Carbon Monitoring System in Mountains (CMS-Mountains): Development and Testing in the Western U.S. (Lin-CMS 2015 & Lin-CMS 2018)

John C. Lin, **Brett Raczka**, Henrique Duarte, David R. Bowling, Jeffrey L. Anderson, Timothy J. Hoar, Christian Frankenberg, Philipp Koehler, Karen Yuen

THE UNIVERSITY OF UTAH

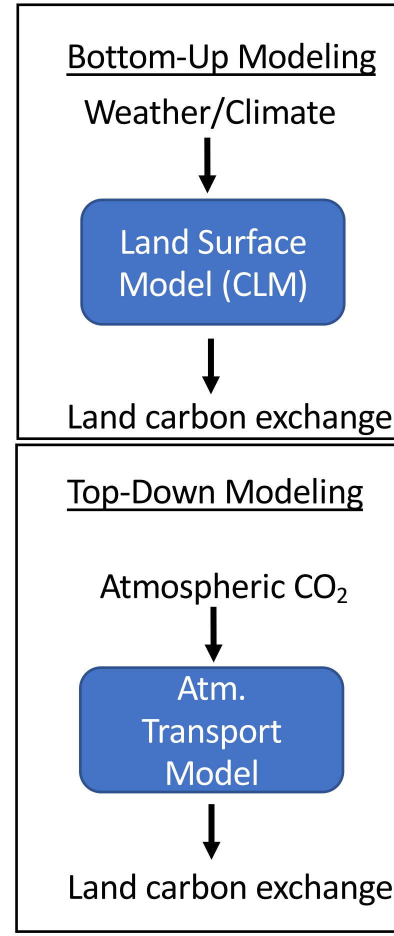
NCAR NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NASA

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891 Caltech

JPL Jet Propulsion Laboratory

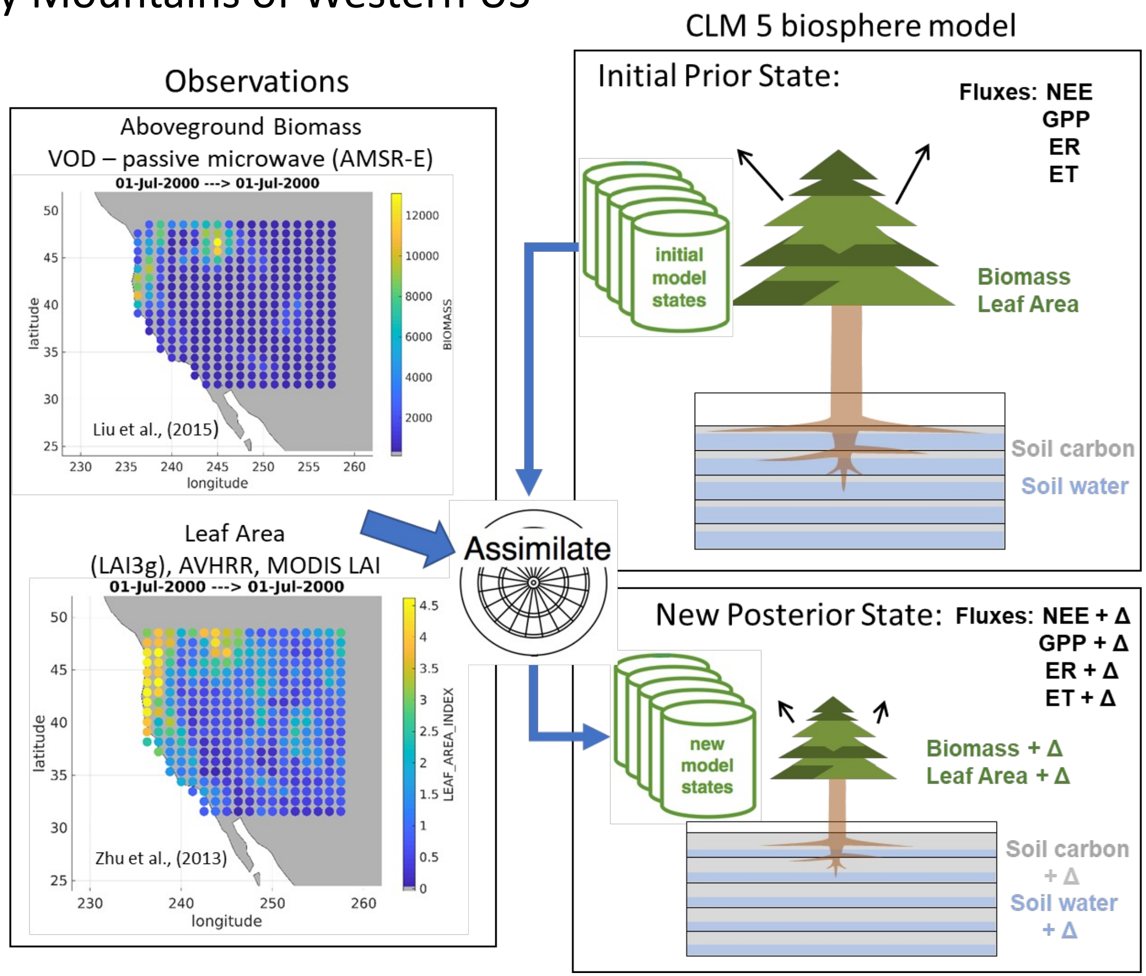
Goal: Monitor carbon flux across complex terrain of Western US



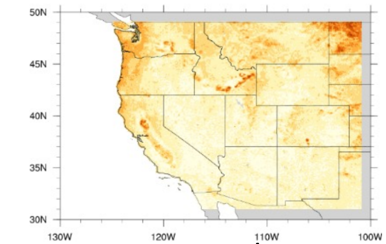
Vulnerable carbon stocks, drastic change to landscape and ecosystem functioning

Overarching Goal: Develop Land surface data assimilation system, CLM5-DART

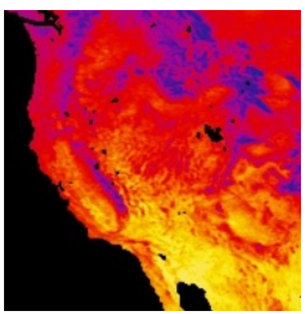
"Develop a carbon monitoring system across complex terrain of Rocky Mountains of Western US"



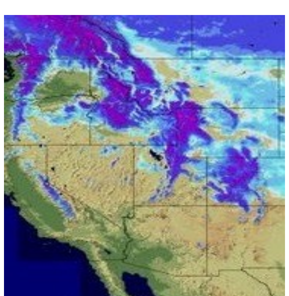
Solar Induced Fluorescence (SIF)



(TROPOMI, OCO-2/3, GOME-2)



Land Surface Temp (ECOSTRESS)



Snow Cover (MODIS)

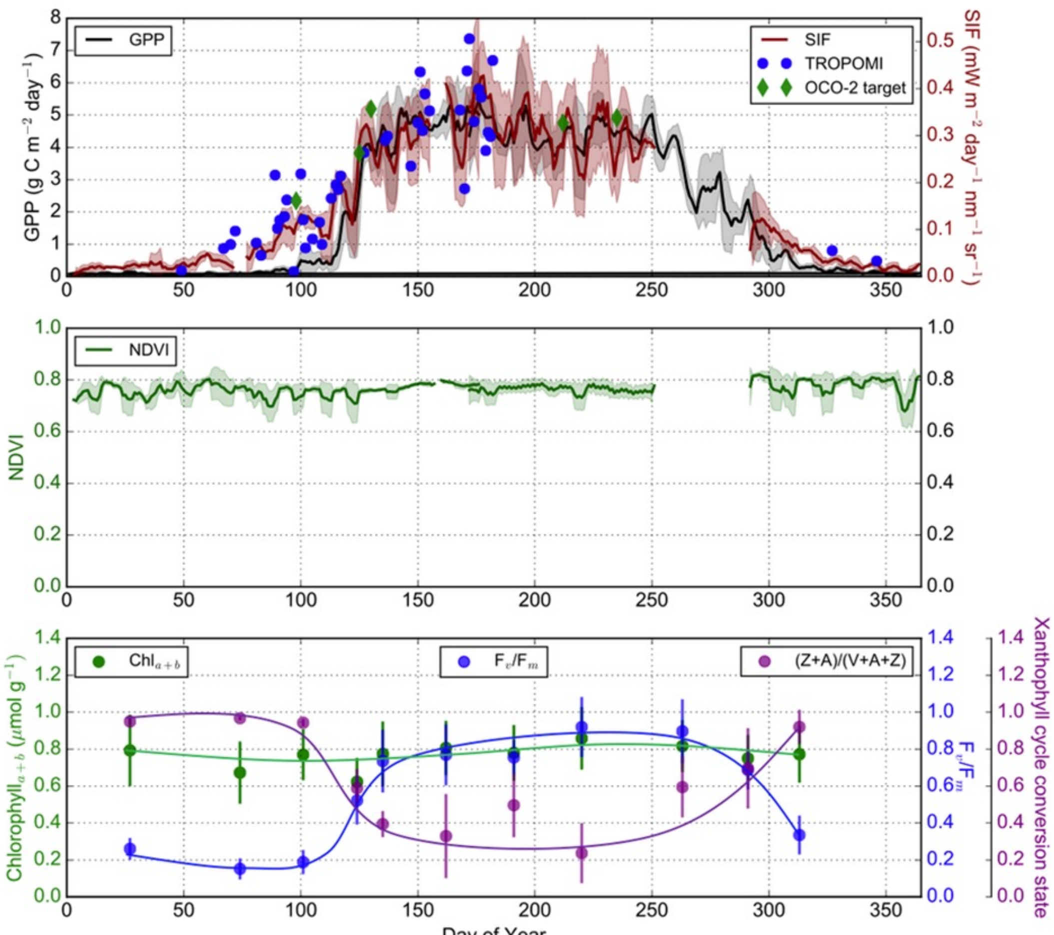
CMS-Mountains-I Review

Demonstration of strong SIF-GPP relationship for Western US evergreen species

PNAS

Mechanistic evidence for tracking the seasonality of photosynthesis with solar-induced fluorescence

Troy S. Magney[a,b,1], David R. Bowling[c], Barry A. Logan[d], Katja Grossmann[e,2], Jochen Stutz[e], Peter D. Blanken[f], Sean P. Burns[f,g], Rui Cheng[a], Maria A. Garcia[c], Philipp Köhler[a], Sophia Lopez[d], Nicholas C. Parazoo[b], Brett Raczka[c], David Schimel[b], and Christian Frankenberg[a,b,1]



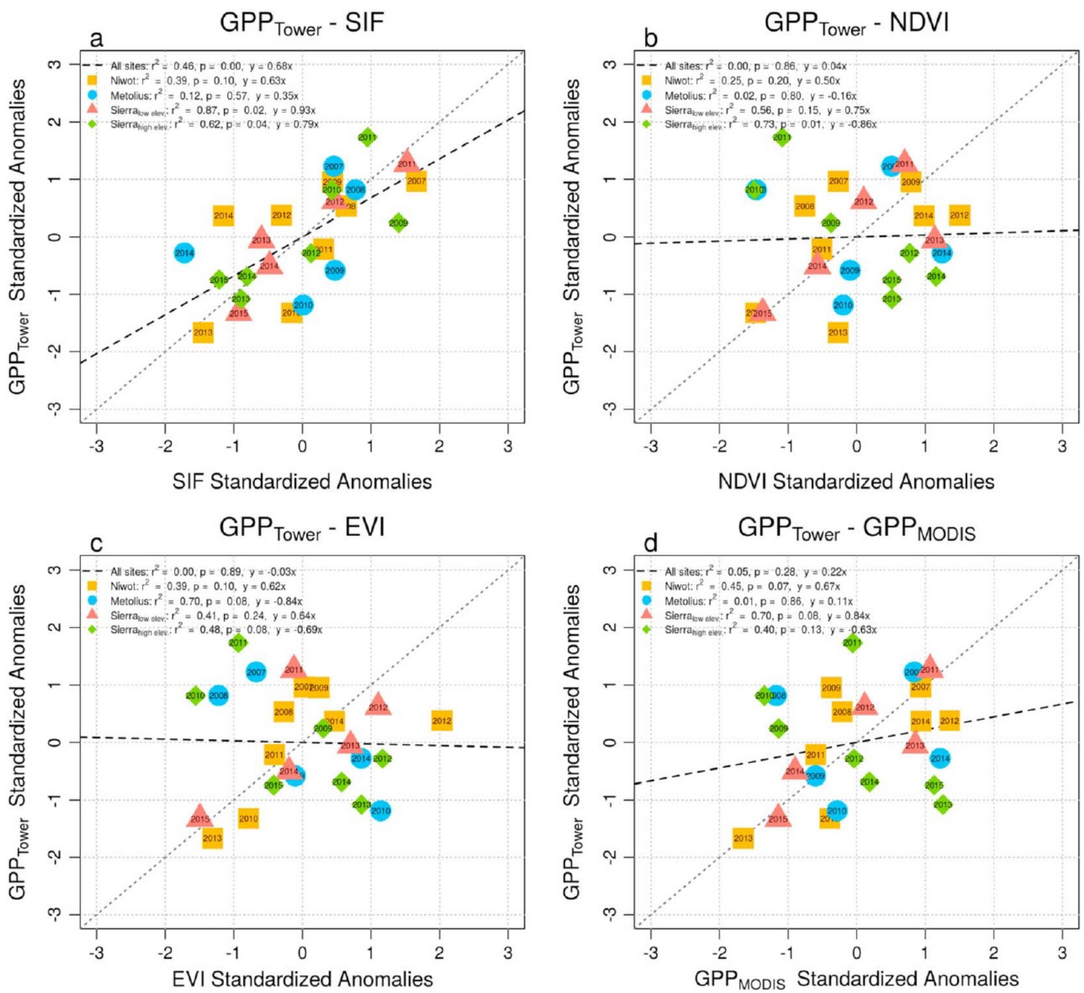
- SIF is a useful indicator of timing/magnitude of GPP (Niwot Ridge, CO)
- Traditional 'green-ness' indicators do not track seasonal GPP
- The GPP seasonality related to leaf pigment transition (xanthophyll cycle)

Demonstration of strong SIF-GPP relationship for Western US evergreen species

Geophysical Research Letters

Solar-Induced Fluorescence Detects Interannual Variation in Gross Primary Production of Coniferous Forests in the Western United States

Lauren M. Zuromski[1], David R. Bowling[1,2], Philipp Köhler[3], Christian Frankenberg[3], Michael L. Goulden[4], Peter D. Blanken[5], and John C. Lin[1]



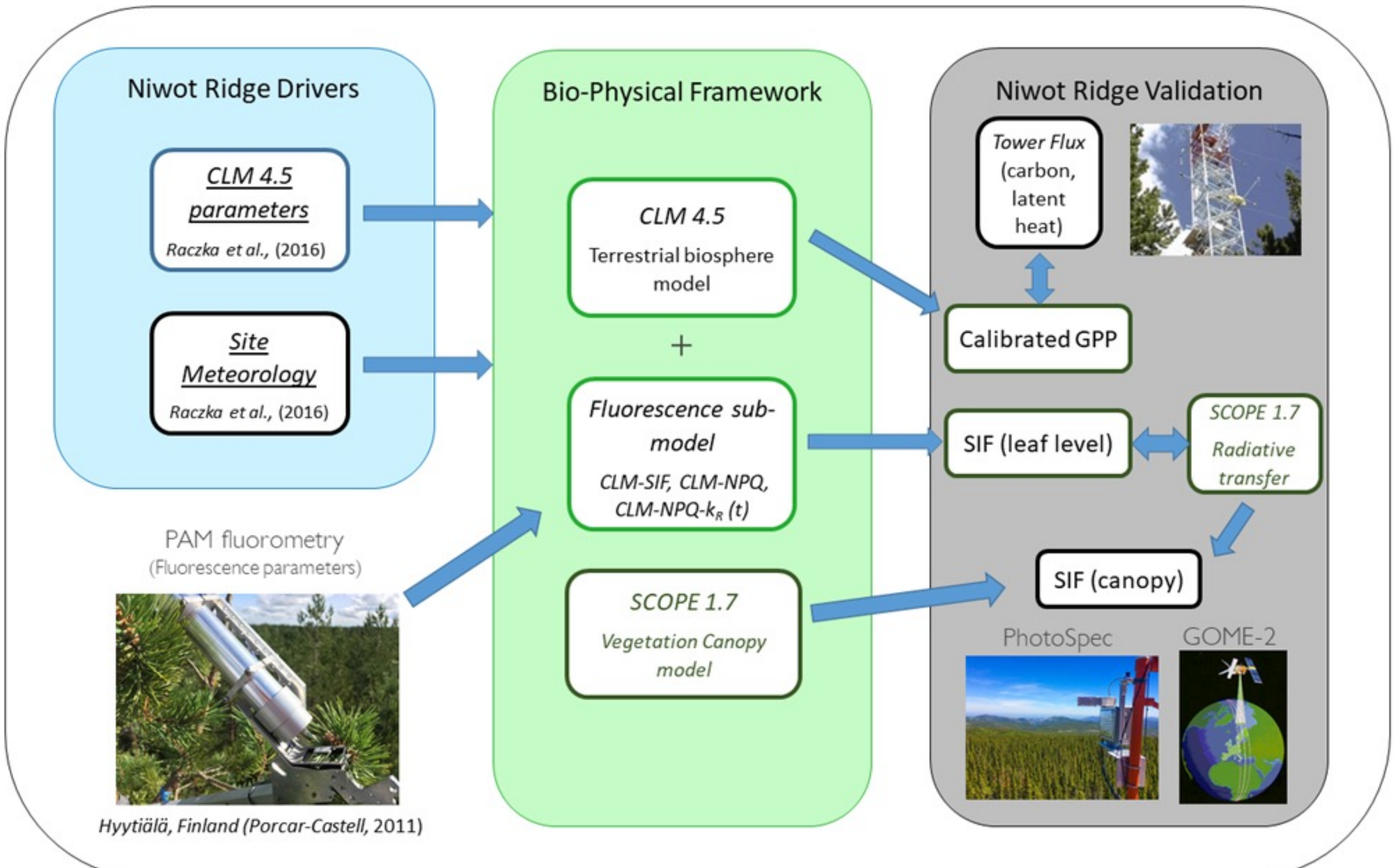
- Solar-induced fluorescence detected inter-annual variation in GPP and small disturbances with greater success than traditional satellite-based products.

Add representation of SIF within a land surface model: Community Land Model (CLM)

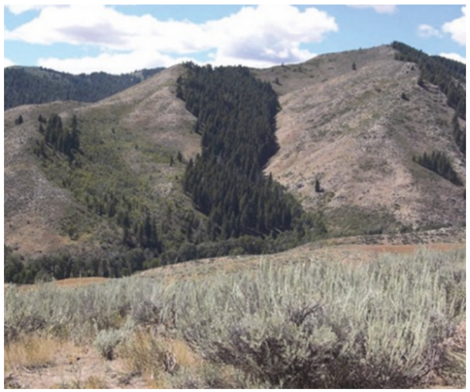
Sustained Nonphotochemical Quenching Shapes the Seasonal Pattern of Solar-Induced Fluorescence at a High-Elevation Evergreen Forest

JGR Biogeosciences

Brett Raczka[1], A. Porcar-Castell[2], T. Magney[3,4], J. E. Lee[5], P. Köhler[4], C. Frankenberg[3,4], K. Grossmann[6,7,8], B. A. Logan[9], J. Stutz[6,7], P. D. Blanken[10], S. P. Burns[10,11], H. Duarte[12], X. Yang[13], J. C. Lin[12], and D. R. Bowling[1]



Do more spatially resolved land surface maps and meteorology improve biomass simulations?

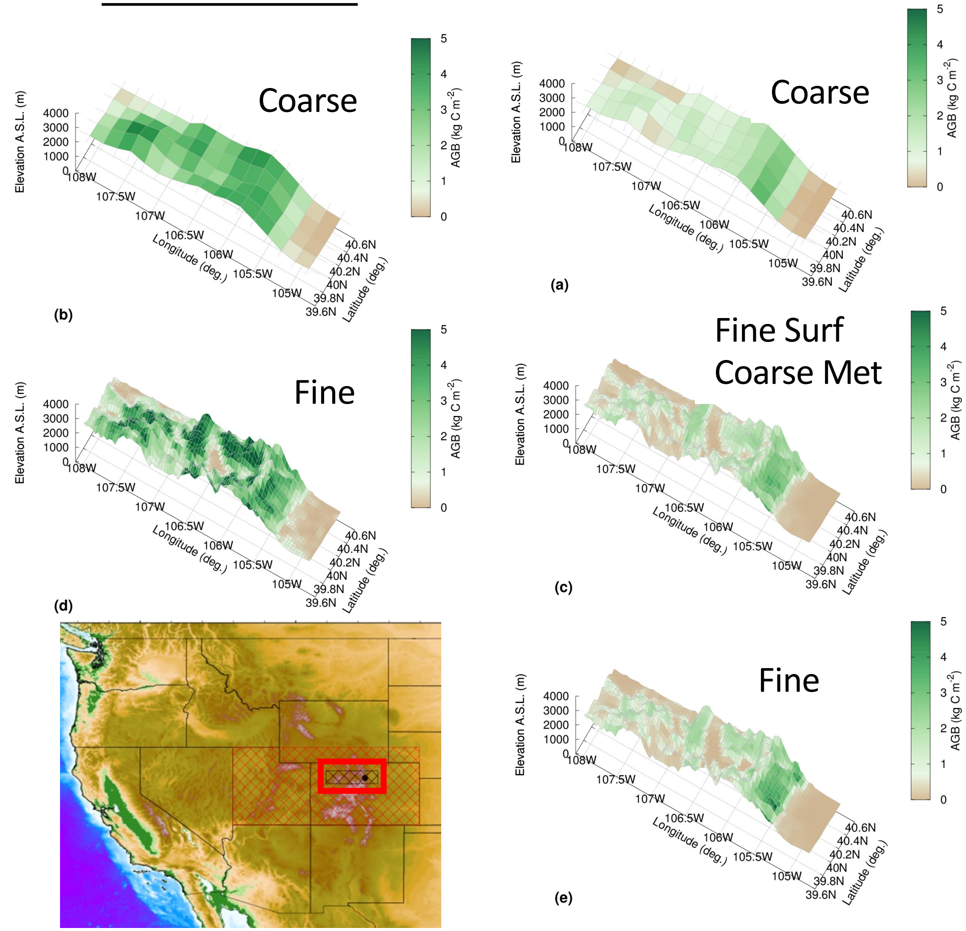


Fine (1/24°) and Coarse (1/2°) CLM surface maps and GRIDMET meteorology

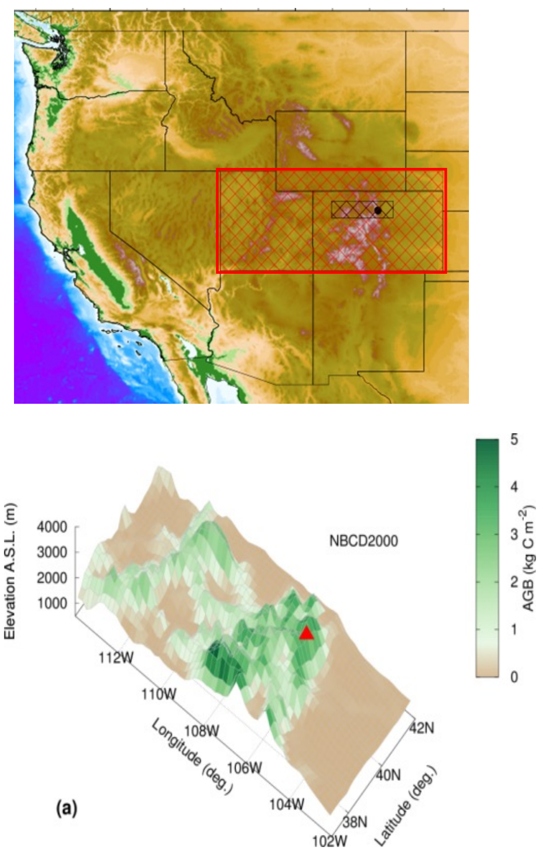
Fan et al., 2019:

*"The next questions are as follows: where and when, across the diverse and dynamic environments of the globe, do we expect that these terrain influences will matter to ESM predictions of large-scale water, energy, and biogeochemical fluxes? …**will the hillslope-scale structures, however, deterministic and predictable, simply average out over an ESM grid cell and hence matter little to global predictions?"***

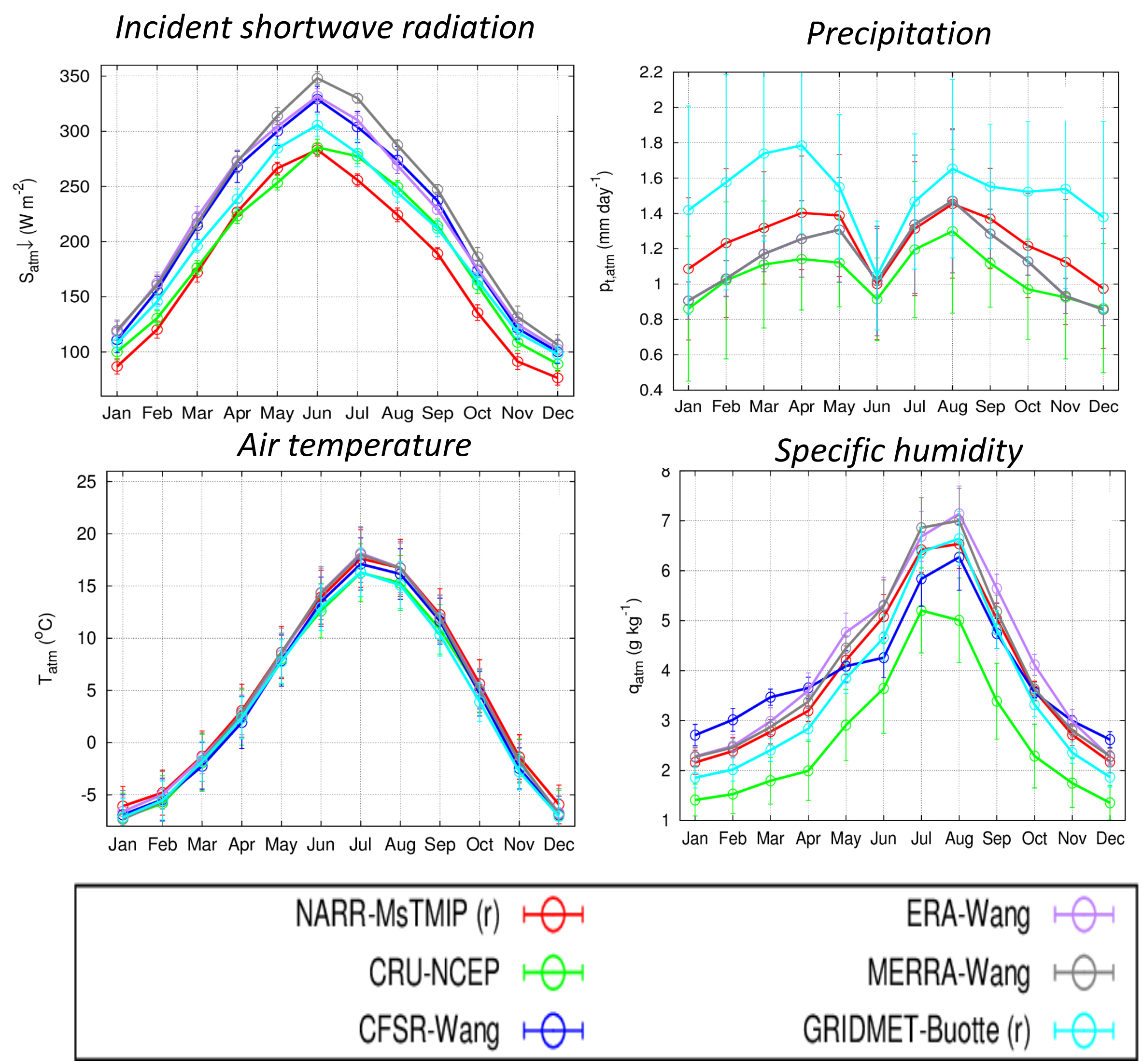
<u>Observations</u> <u>Simulations</u>



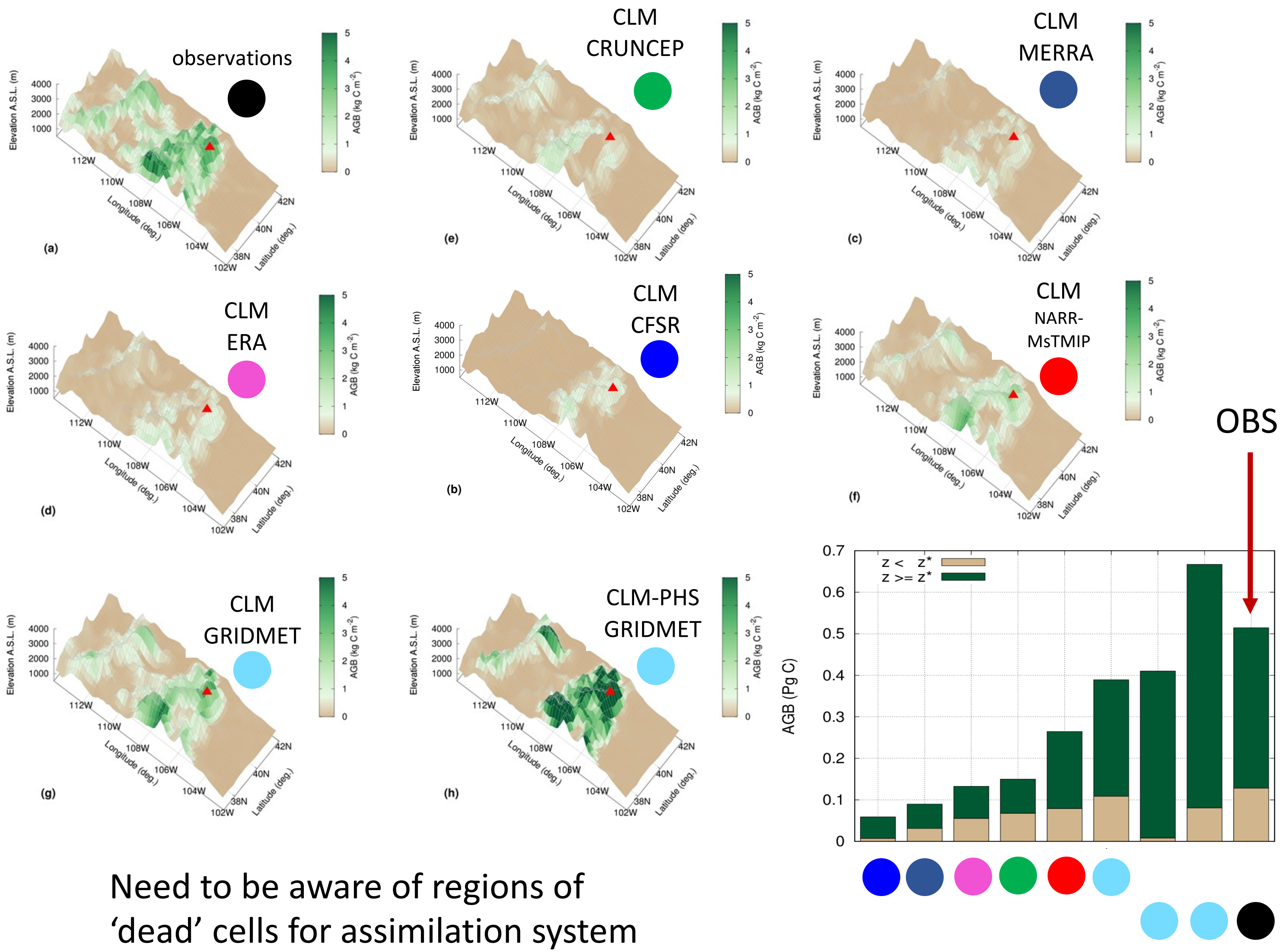
Meteorology data products for complex terrain tend to be too warm/dry



* z > 2235 m
75% of total AGB
(NBCD2000 product,
Kellndorfer et al., 2013)



Simulation of biomass is highly sensitive to meteorological biases and representation of water limitation



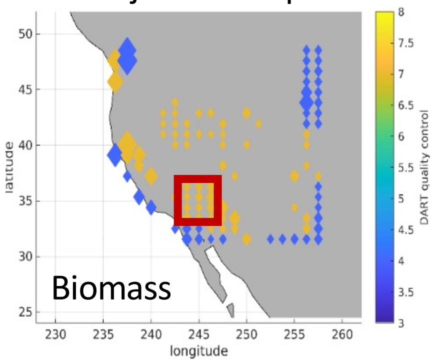
Need to be aware of regions of ‘dead’ cells for assimilation system

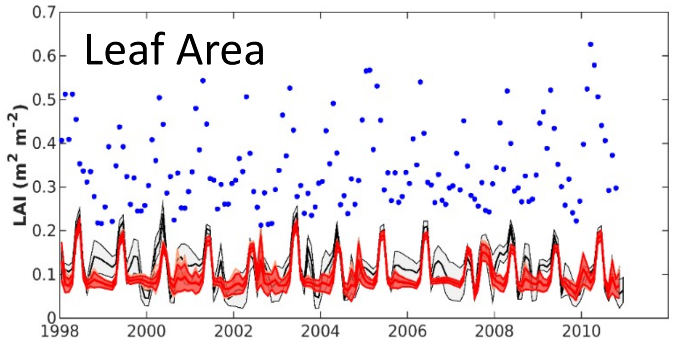
Dead cell regions inhibit functioning of assimilation system

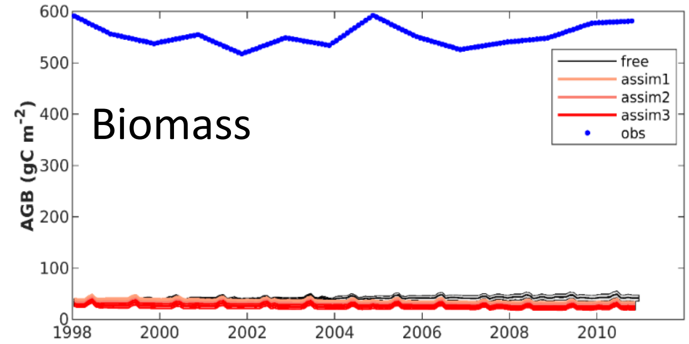
Observations - Blue

Assimilation (w/obs) - Red
Free (no obs)- Black

Observation rejection map



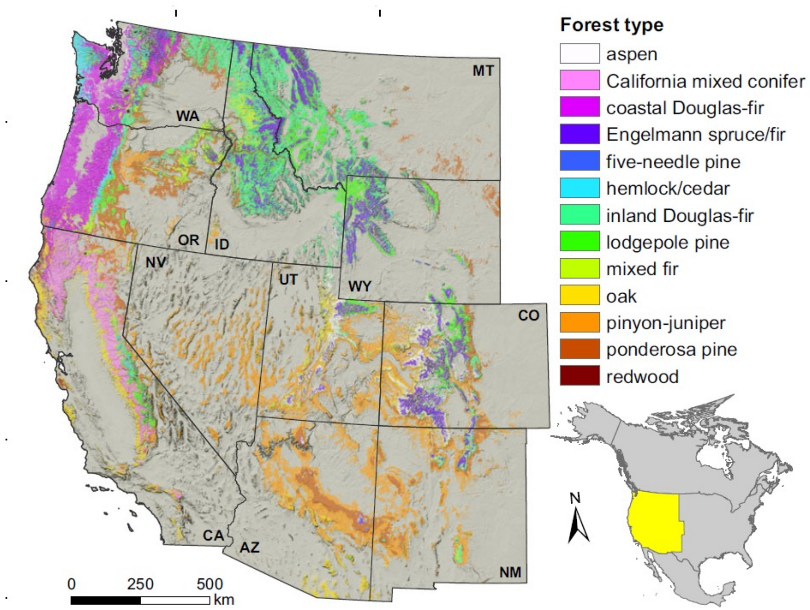




Identifying the most favorable meteorological dataset and model configuration (GRIDMET –CLM5-PHS) helped avoid these dead cell regions that are highly resistant to assimilation updates

Paths for continued land surface model improvement

Custom PFT parameterization

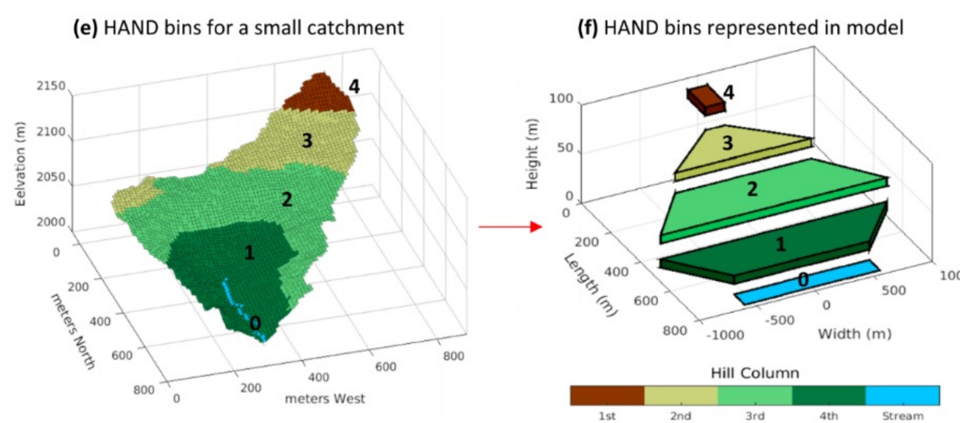


Buotte et al., 2018

Hillslope, Subsurface Hydrology

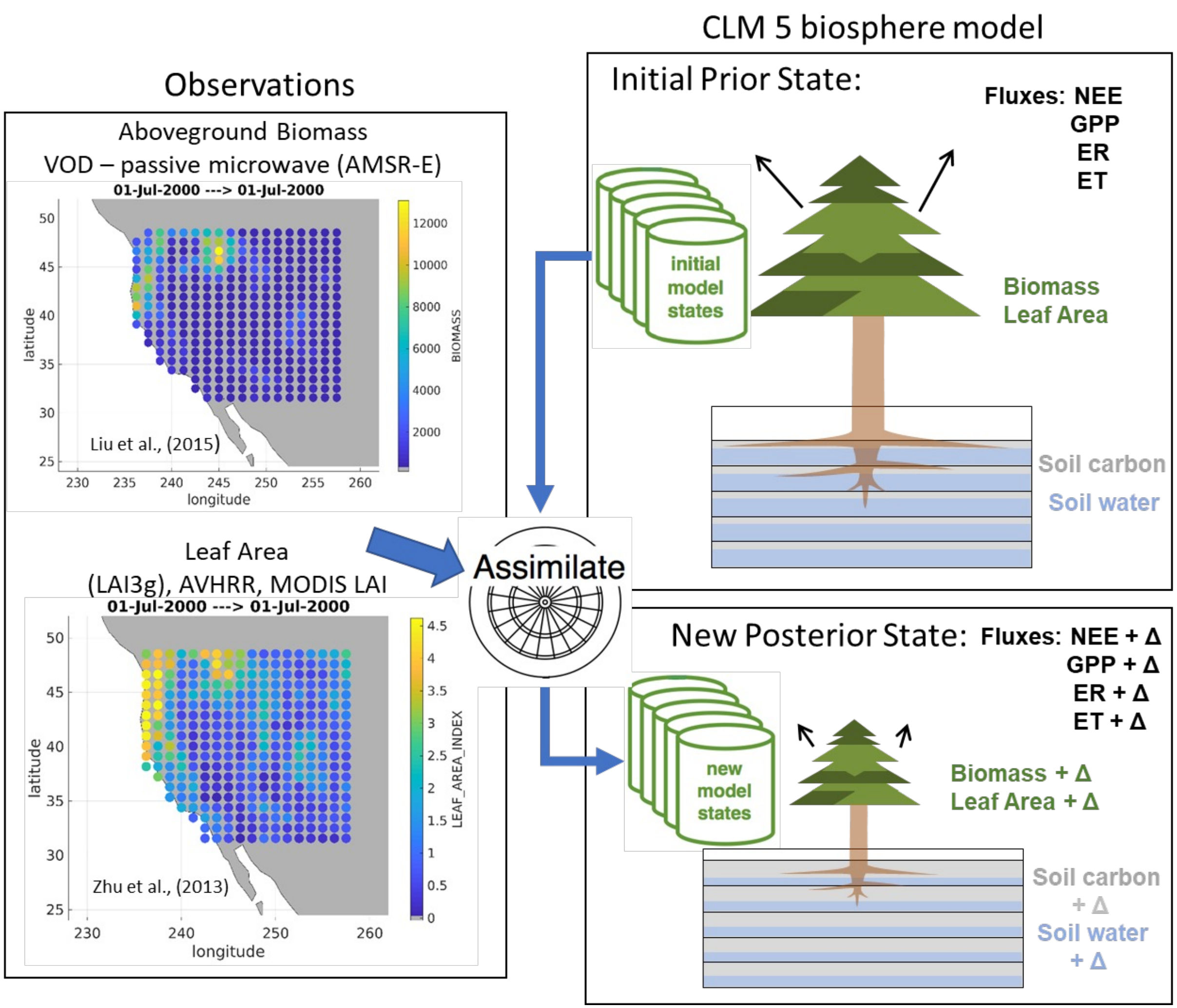
Spatially Explicit
– computationally unrealistic

Spatially Implicit –
empirical, but less computation



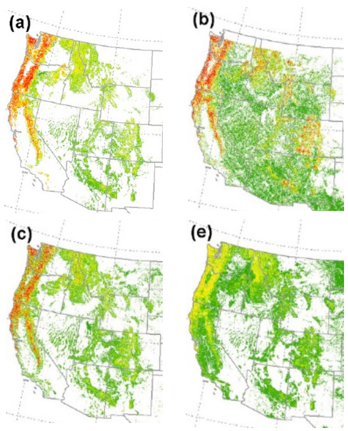
Fan et al., 2019

Land surface data assimilation system: CLM5-DART 'Benchmark Case'

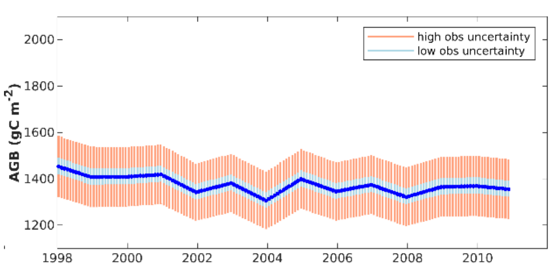


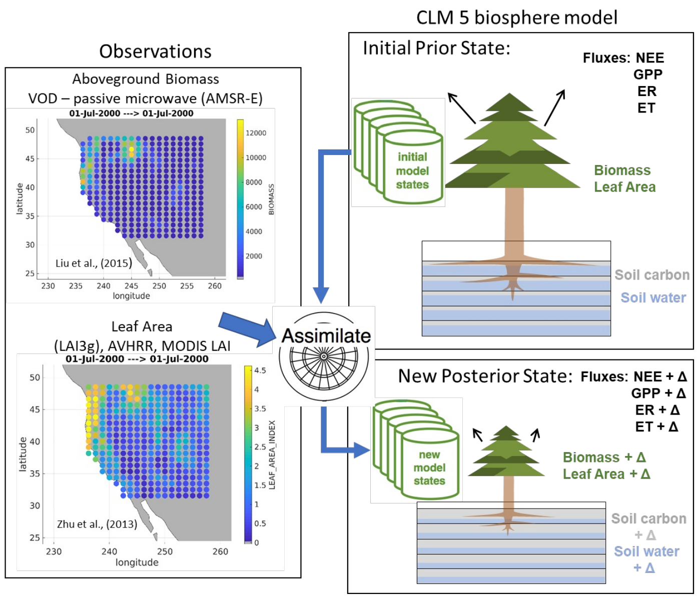
Land surface data assimilation system: CLM5-DART
'Benchmark Case'

NASA CMS Biomass WG (biomass products)



NASA CMS Uncertainty WG



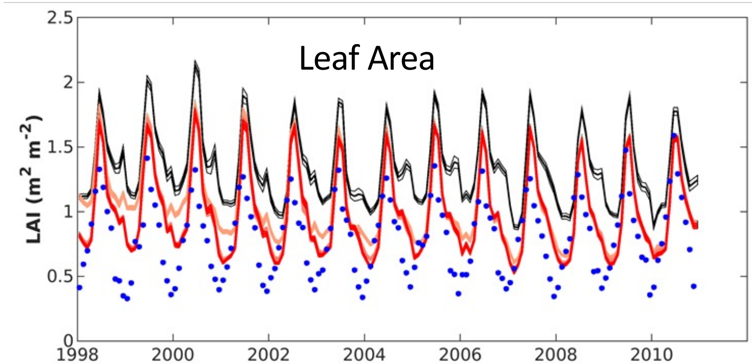


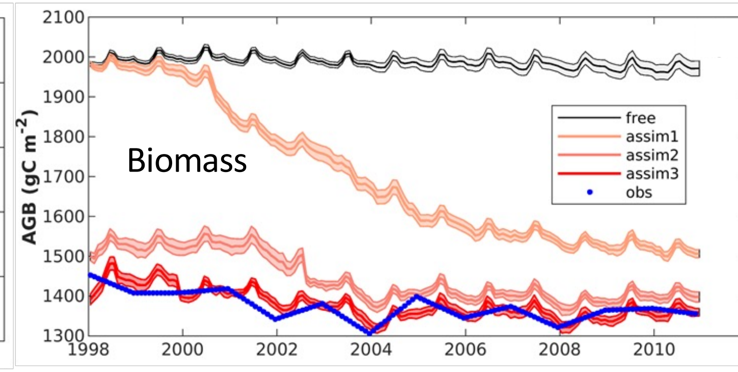
Model State localization

- Leaf carbon
- Live stem carbon
- Dead stem carbon
- Leaf area index
- Fine root carbon
- Live coarse root carbon
- Dead coarse root carbon
- Live stem nitrogen
- Dead stem nitrogen
- Litter carbon, slow
- Litter carbon, medium
- Litter carbon, fast
- Litter nitrogen, slow
- Litter nitrogen, medium
- Litter nitrogen, fast

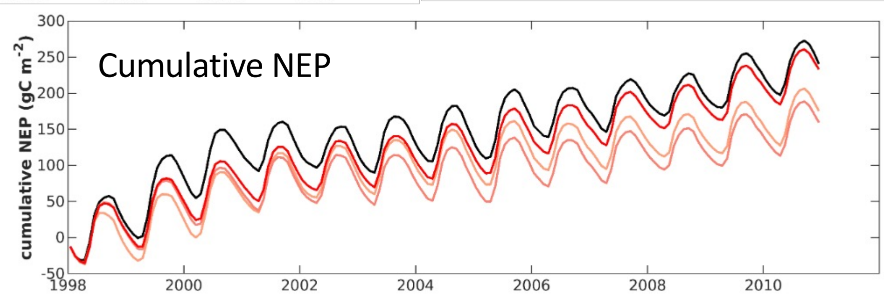
Assimilation of leaf area and biomass reduce simulated biomass, GPP, ER. Net carbon exchange holds steady

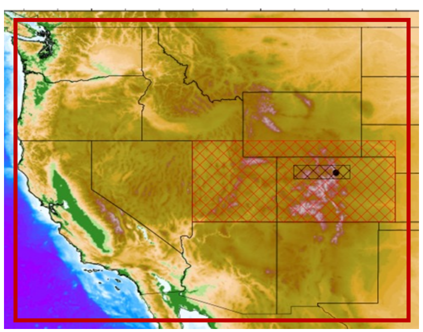
Western US
Assimilation
overview





Observations - Blue
Assimilation (w/obs) - Red
Free (no obs) - Black





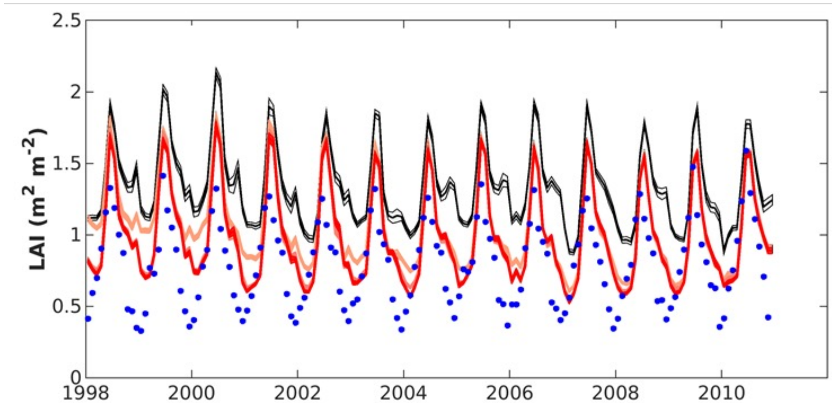
Simulation Name	AGB (kgC m^{-2})	LAI (m m^{-2})	GPP (gC m^{-2} $month^{-1}$)	ER (gC m^{-2} $month^{-1}$)	NEP (gC m^{-2} $month^{-1}$)
Free	1.98	1.31	48.18	47.18	1.00
State-15	1.33	0.93	37.08	39.52	-2.43
State-9	1.36	0.96	38.49	37.21	1.28
State-4	1.44	0.92	37.01	37.15	-0.05

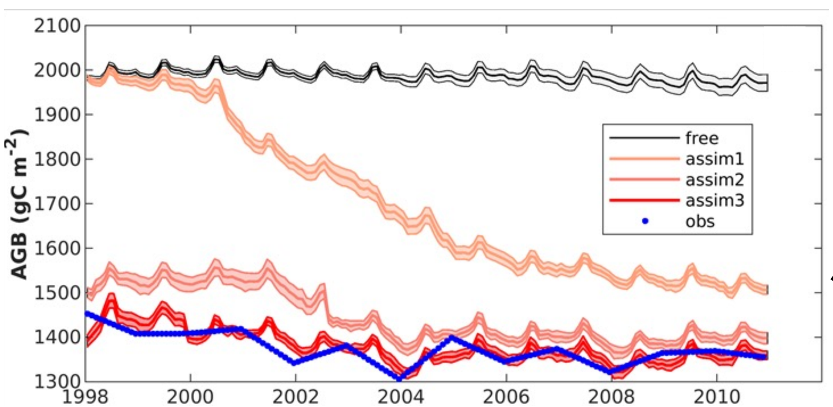
Was the assimilation successful? Diagnosing observation acceptance rate and RMSE

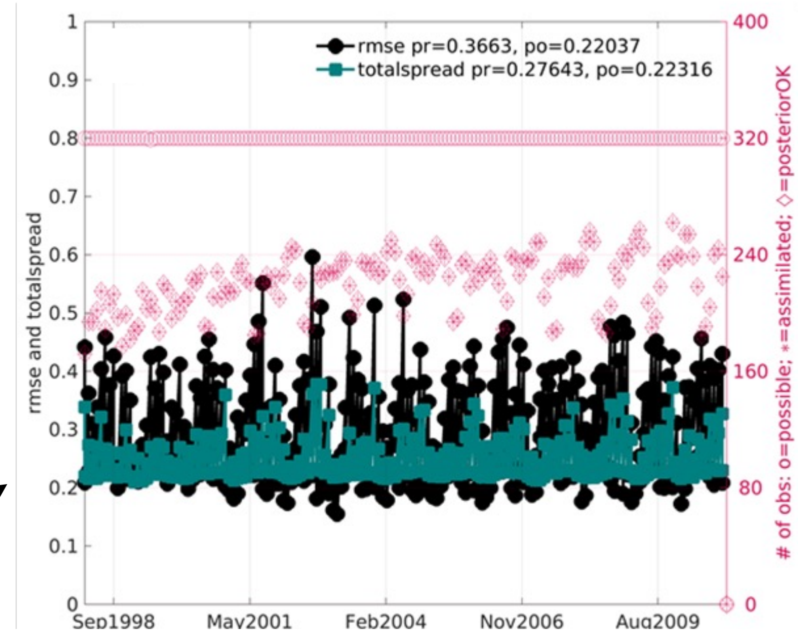
Observations - Blue

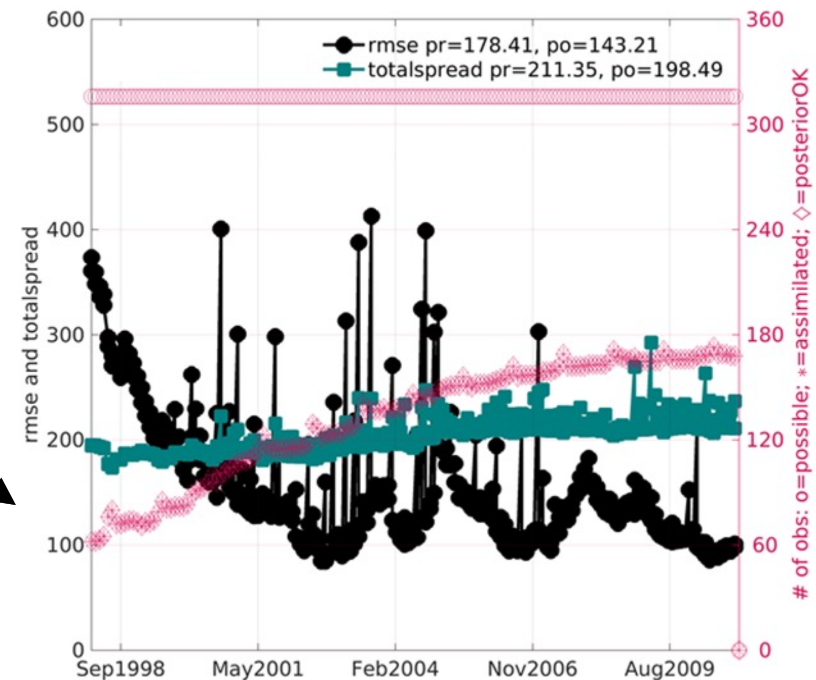
Assimilation (w/obs) - Red

Free (no obs) - Black





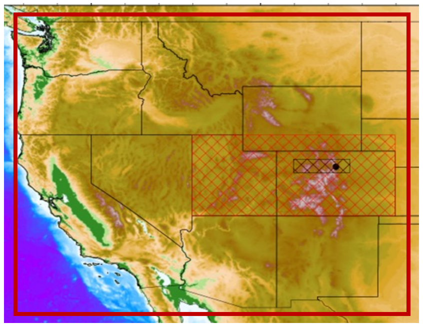


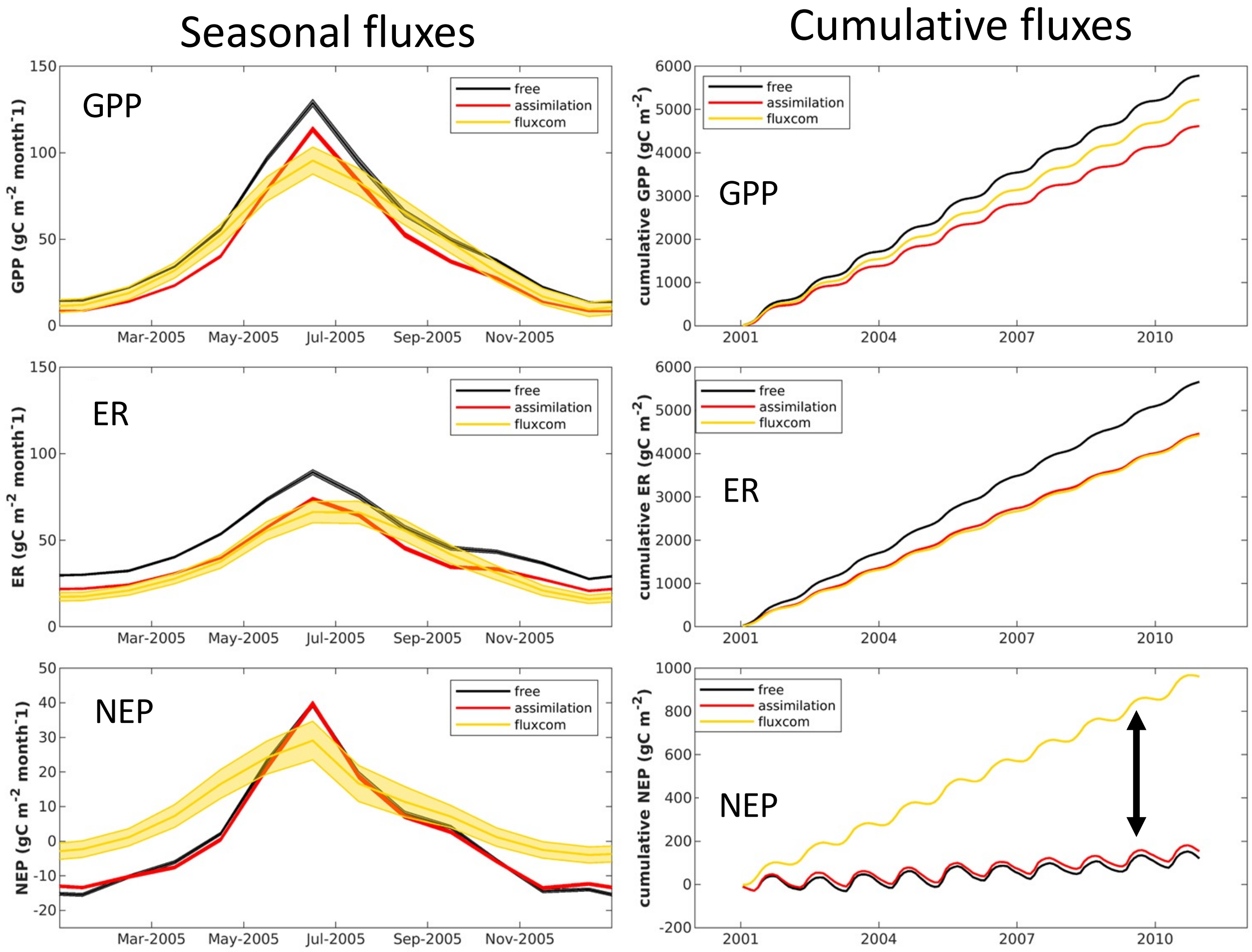


Our assimilation estimate of carbon uptake much weaker than another observation-constrained product (FLUXCOM)

CLM5-DART vs. FLUXCOM (observation constrained, machine learning, model ensemble)

- GPP mismatch
- ER very similar
- NEP: strong winter mismatch

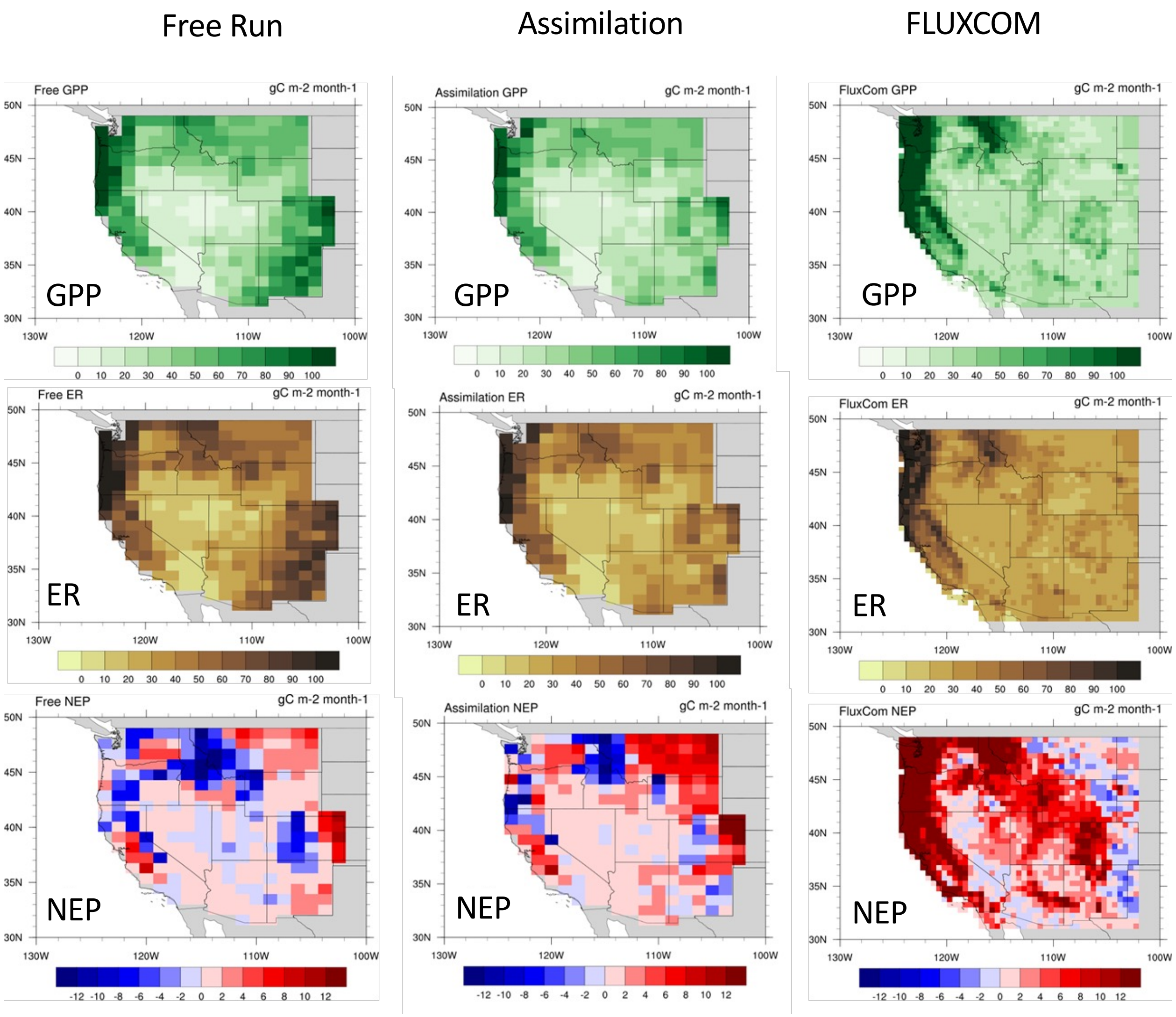




Our assimilation estimate of carbon uptake much weaker than another observation-constrained product (FLUXCOM)

CLM5-DART not getting high elevation uptake, low elevation neutral

- AGB observations in interior West relatively low
- Water variables in CLM not receiving direct adjustments, (downstream variables)

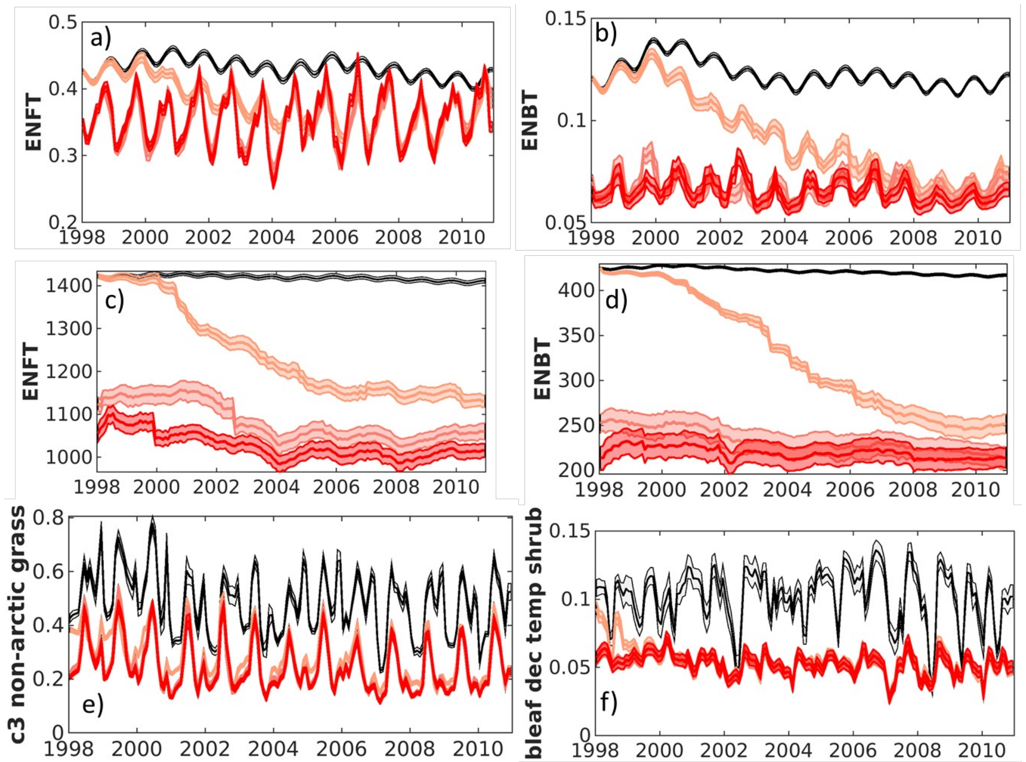


Opportunities for improved assimilation: PFT specific observations

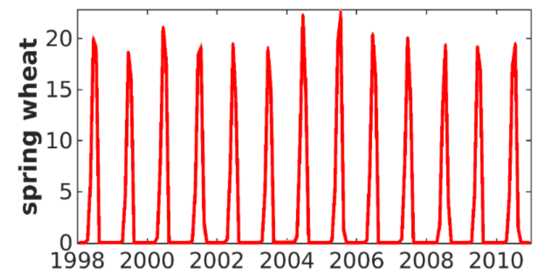
Leaf Area

AGB

Leaf Area



The assimilation adjustments to natural vegetation looks fine, crops are resistant to assimilation adjustments

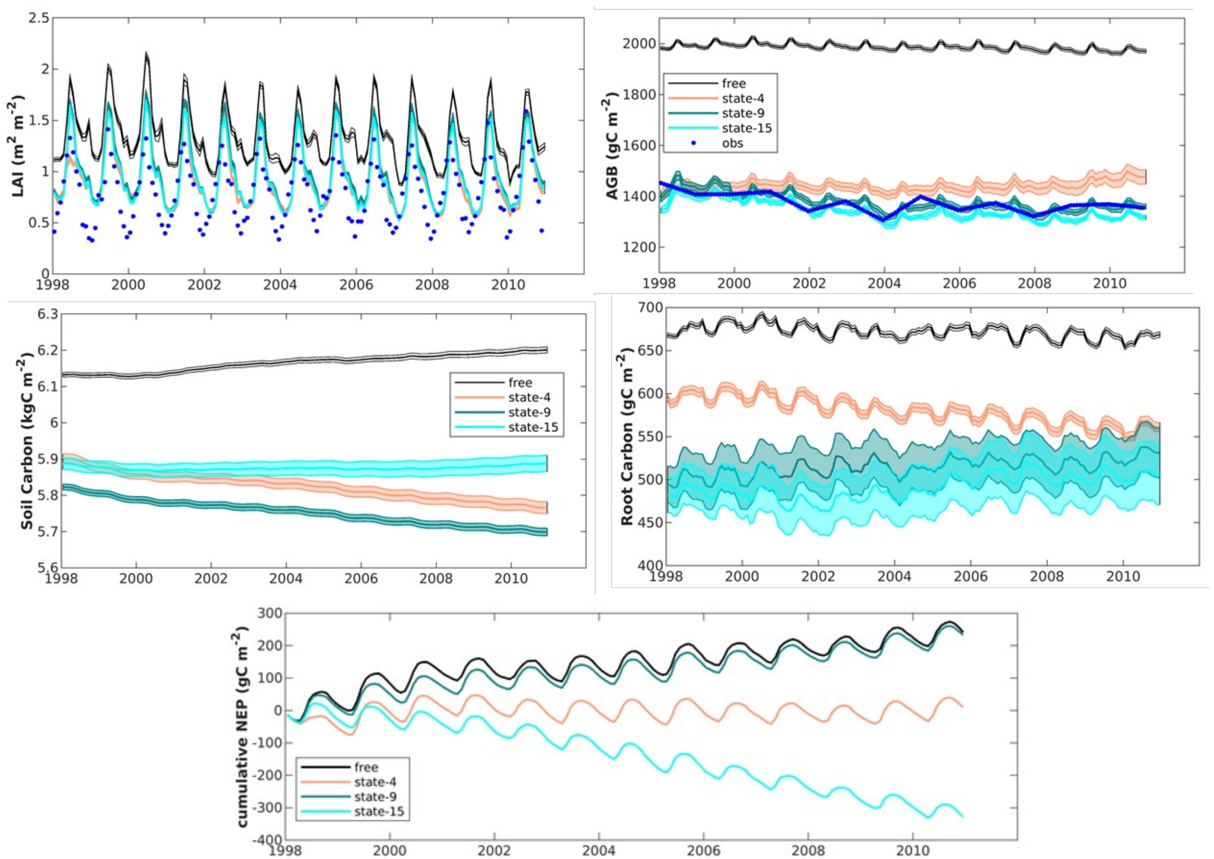


- Robert Kennedy, OSU (LandTrender biomass)

Opportunities for improved assimilation: expanding CLM adjusted state variables

Leaf carbon
Live stem carbon
Dead stem carbon
Leaf area index
Fine root carbon
Live coarse root carbon
Dead coarse root carbon
Live stem nitrogen
Dead stem nitrogen
Litter carbon, slow
Litter carbon, medium
Litter carbon, fast
Litter nitrogen, slow
Litter nitrogen, medium
Litter nitrogen, fast

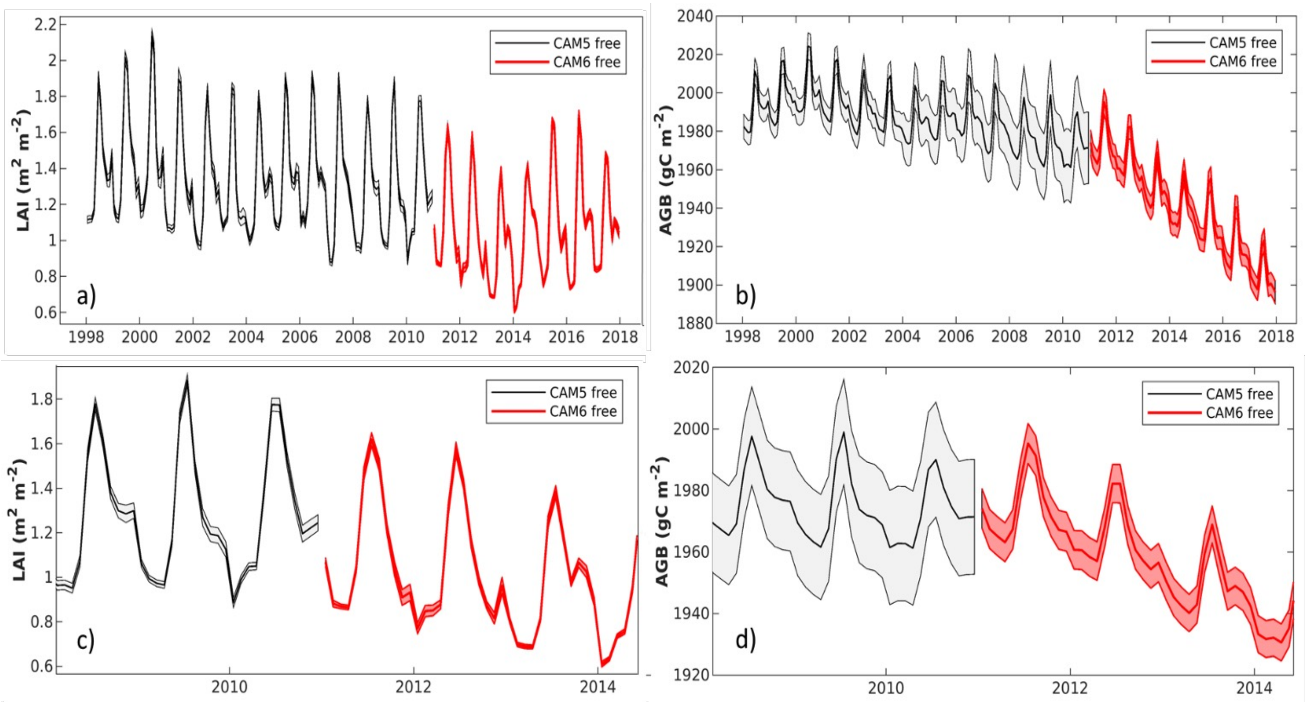
- Should expand to include soil carbon, water state variables.



CMS-Mountains-II

CMS-II (Lin 2018) advances

- Successfully extended the CLM5 ensemble simulation through 2018 (2019)
- We are poised to add new data streams for 1998-2019 assimilation

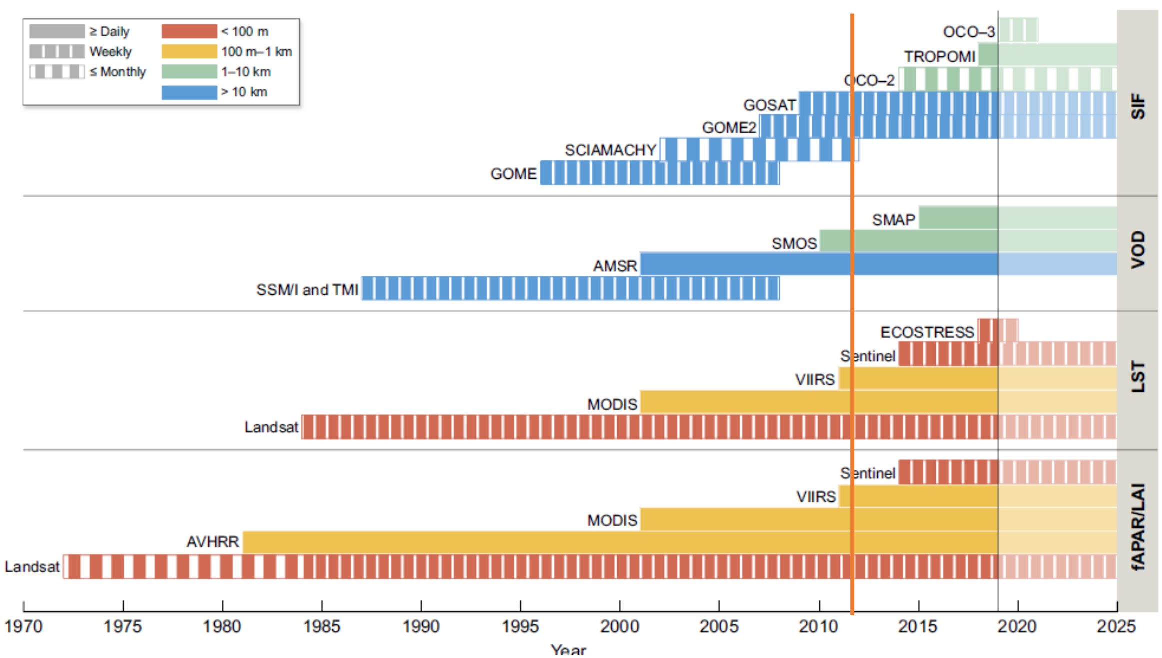


CMS-II (Lin 2018) goals: add data streams

- Successfully extended the CLM5 ensemble simulation through 2018 (2019)
- We are poised to add new data streams for 1998-2019 assimilation

New Phytologist

William K. Smith[1], Andrew M. Fox[1], Natasha MacBean[2], David J. P. Moore[1] and Nicholas C. Parazoo[3]



<u>Add Observation Streams</u>

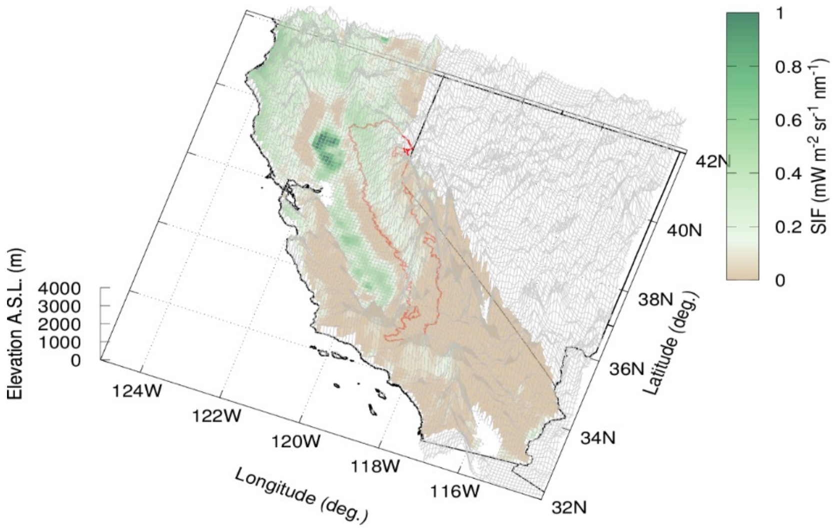
- GLASS LAI
- LandTrendr biomass (PFT)

- ECOSTRESS, LST
- SIF-TROPOMI
- SNODAS

<u>Assimilation framework</u>

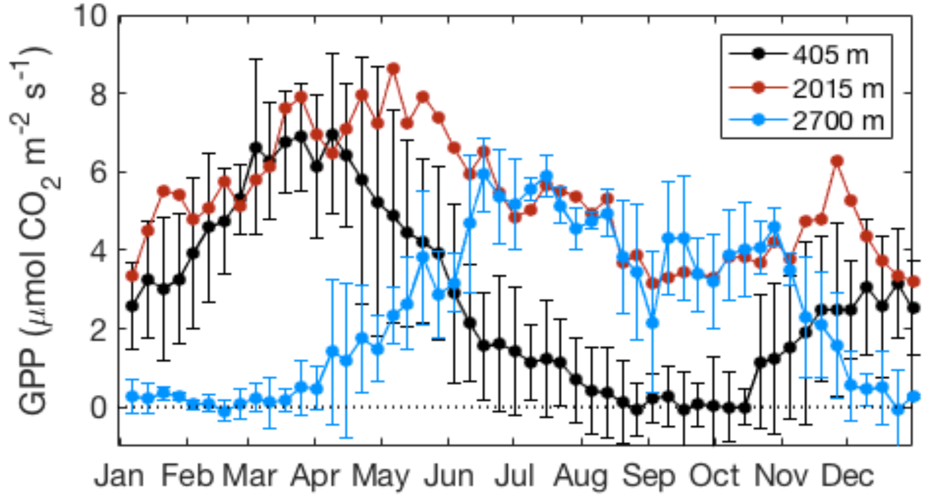
CMS-II (Lin 2018) goals: High resolution TROPOMI-SIF to diagnose phenology

High Resolution TROPOMI-SIF (5x5 km, 4-8 days)



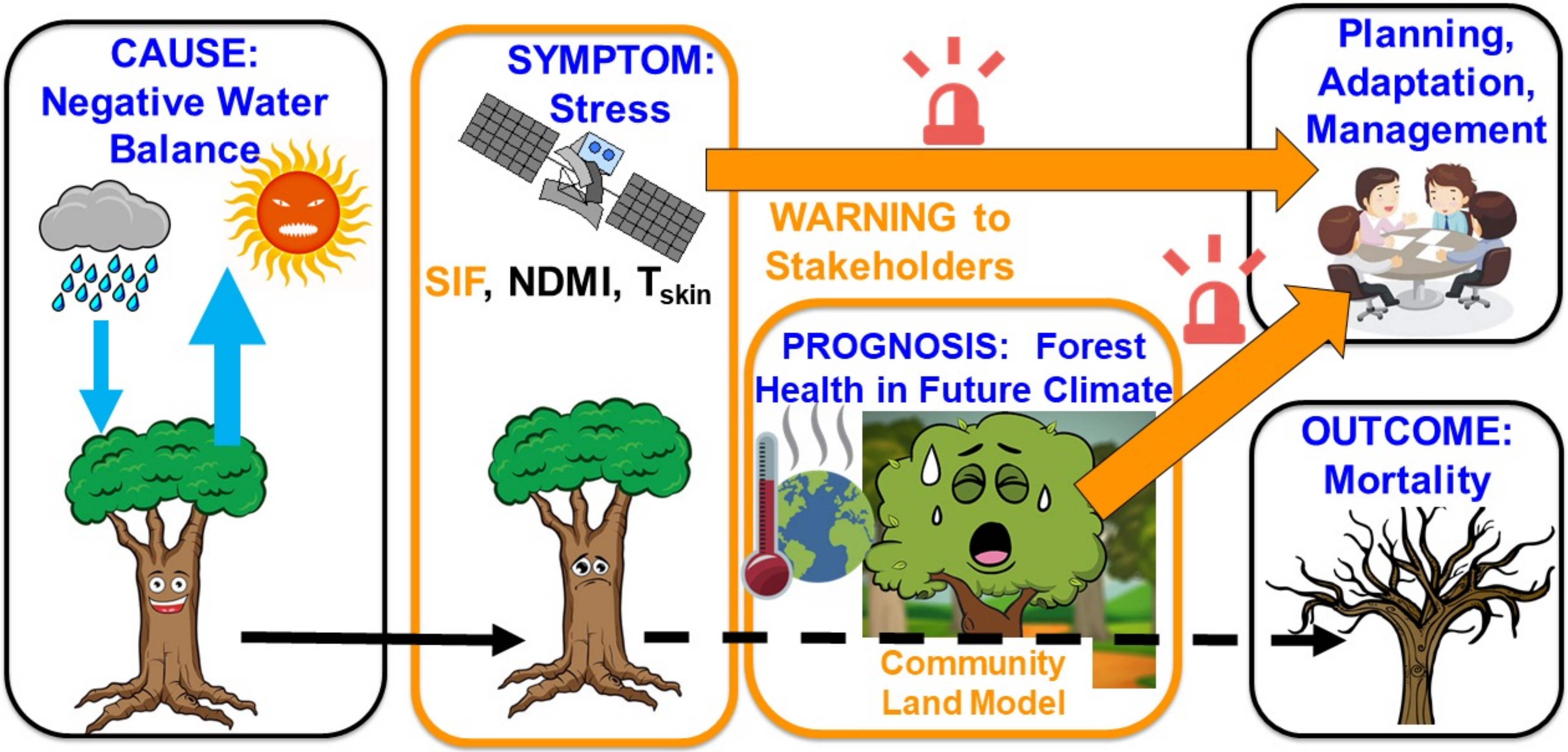
- Characterize seasonal phenology based on elevation, slope and aspect

Southern Sierra Critical Zone Observatory Flux Tower Sites



- Provide insight into phenological transition across elevation gradient
- Implement this understanding into improved phenological model in CLM 5

CMS-II (Lin 2018) goals: Forest Health Early Warning System



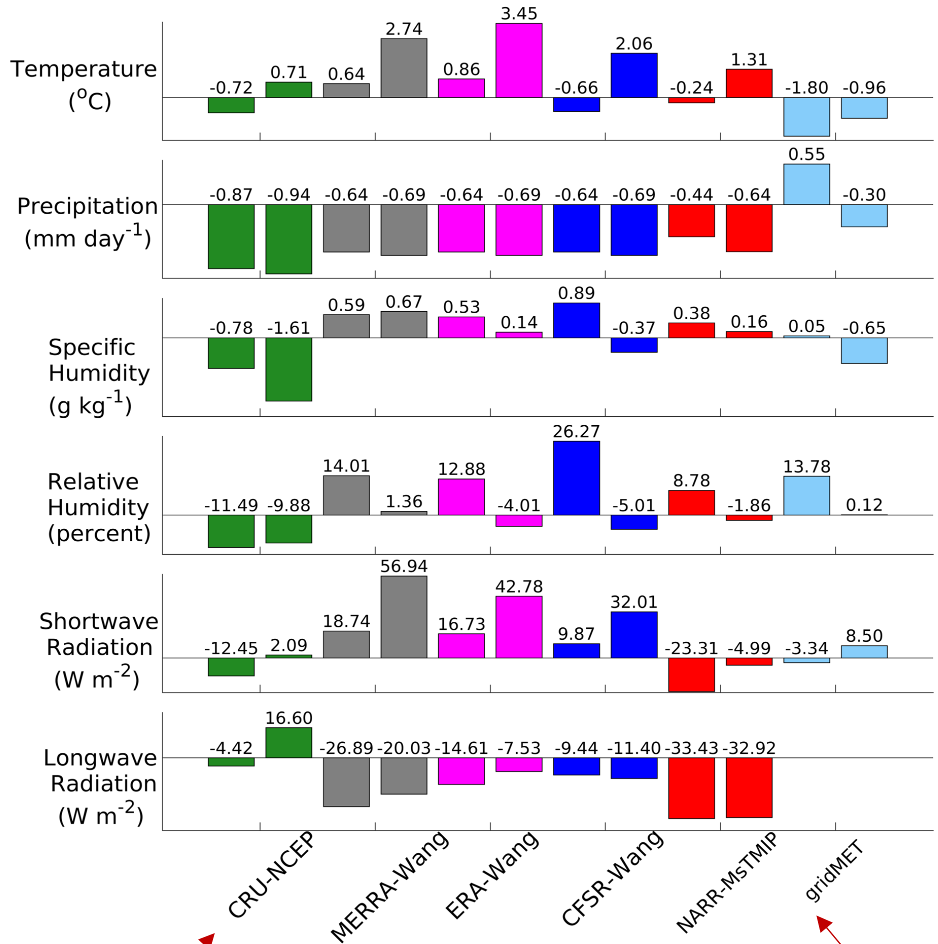
Questions?

Meteorological datasets tend to be too warm/dry across Western US

- Meteorological biases at Niwot Ridge, Colorado

- High temp
- High SW radiation
- Low precip

- Asking for trouble within a water limited region



Default CLM4.5

Products with bias improvement

PRISM-based (Abatzoglou)

Simulation of biomass is highly sensitive to meteorological biases and representation of water limitation