Towards a Complex Terrain Carbon Monitoring System (CMS-Mountains): Development and Testing in the Western U.S.

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MOTIVATION

The forests of the Western US provide a significant contribution to both biomass and land-atmosphere carbon exchange. These forests, however, are vulnerable to fires, drought and insect attacks. Carbon monitoring has been challenged by highly heterogeneous atmospheric and land surface conditions typical for complex terrain. Our goal is to design a carbon monitoring system that combines remotely-sensed observations within a land surface model (Community Land Model; CLM 5.0) to estimate biomass stocks, land-atmosphere carbon exchange, and anticipates conditions that threaten forest health.

Importance of meteorology and spatial resolution for simulating complex, mountainous terrain

A meteorological data set designed for complex terrain (gridMET) combined with a model representation of plant hydraulics stress (CLM5-PHS), provided the most accurate representation of biomass across the Western US (Figs. 1&2). The increase of land surface and meteorology spatial resolution had marginal effects upon simulated biomass (Fig. 3). (Duarte et al., (in revision)).

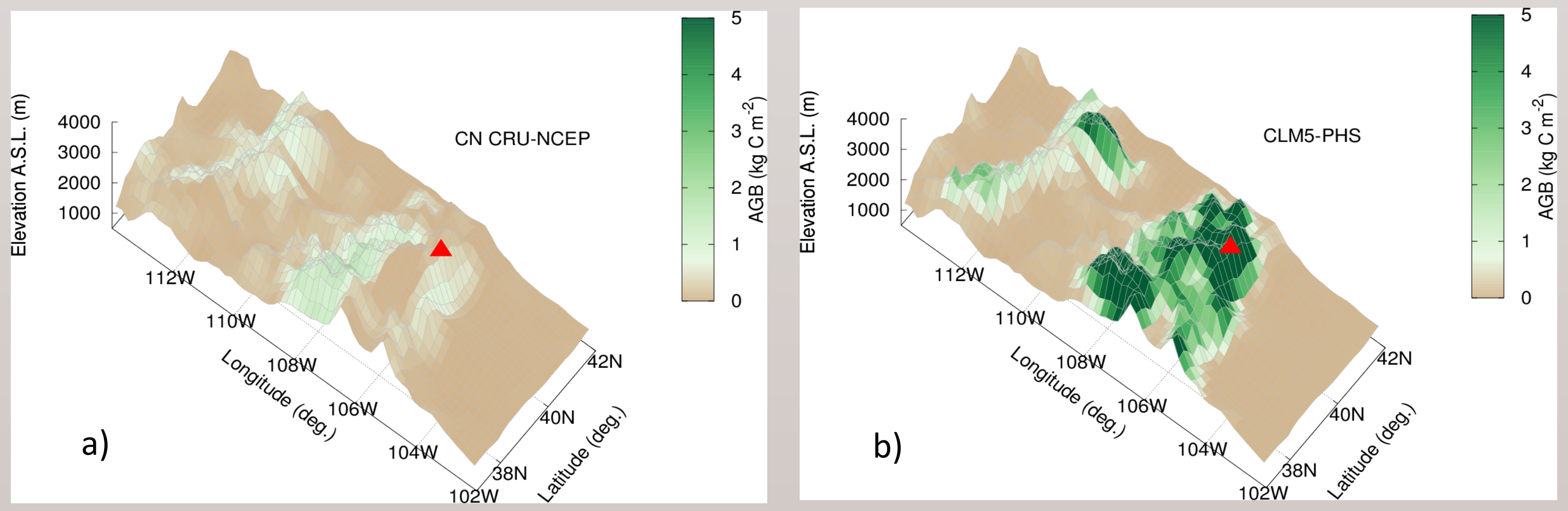
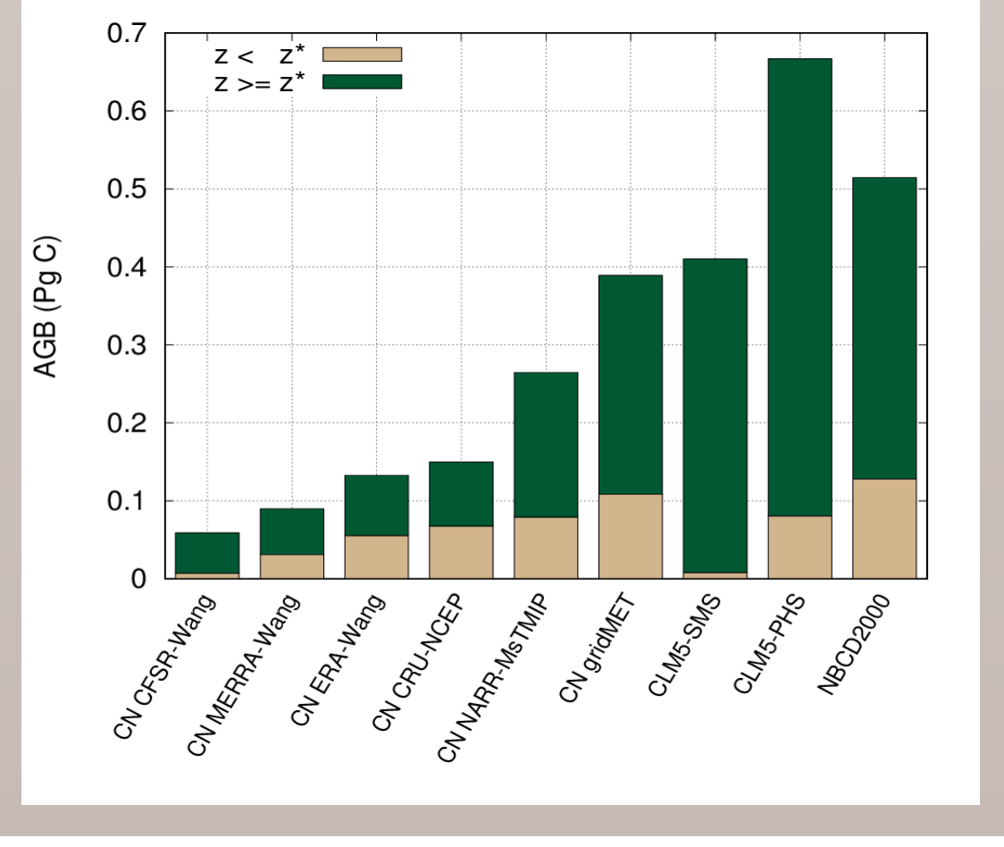


Figure 1. Above-ground biomass simulations for an (a) 'out of the box' CLM 4.5 simulation using standard meteorology and standard representation of soil moisture stress, and (b) an optimized CLM 5.0 simulation driven by gridMET meteorology with representation of plant hydraulic stress. The spatial domain is Utah and Colorado.

Figure 2. Total above-ground biomass over the Utah/Colorado domain in Fig. 1 (year 2000) for high and low elevations (values plotted with stacked bars). Simulation results for each meteorological dataset and model configuration are compared to the NBCD2000 data product (rightmost bar). The threshold elevation above sea level ($z^* = 2235$ m).



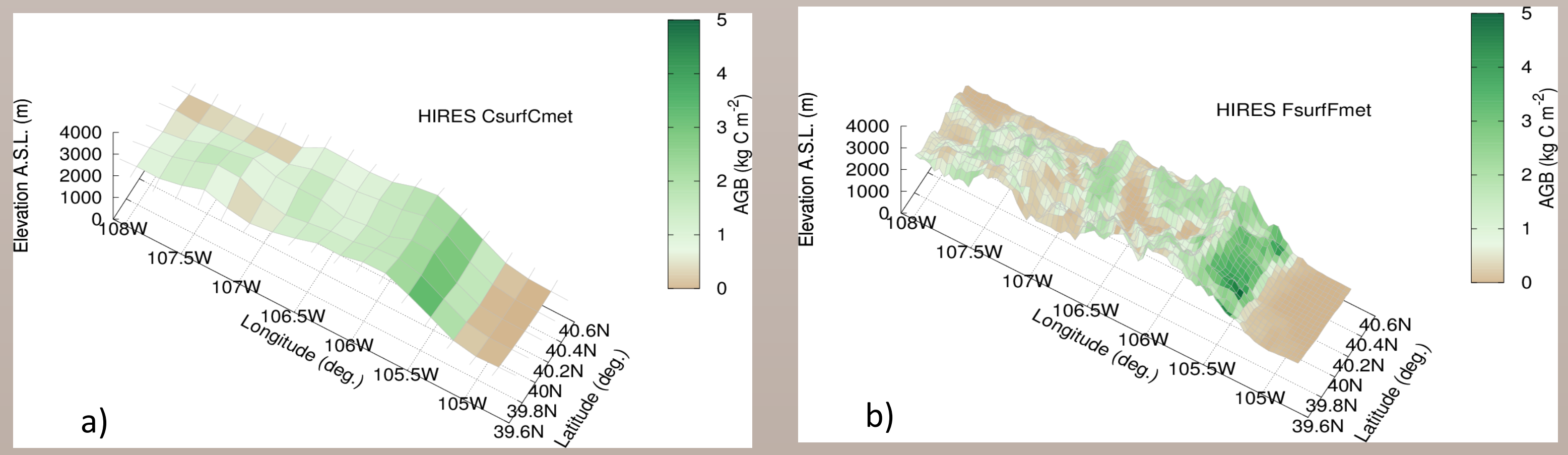


Figure 3. A comparison of the influence of spatial resolution of the land surface map and the gridMET meteorological dataset upon simulated above-ground biomass. Simulations are provided for (a) coarse (1/5°×1/5°) surface map and coarse (1/2°×1/2°) gridMET, and (b) fine (1/24°×1/24°) surface map and fine (1/24°×1/24°) gridMET. The spatial domain represents an elevation transect across the Colorado Rocky Mountains.

Data assimilation used to improve simulated land surface carbon exchange across the Western US

Assimilating observations of leaf area and biomass into CLM 5.0 using the Data Assimilation Research Testbed (DART) (Fig. 4), improved the accuracy of the model simulation (Raczka et al., (in prep, JAMES)).

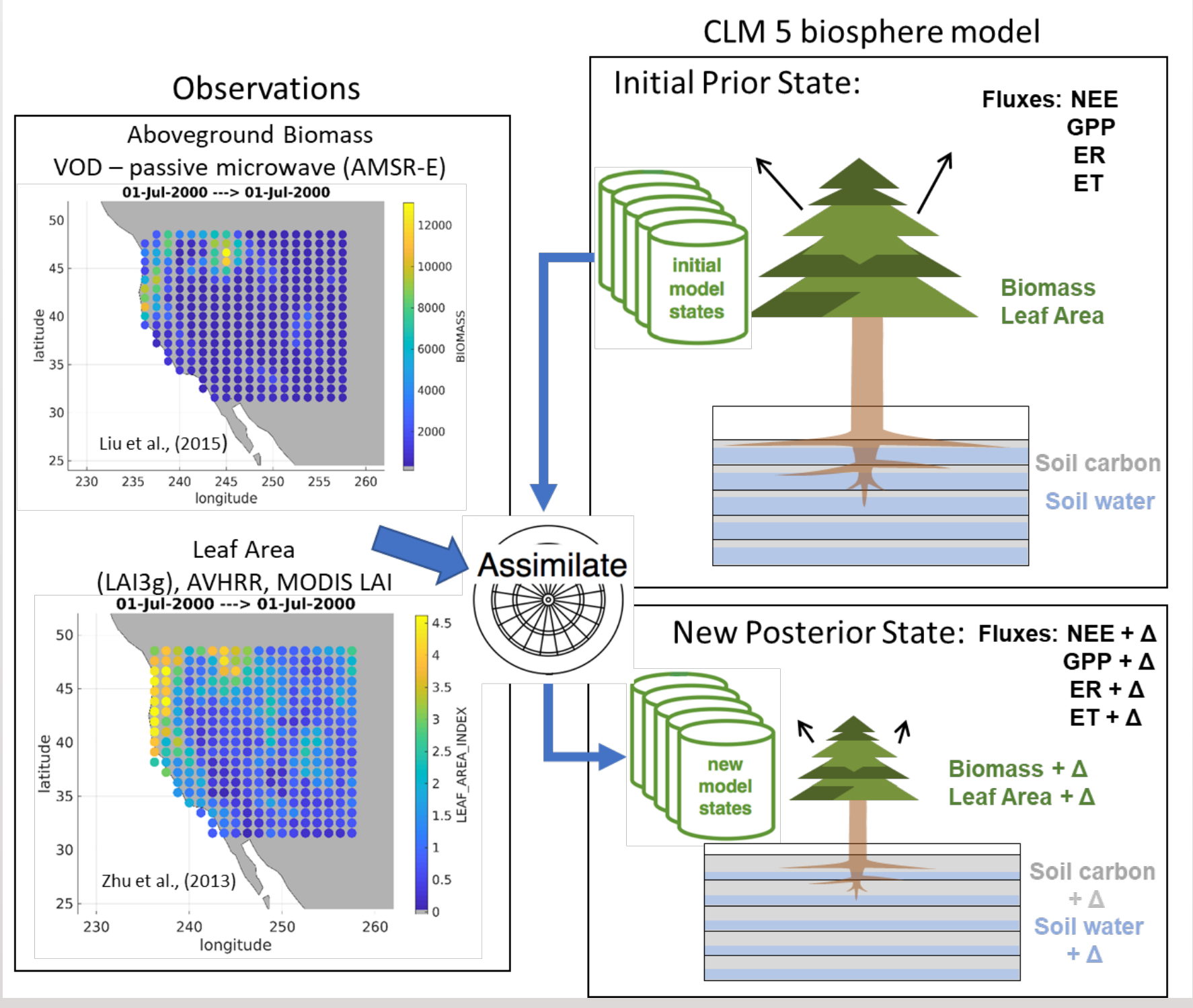


Figure 4. Overview of the data assimilation approach (left panel) which uses remotely sensed observations of leaf area index (LAI) and aboveground biomass (AGB) to correct biases in the CLM5.0 model state. The assimilation system directly adjusts biomass state variables, and indirectly adjusts land-atmosphere carbon exchange.

The assimilation of observations significantly reduces the biomass stocks within CLM5.0, and changes the project land-atmosphere carbon exchange from a land carbon sink to a source (Fig. 5).

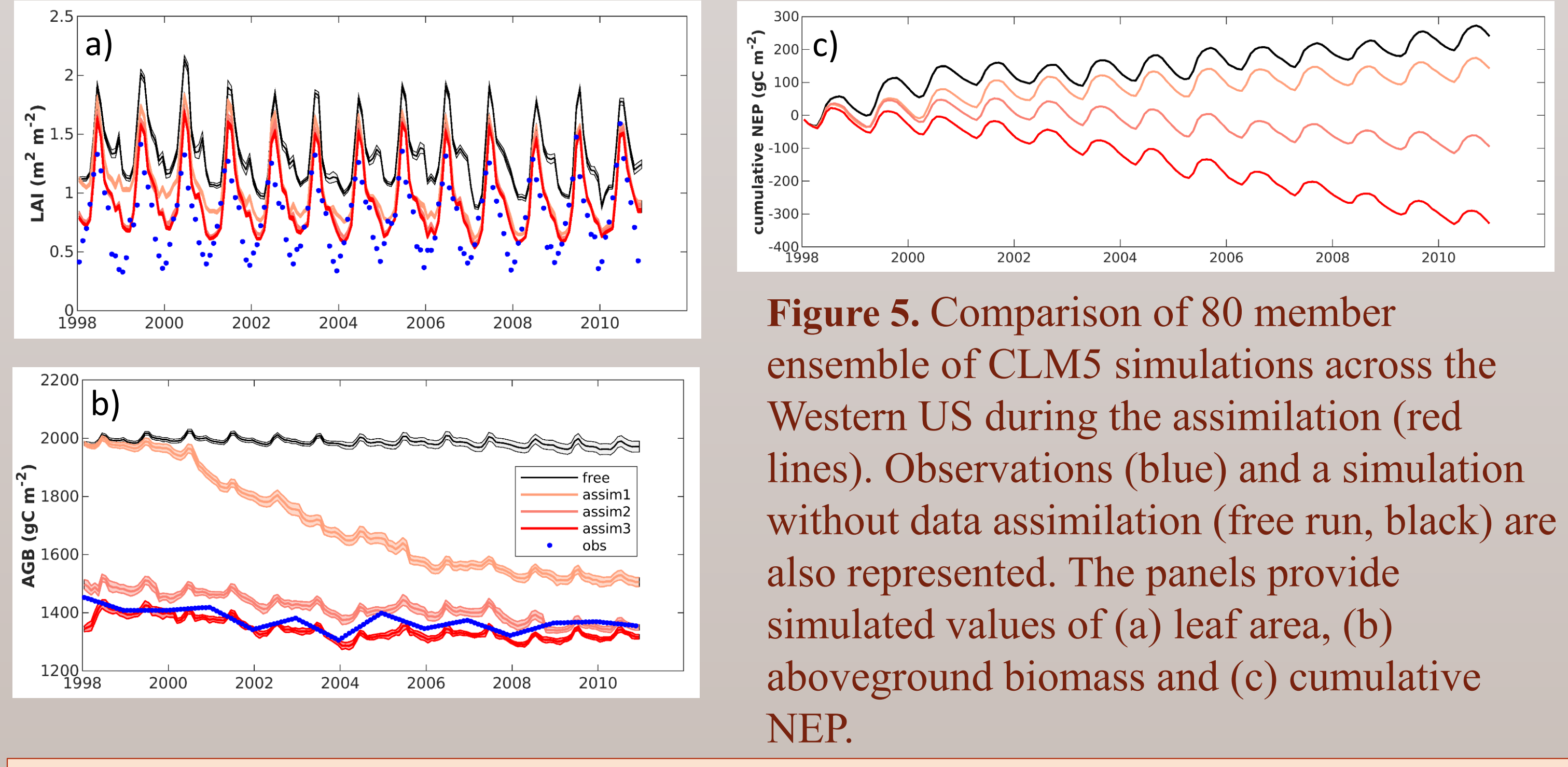


Figure 5. Comparison of 80 member ensemble of CLM5 simulations across the Western US during the assimilation (red lines). Observations (blue) and a simulation without data assimilation (free run, black) are also represented. The panels provide simulated values of (a) leaf area, (b) aboveground biomass and (c) cumulative NEP.

The CLM 5.0 assimilation run simulates a strong carbon source from the land to atmosphere, whereas FluxCom estimates the Western US as a strong carbon sink to land (Fig. 6).

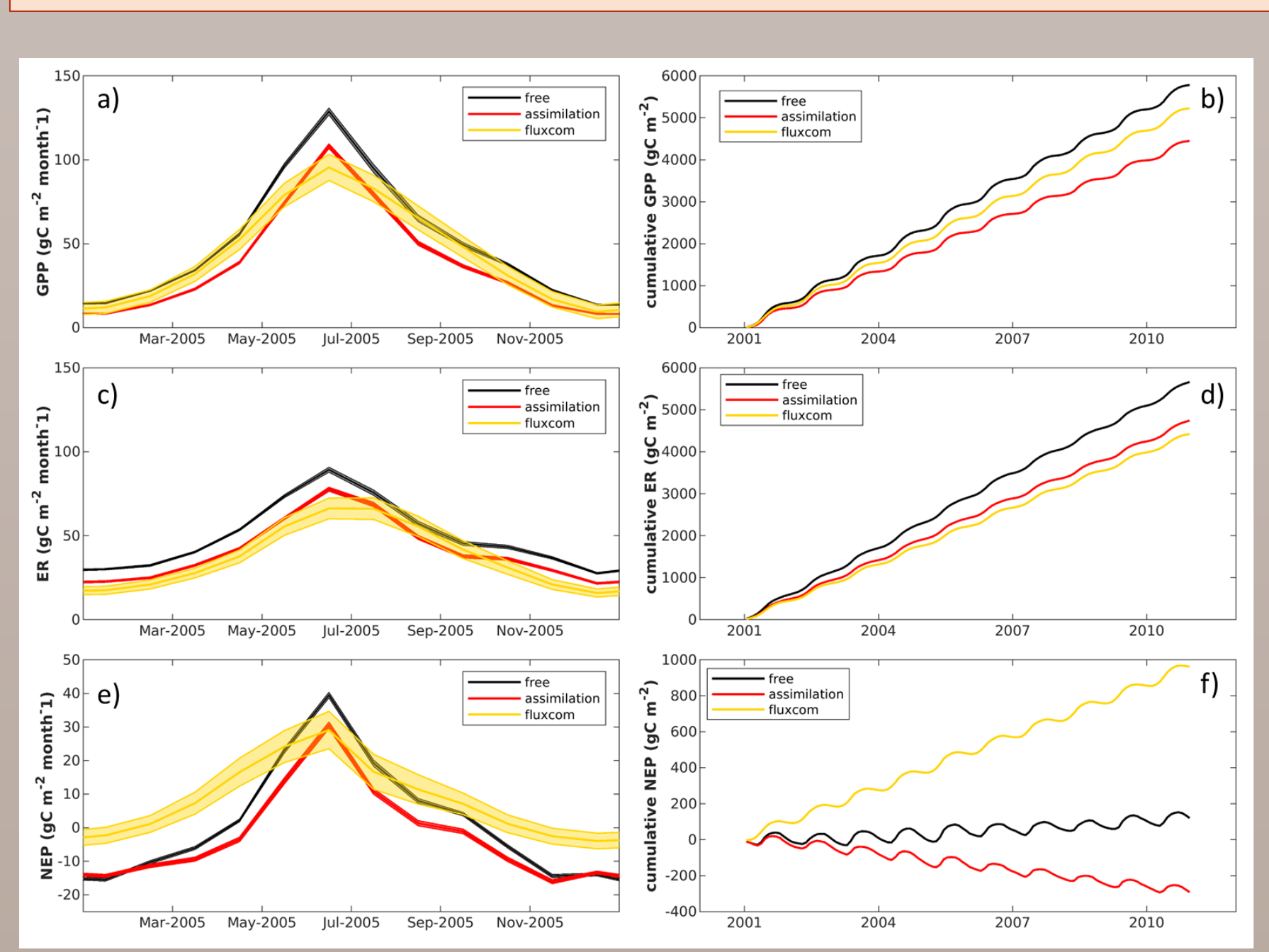


Figure 6. Simulated carbon fluxes (a,c,e) and cumulative carbon fluxes (b,d,f) between a free (black) and assimilation (red) CLM5 runs compared against FluxCom (Jung et al., 2019) 'observations' (yellow) averaged over the Western US.

Observation constrained maps of biomass and carbon exchange

In general, FluxCom estimates a strong sink of carbon in high mountainous terrain whereas CLM5.0 projects these regions to be carbon neutral or a carbon source to the atmosphere (Fig. 7).

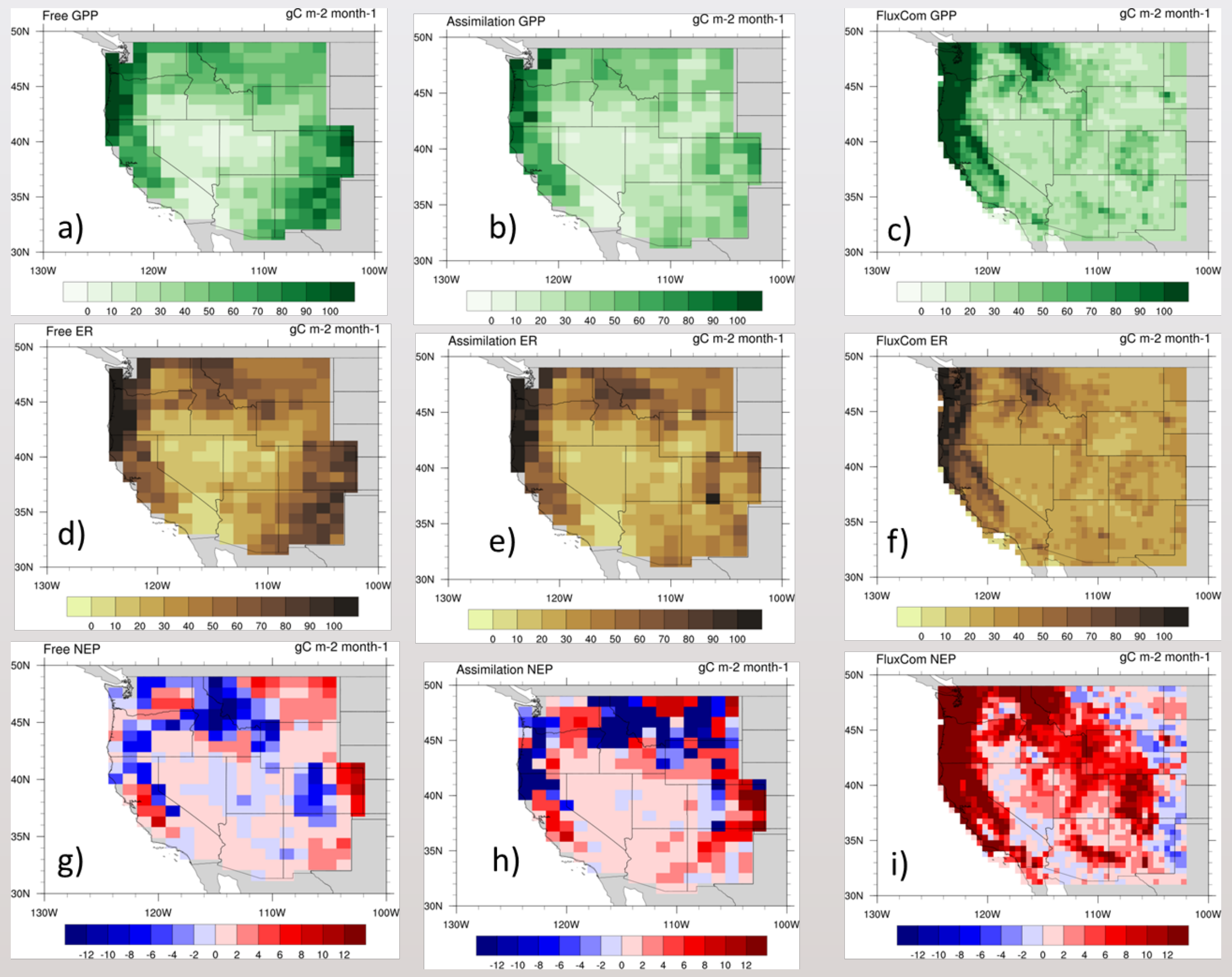


Figure 7. Spatial maps of average carbon fluxes (2001-2010) for a-c) GPP, d-f) ER, and g-i) NEP for free and assimilated CLM5 ensemble simulations and the median ensemble from FluxCom.

The assimilation runs are dependent upon the system setup (DART-CLM5). For example, varying the number and type of state variables in CLM 5.0 that are directly/indirectly adjusted by the observations changes the simulated carbon stocks and land-atmosphere exchange (Fig. 8). All previous figures based on the assimilation run 'state-15' in Figure 8.

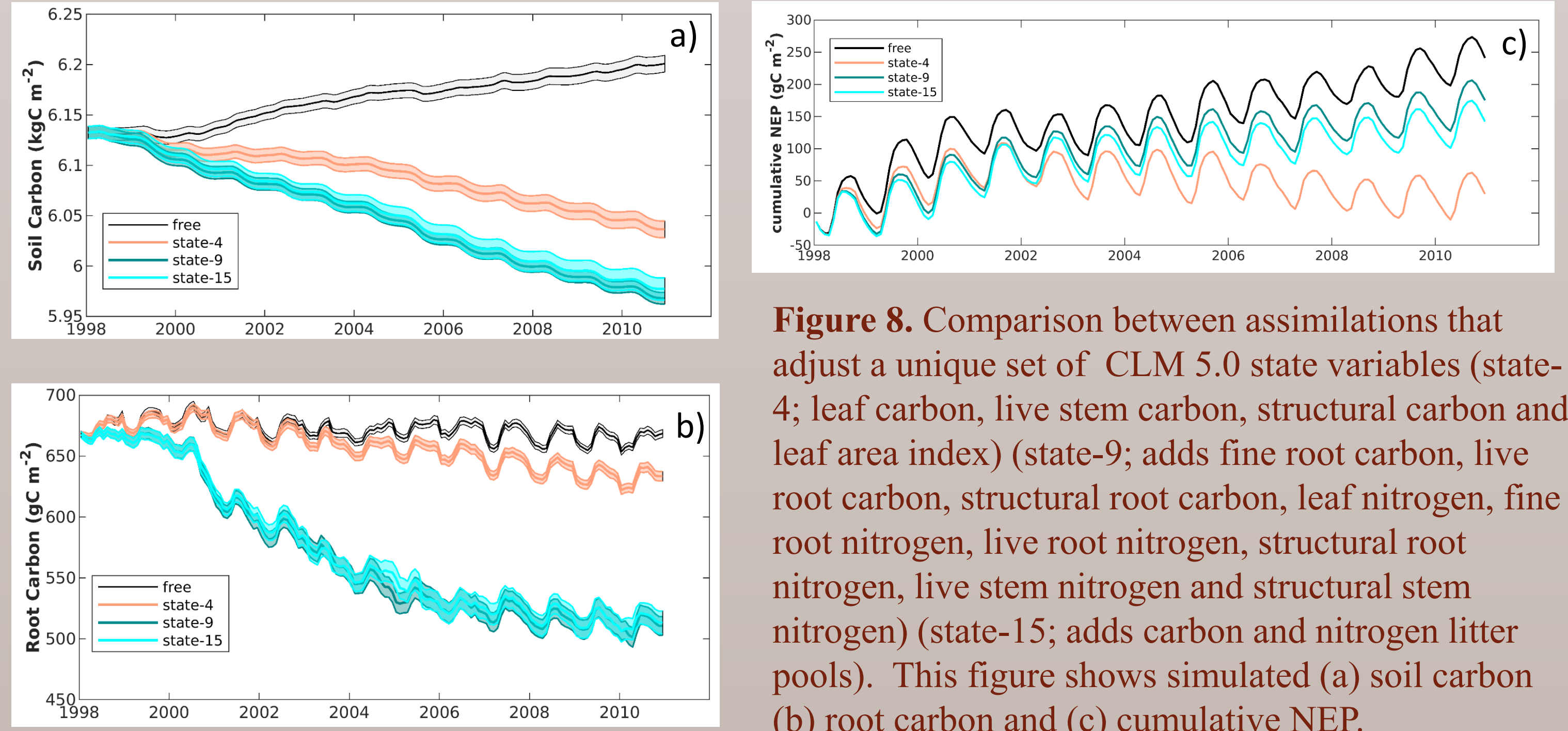


Figure 8. Comparison between assimilations that adjust a unique set of CLM 5.0 state variables (state-4; leaf carbon, live stem carbon, structural carbon and leaf area index) (state-9; adds fine root carbon, live root carbon, structural root carbon, leaf nitrogen, fine root nitrogen, live root nitrogen, structural root nitrogen, live stem nitrogen and structural stem nitrogen) (state-15; adds carbon and nitrogen litter pools). This figure shows simulated (a) soil carbon (b) root carbon and (c) cumulative NEP.

Citations

- Duarte et al., (in revision), 'How Can Biosphere Models Grow Enough Vegetation Biomass in the Mountains of Western US? Implications of Met Forcing', JGR-Biogeosciences
- Jung, M., Koirala, S., Weber, U. et al. The FLUXCOM ensemble of global land-atmosphere energy fluxes. Sci Data **6,** 74 (2019). https://doi.org/10.1038/s41597-019-0076-8
- Raczka et al., (in prep) 'Assimilating remotely sensed observations of carbon stocks indicate a neutral carbon sink across the Western US', (target journal: JAMES)

ACKNOWLEDGEMENTS

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