MODELING THE SEMI-ARID CARBON CYCLE

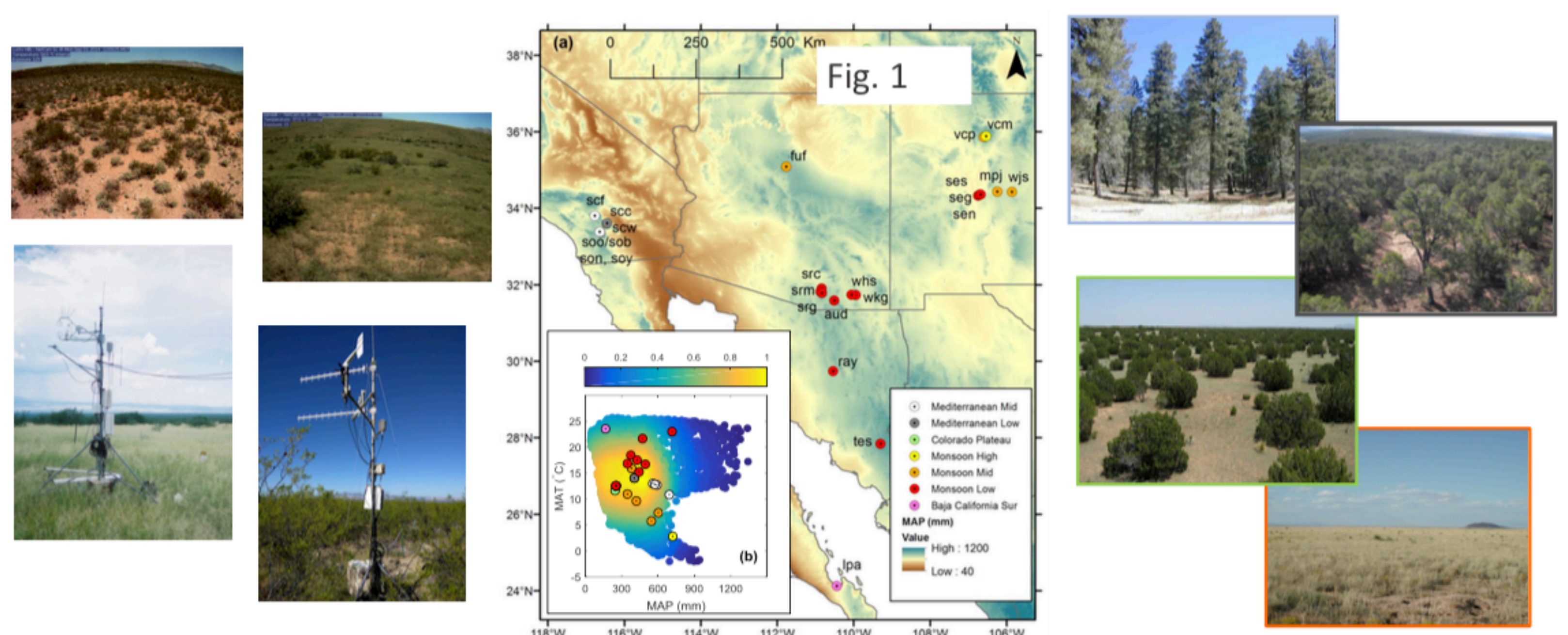
Terrestrial biosphere models underestimate the mean and inter-annual variability of net CO_2 fluxes in semi-arid ecosystems

1 INTRODUCTION

Recent studies based on analysis of atmospheric CO_2 inversions, satellite data and terrestrial biosphere model (TBM) simulations have suggested that semi-arid ecosystems play a dominant role in the interannual variability and long-term trend in the global carbon sink. However, the TBMs used in these studies have not yet been extensively tested against in situ carbon and water stocks and fluxes. Model evaluation and testing is therefore needed to ensure semi-arid vegetation, carbon and water cycle processes are well represented in global scale TBMs before they can be reliably used to predict semi-arid ecosystem contributions to the global carbon cycle. To bridge this gap, we have tested TRENDY and ORCHIDEE TBM annual net and gross CO_2 flux and ET simulations against observations of from 12 Ameriflux sites spanning southwestern US semi-arid grass, shrub and forest sites.

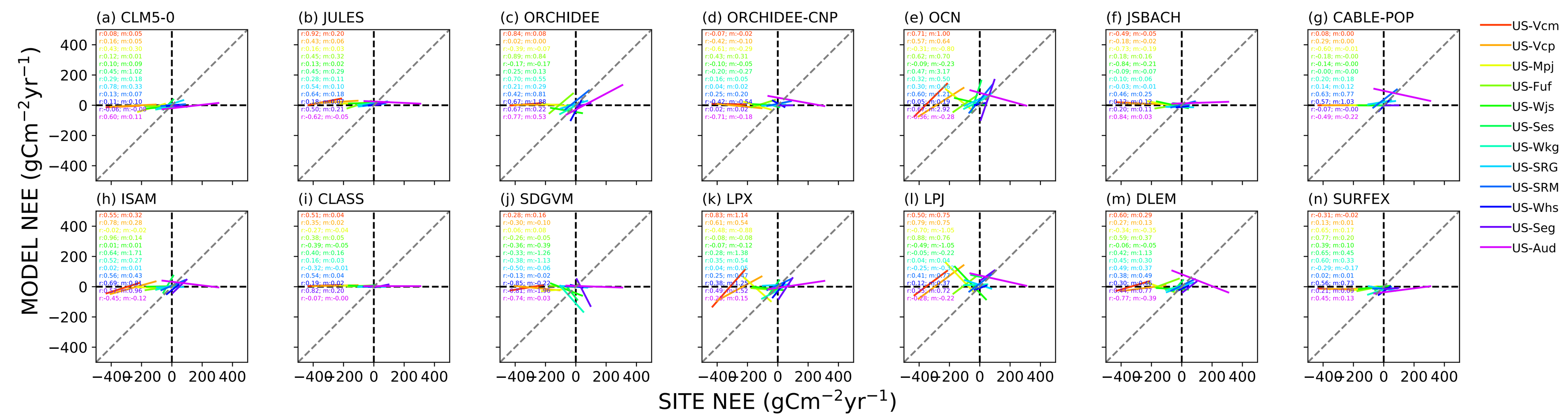
2 SITES, MODEL SETUP and METHODS

- Site data: Eddy covariance arbon (net CO_2 flux – NEE; gross C uptake – GPP; Ecosystem Respiration – Reco) and water (ET) fluxes (+site-based vegetation, LAI and soil texture) from 12 Ameriflux forest, shrub and grassland-dominated sites across SW US in high and low elevation monsoon climate zones (Fig. 1 – Biederman et al., 2017).



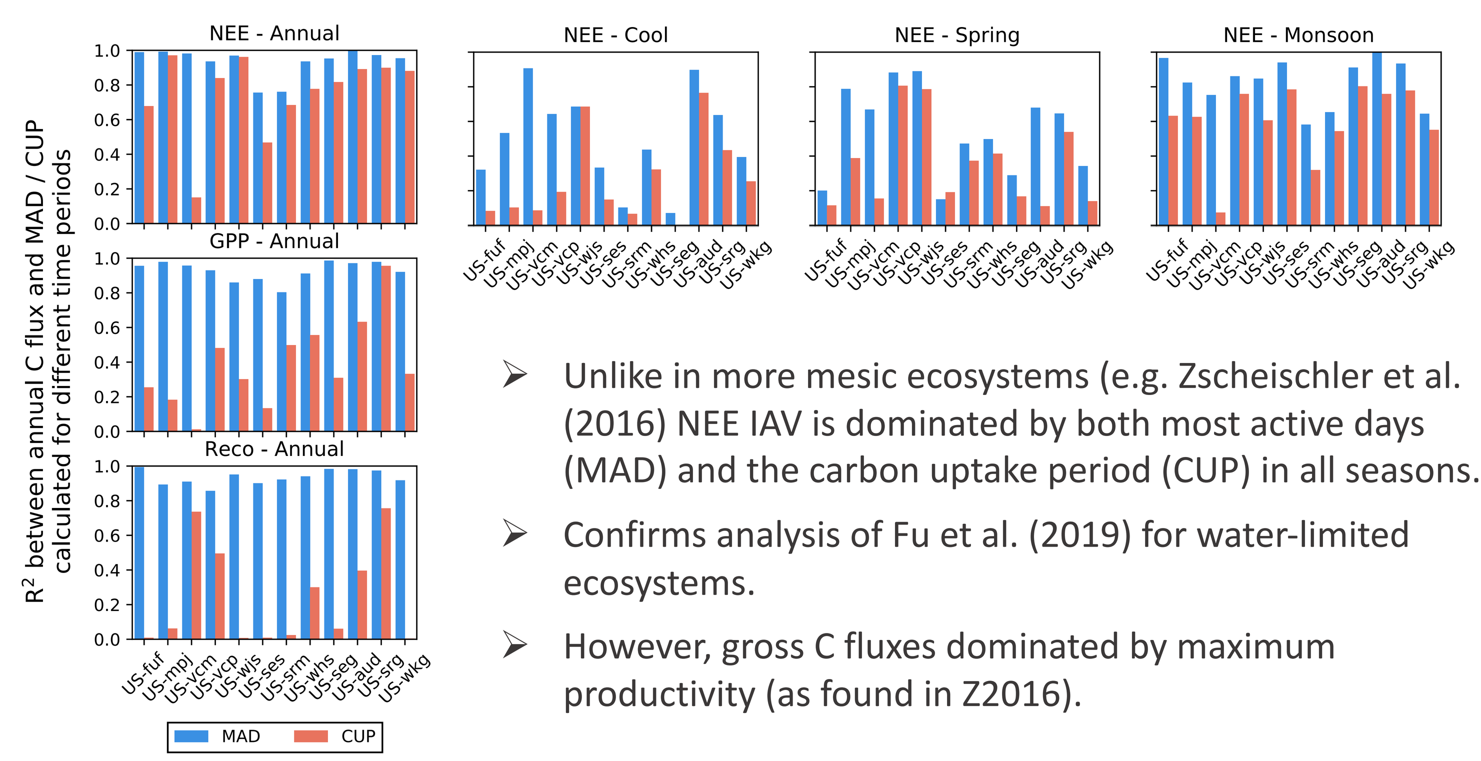
- Analyzed site eddy covariance fluxes to determine contributions (fraction of variability explained – R^2) of most active days (MAD – method of Zscheischler et al., 2016) and carbon uptake period (CUP, where NEE < 0) to annual C fluxes (and seasonal contribution to ann NEE).
- Site-based analysis of contribution (R^2) of annual GPP and Reco to annual NEE; and seasonal NEE, GPP and Reco annual NEE to according to dominant vegetation type.
- Carbon, water and vegetation model-data comparison across 12 Ameriflux forest, shrub and grassland-dominated sites:
- Evaluate annual NEE for 14 LSMs from TRENDY v7 model inter-comparison (Sitch et al., 2015, *Biogeosciences*) Evaluate ORCHIDEE LSM – part of the IPSL earth system model
- *In situ* ORCHIDEE v2.0 (CMIP6) runs with site-based climate forcing, vegetation cover, soil texture compared to all C fluxes and ET observations.
- Test sensitivity (linear regression) of modeled C fluxes to climatic variables.
- Tested ability of a bare soil evaporation resistance term for improving ET.

3 Do TRENDY model simulations accurately capture SW site semi-arid interannual net CO_2 (NEE) dynamics?



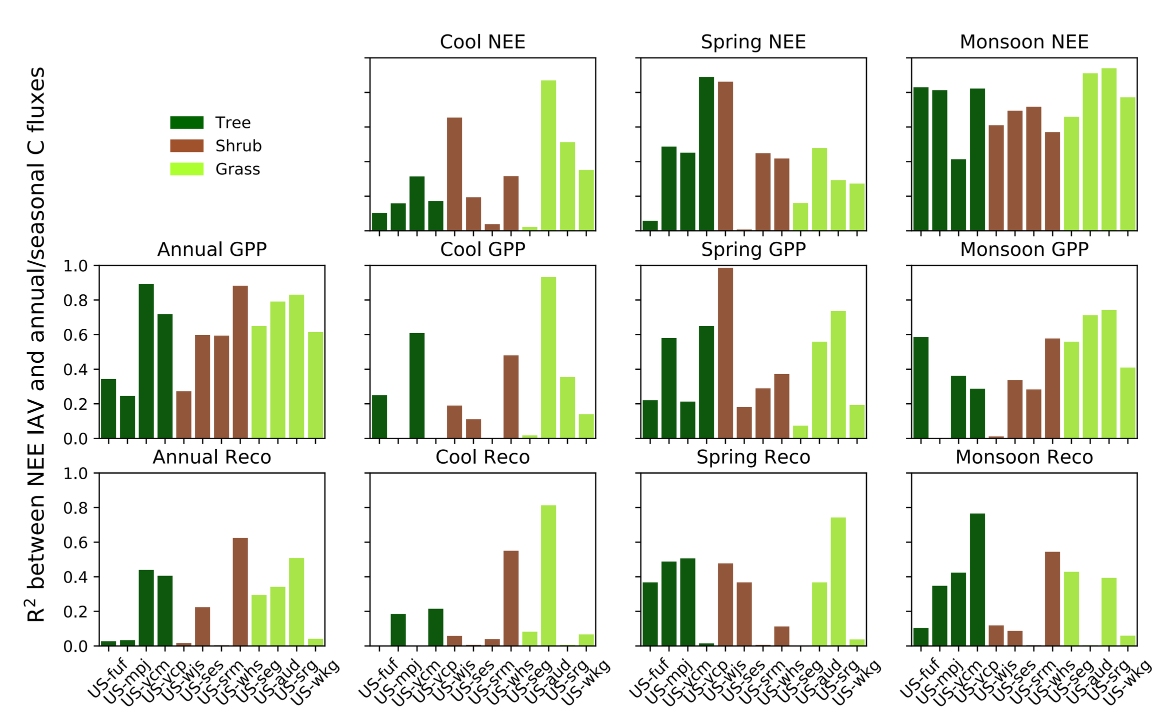
- No! Across all sites LSMs underestimate magnitude of mean annual NEE and poorly capture IAV.
- NOT due to incorrect site-level vegetation, soil texture or climate forcing.

4 What is causing NEE IAV at SW US semi-arid sites?



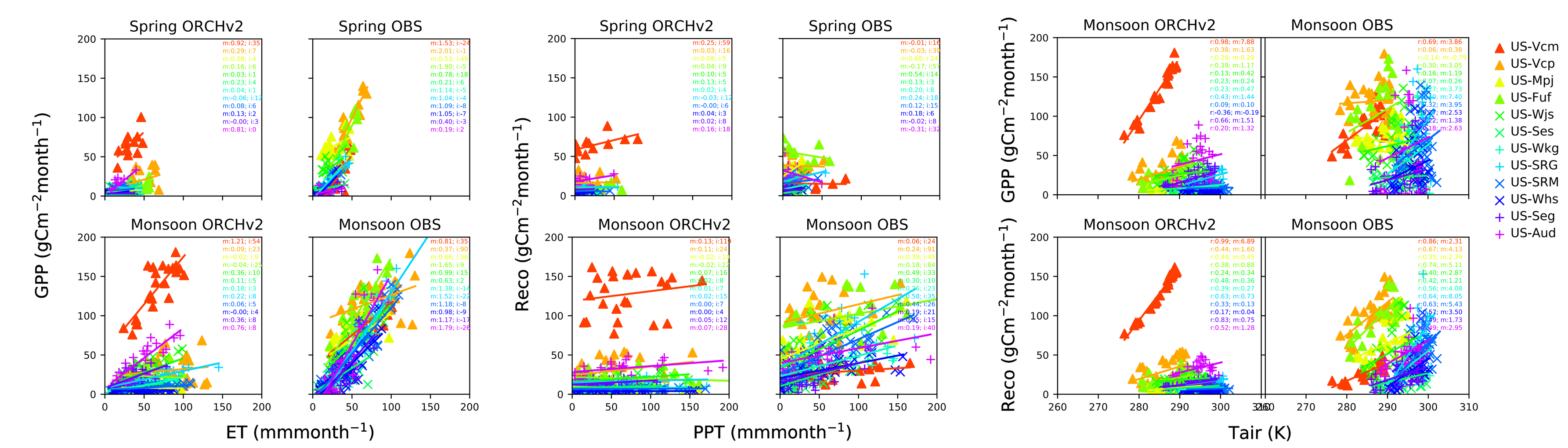
- Unlike in more mesic ecosystems (e.g. Zscheischler et al. (2016) NEE IAV is dominated by both most active days (MAD) and the carbon uptake period (CUP) in all seasons.
- Confirms analysis of Fu et al. (2019) for water-limited ecosystems.
- However, gross C fluxes dominated by maximum productivity (as found in Z2016).

- Annual GPP dominates the NEE IAV (more so for grass-dominated sites).
- The monsoon period dominates the NEE IAV (more so for sparse-vegetation sites).
- At tree and shrub-dominated sites, the warm, moisture-limited spring is also important control on NEE IAV (from both GPP and Reco).
- Monsoon Reco more important at tree sites.



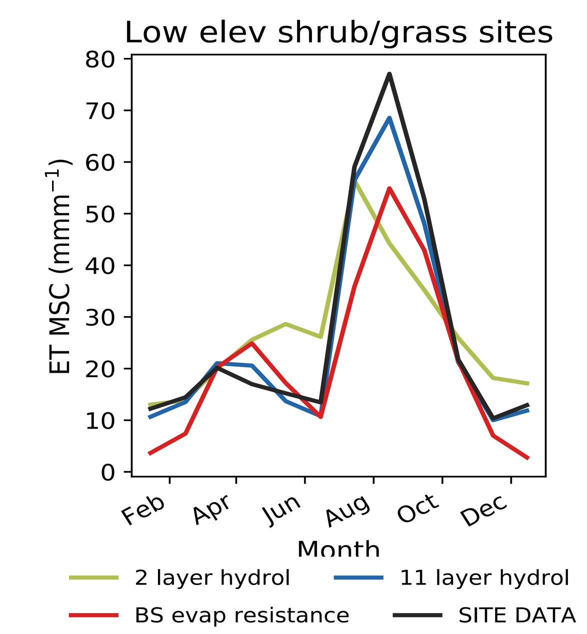
5 Are C flux sensitivities to seasonal climatic variables accurately simulated by TBMs? (*Case study with ORCHIDEE TBM)*

- Across all sites, model GPP is less sensitive to plant water availability (ET) than is observed during both the spring and monsoon periods (*see figure below*).
- Similarly, model Reco is not sensitive enough to precipitation (PPT); Reco at very low moisture needs be higher in the model (→ issue with surface layer moisture? *See Section 6)*.
- Both gross C fluxes are less sensitive to Tair in the model than what is observed during both seasons.



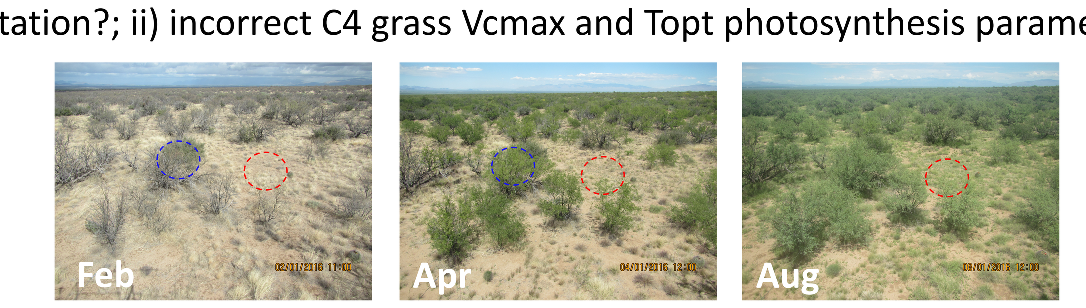
6 Are ET temporal dynamics accurately simulated by TBMs?

- ET well simulated by 11-layer mechanistic hydrology using Richards' equations. Big improvement on 2-layer bucket model. (MacBean et al., in review)
- Bare soil evaporation resistance degrades fit to data → more an issue with T (due to incorrect LAI?)



7 HYPOTHESES and PERSPECTIVES for FUTURE MODEL DEVELOPMENT

- Spring GPP contribution to NEE IAV for trees and shrubs could be due to their ability to tap deeper water reserves; therefore, need for higher model GPP sensitivity to moisture could be improved by dynamic root water uptake as the soil dries + addition of groundwater.
- Model inability to capture correct GPP sensitivity to moisture availability in Monsoon could be due to: i) differences in perennial and annual (summer) C4 grass phenology (e.g. in photos below: summer C4 grasses infill bare soil patches during monsoon) – not in models → therefore, not enough vegetation?; ii) incorrect C4 grass Vcmax and Topt photosynthesis parameters ?



- Models need higher Reco during periods of limited moisture → could be due to: i) incorrect response of Rh to soil moisture?; ii) abiotic CO_2 release – processes which are not accounted for in models (e.g. Birch Effect, photodegradation of litter, inorganic carbonate reactions)?

Natasha MacBean[1] (nmacbean@indiana.edu), Russell L. Scott[2], Joel A. Biederman[2], and Philippe Peylin[3], David J. P. Moore[4].
[1]Indiana University - Bloomington, [2]USDA Agricultural Research Service, [3]Laboratoire des Sciences du Climat et de l'Environnement, [4]University of Arizona.

References: Biederman et al. (2017) GCB; Zscheischler et al. (2016) JGR-B; Fu et al. (2019) GCB; MacBean et al., in review, https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-598/.