Using a Data Assimilation System, JAMES