Initializing carbon cycle predictions from CLM by assimilating biomass and LAI observations

Andrew Fox[1,2], Tim Hoar[2], William Kolby-Smith[1], Jeffrey Anderson[2] & David Moore[1]

1. University of Arizona
2. National Center for Atmospheric Research

U.S. DEPARTMENT OF ENERGY | Office of Science | This work is funded by DOE **Regional and Global Climate Modeling DE-SC0016011**

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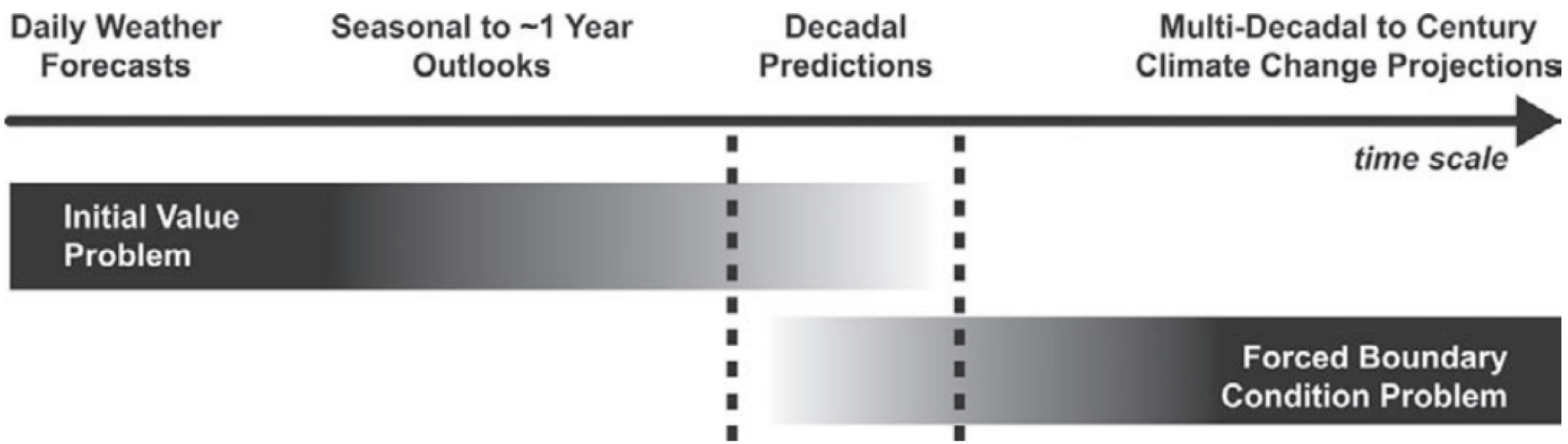
Forecasting the Carbon Cycle?

- Forecasting
  - Near-term, iterative, initialized prediction
- Potentially very useful because:
  - Can be verified
  - Provides information for decision support



(Meehl et al., 2009)

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Sources of uncertainty (& their cure)

- Model Structure — DEVELOPMENT
- Model Parameters — MCMC OPTIMIZATION
- Initial Conditions
- Spin Up
- Climate forcing

STATE DATA ASSIMILATION

Sources of uncertainty (& their cure)

- Model Structure — DEVELOPMENT
- Model Parameters — PARAMETERIZATION
- Initial Conditions
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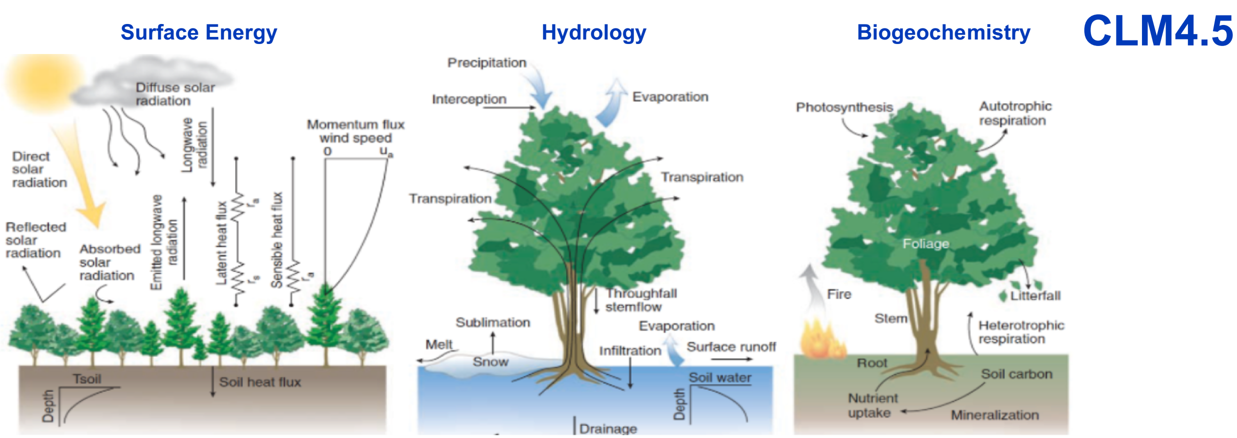
STATE DATA ASSIMILATION

Community Land Model set up

- Multi-instance CLM4.5 BGC set up for a location in central New Mexico, USA
- PFT fractions of Bare, C4 grass, shrub and Needleleaf Evergreen – Temperate
- Spun up by cycling 12 years of ensemble atmospheric reanalysis data



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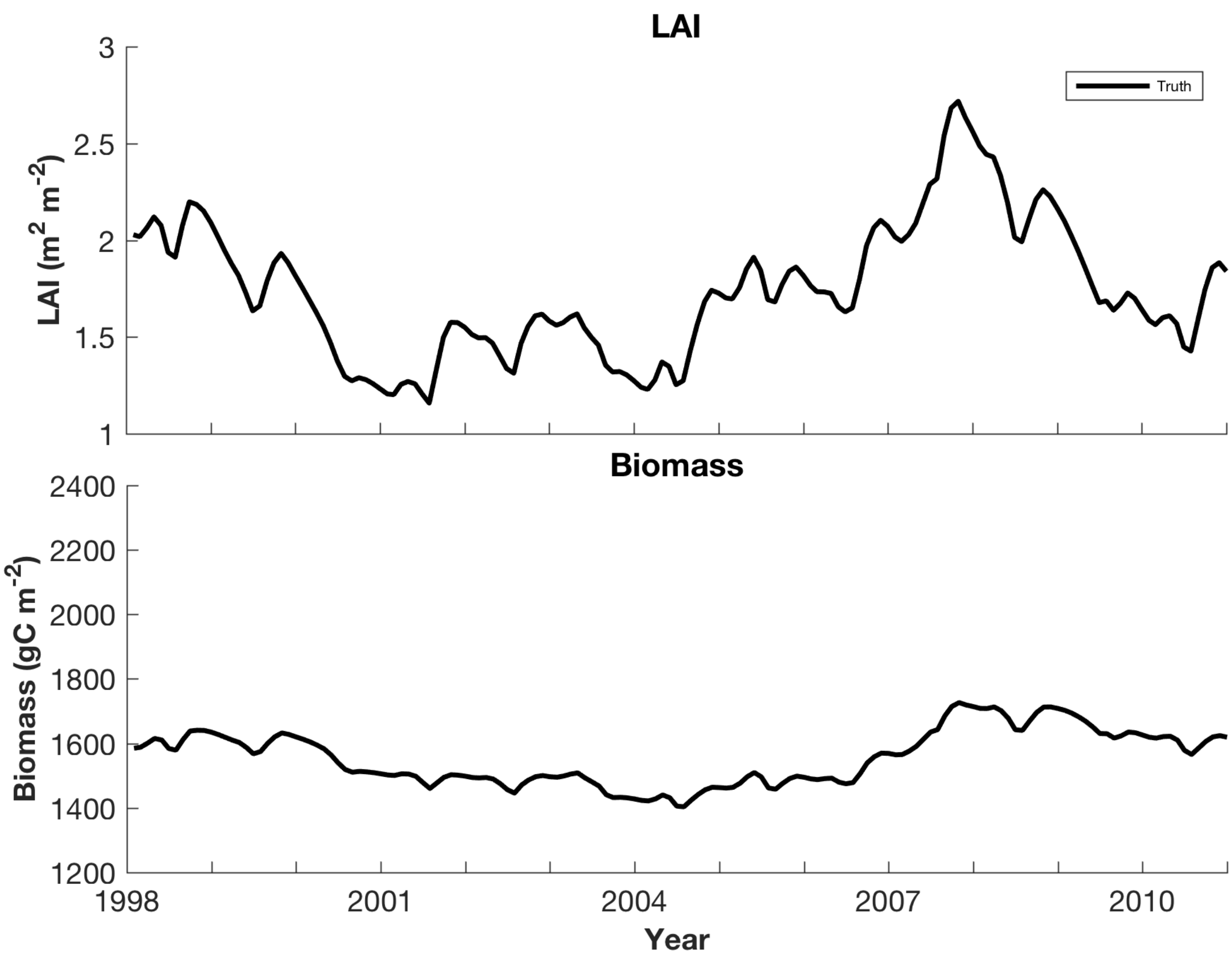
LAI and Biomass – single instance



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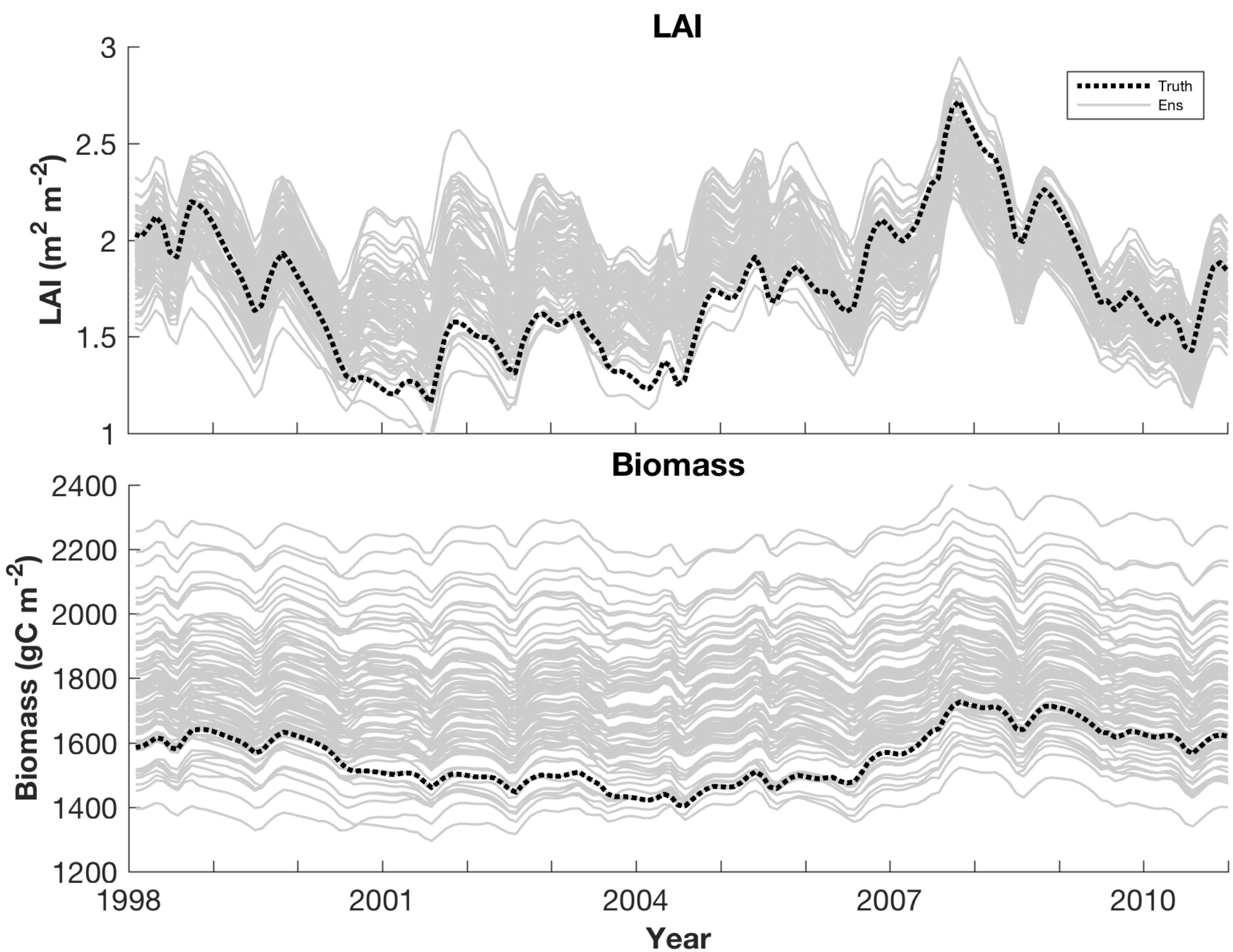
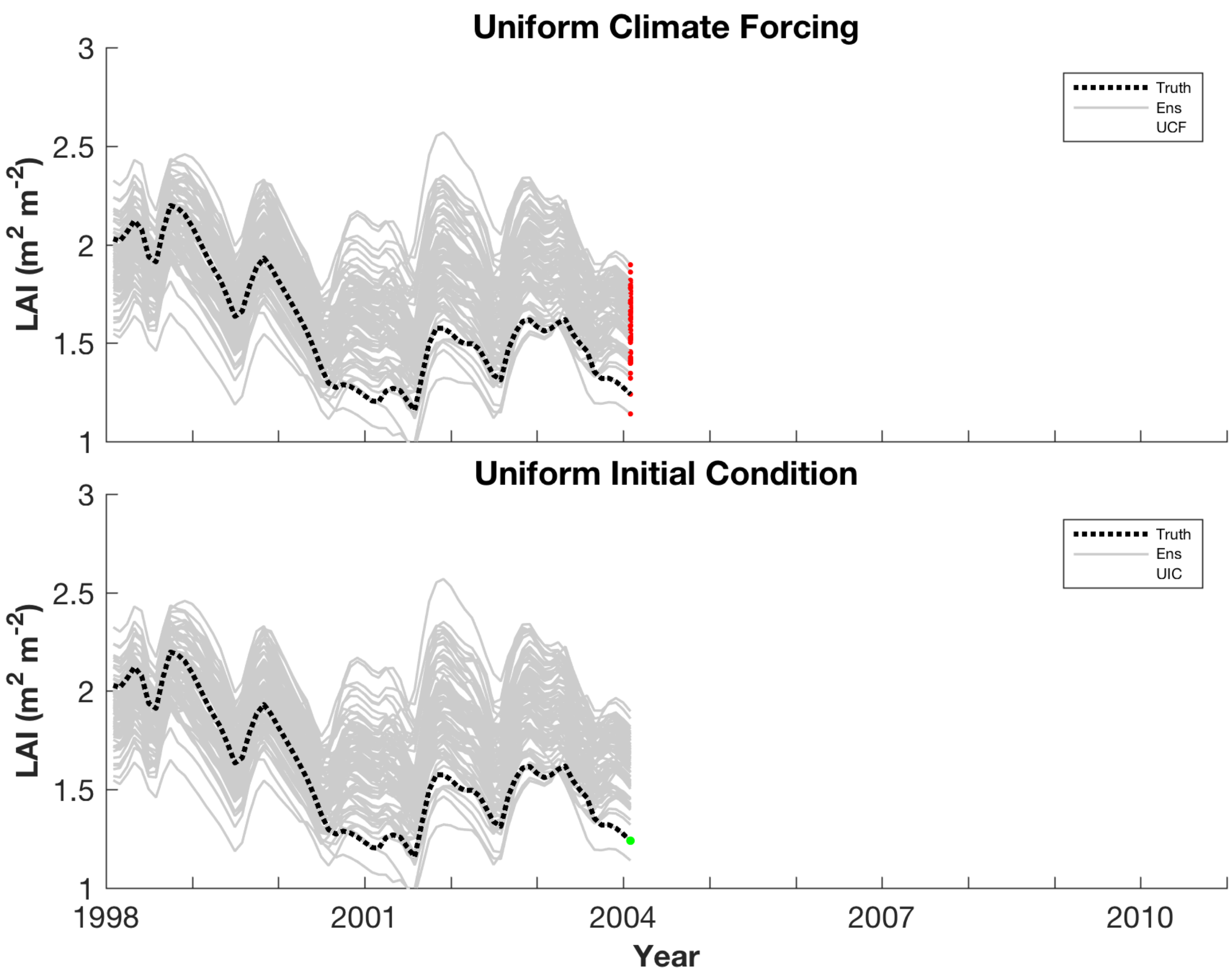
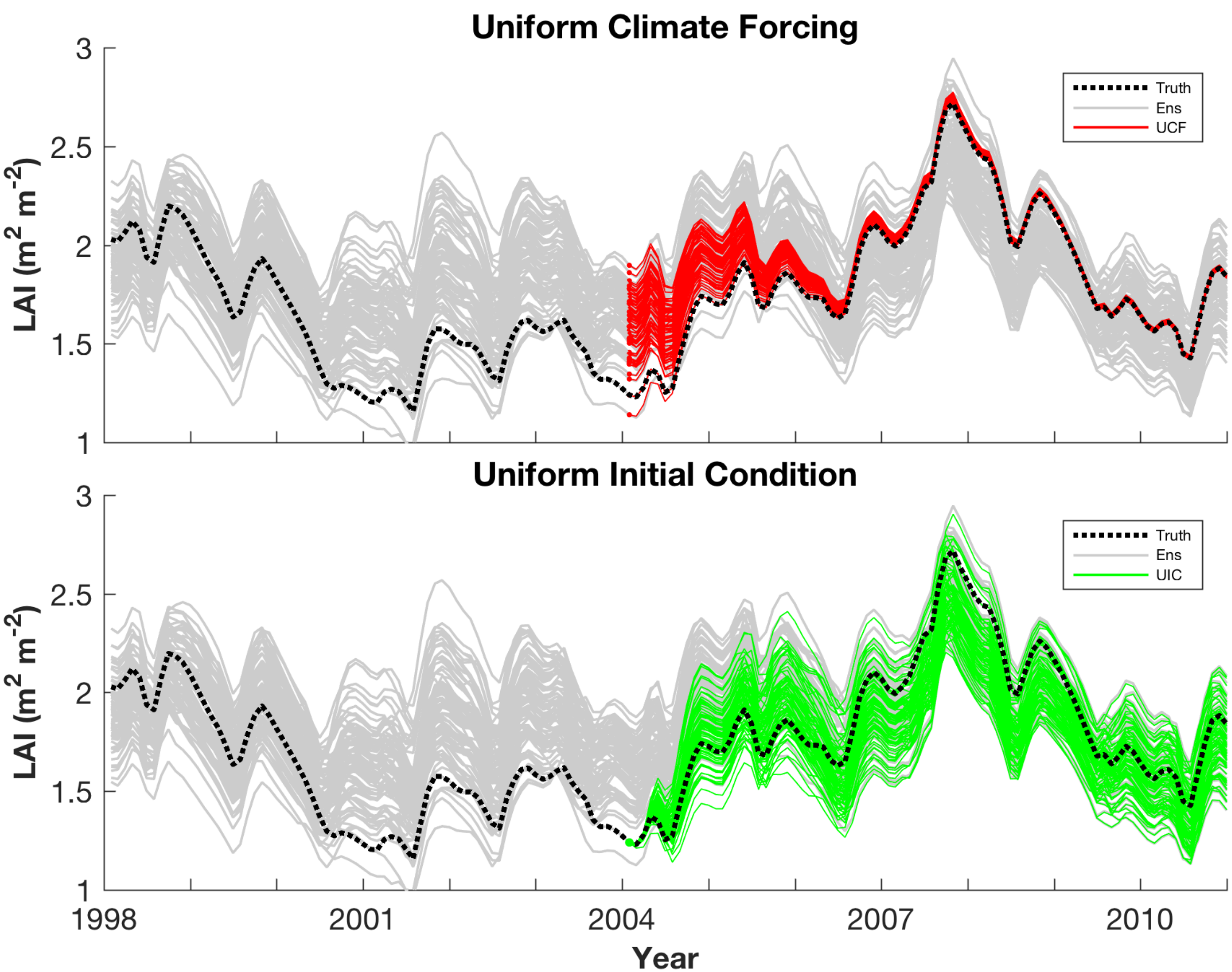
LAI and Biomass – multi-instance



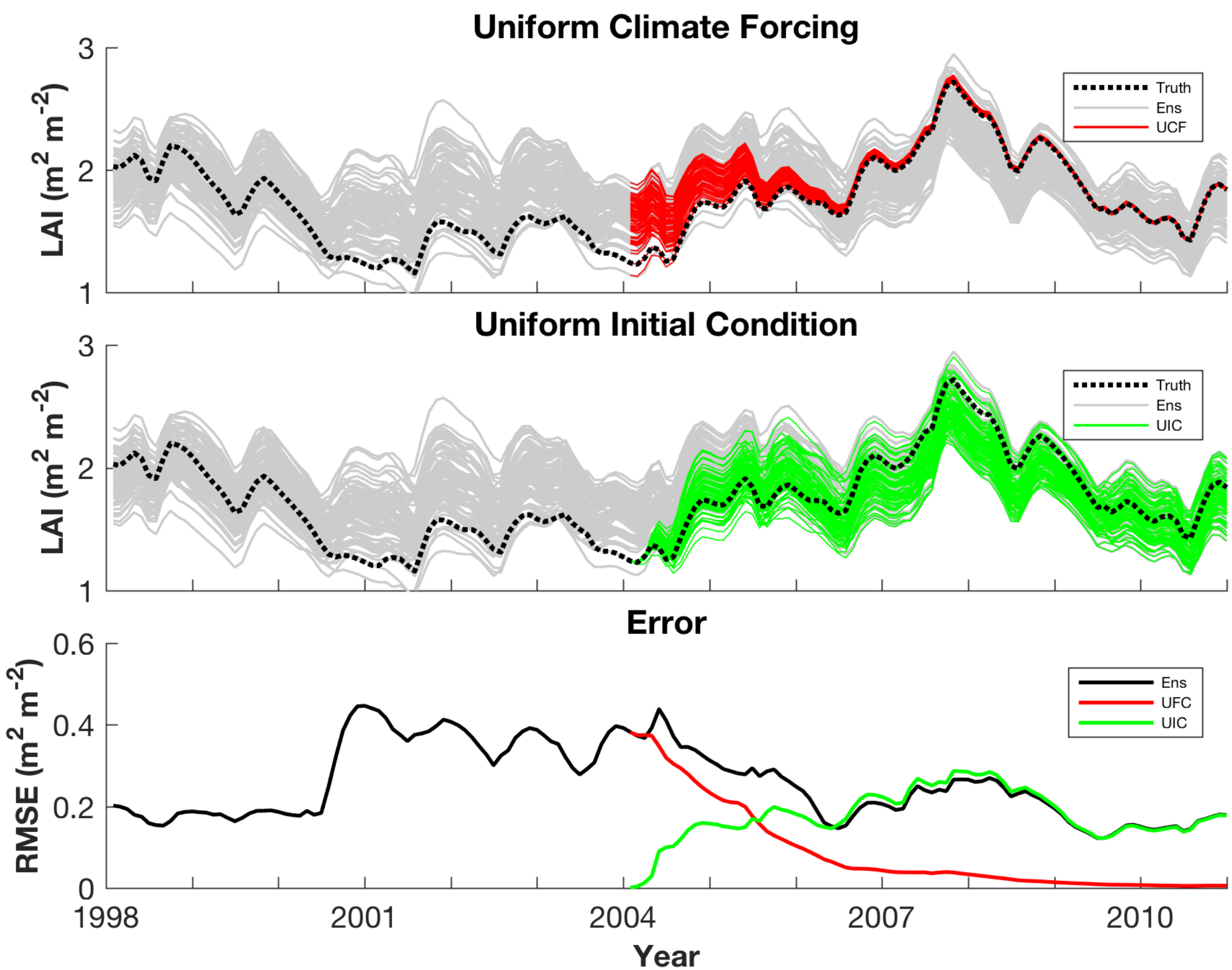
Uniform Climate Forcing v. Initial Conditions



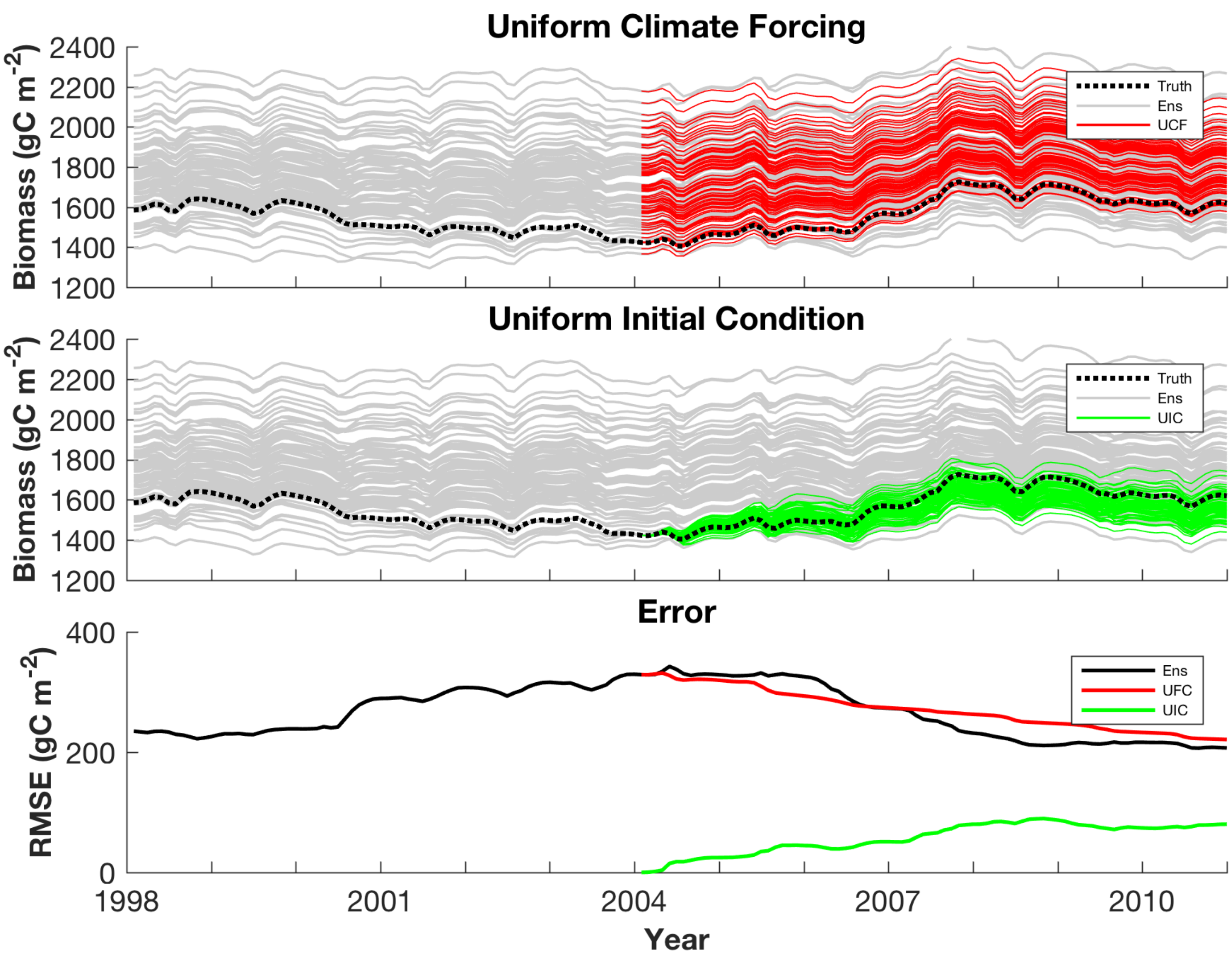
Uniform Climate Forcing v. Initial Conditions



LAI – Error is reduced for 2.5 years



Biomass – Error is reduced for 5+ years



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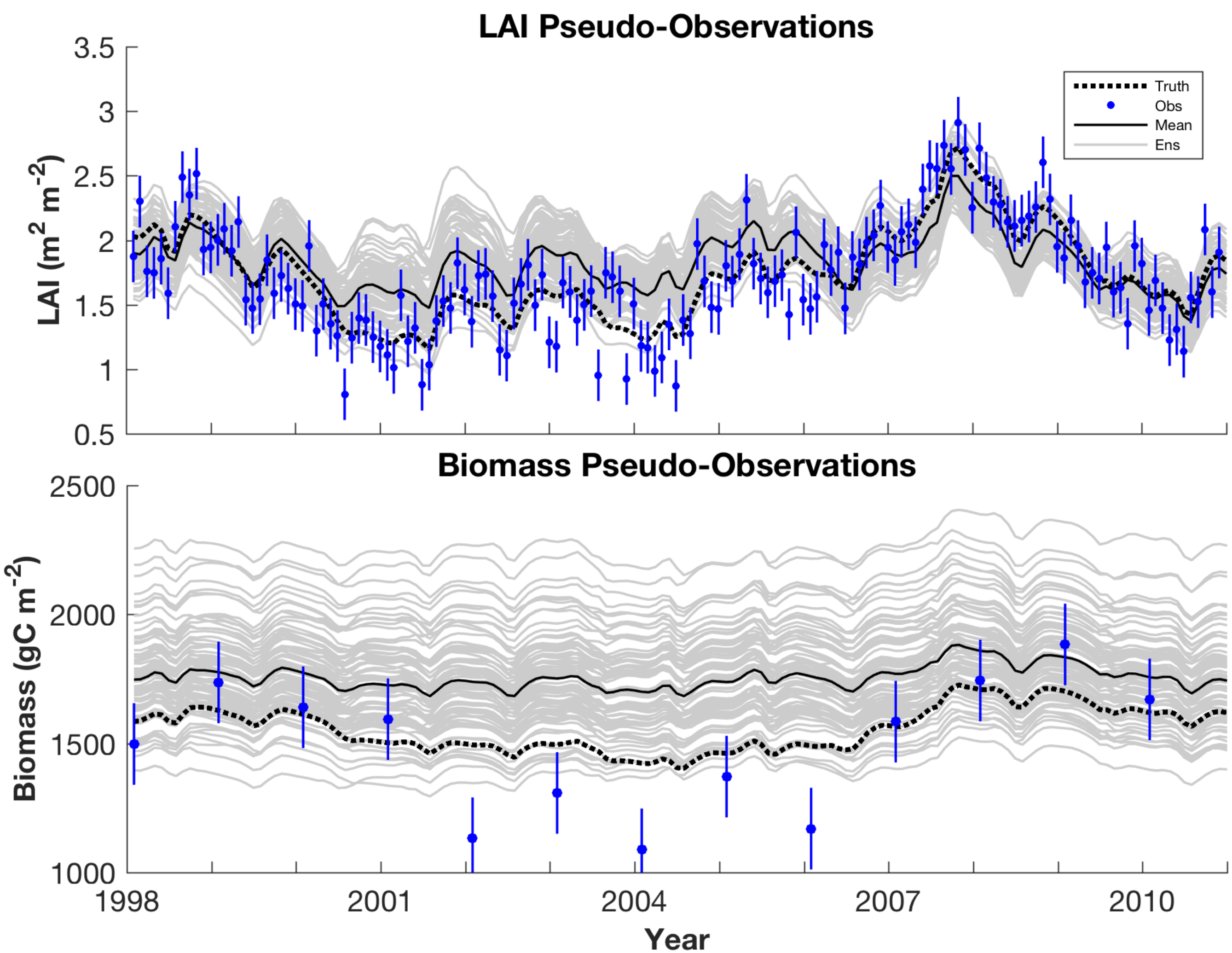
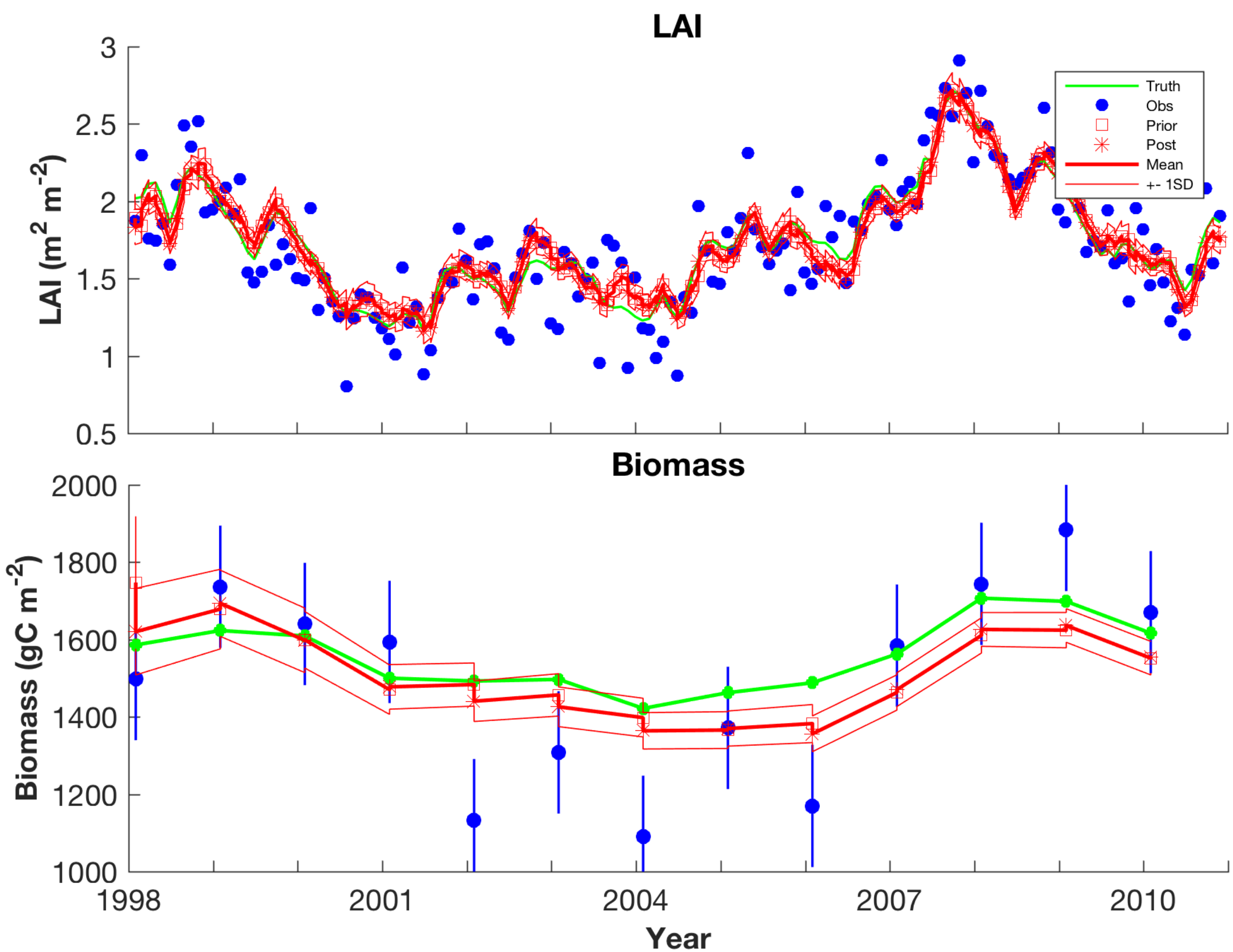
LAI and Biomass – observations of the "truth"



Ensemble is updated at observation time



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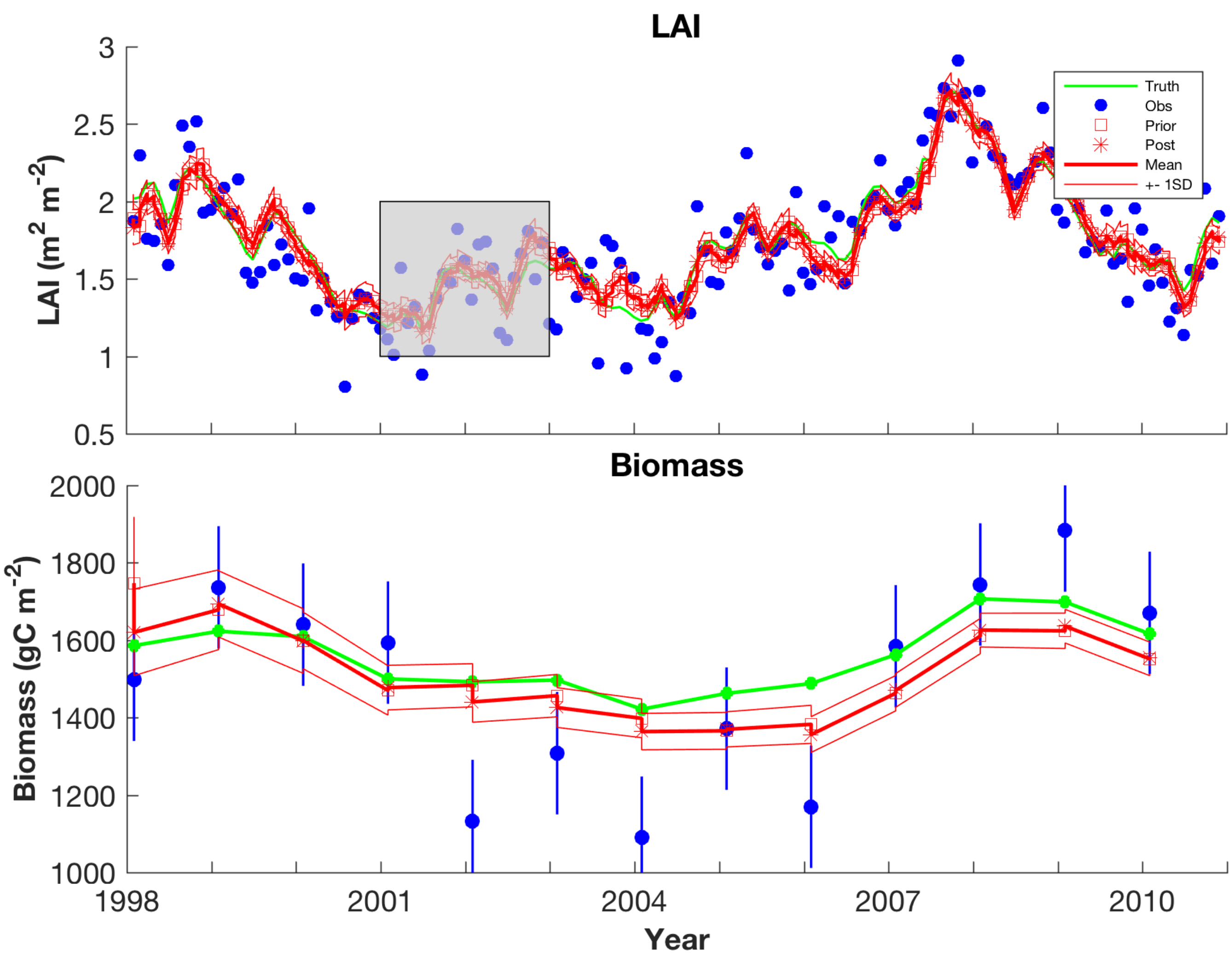

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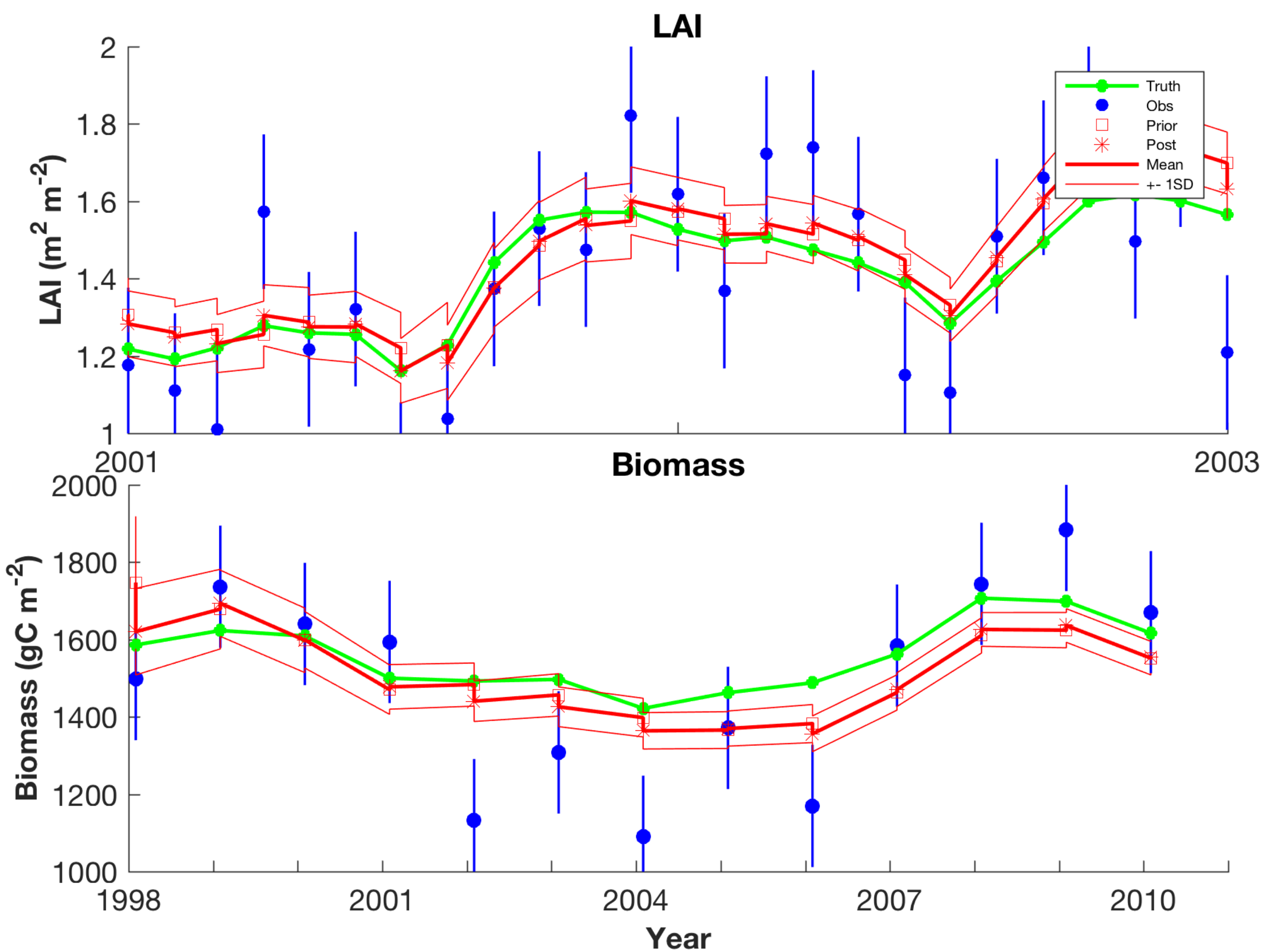

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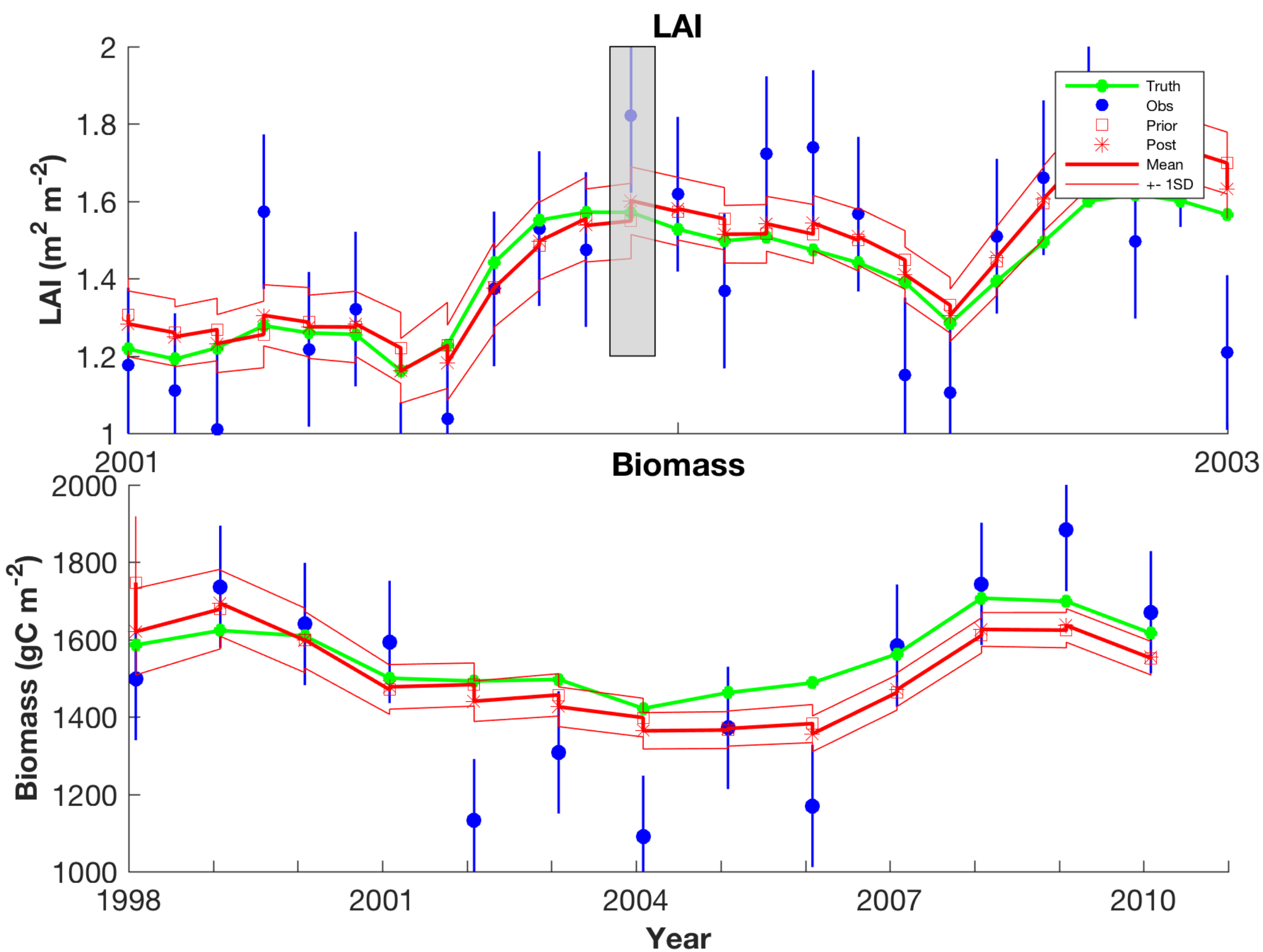
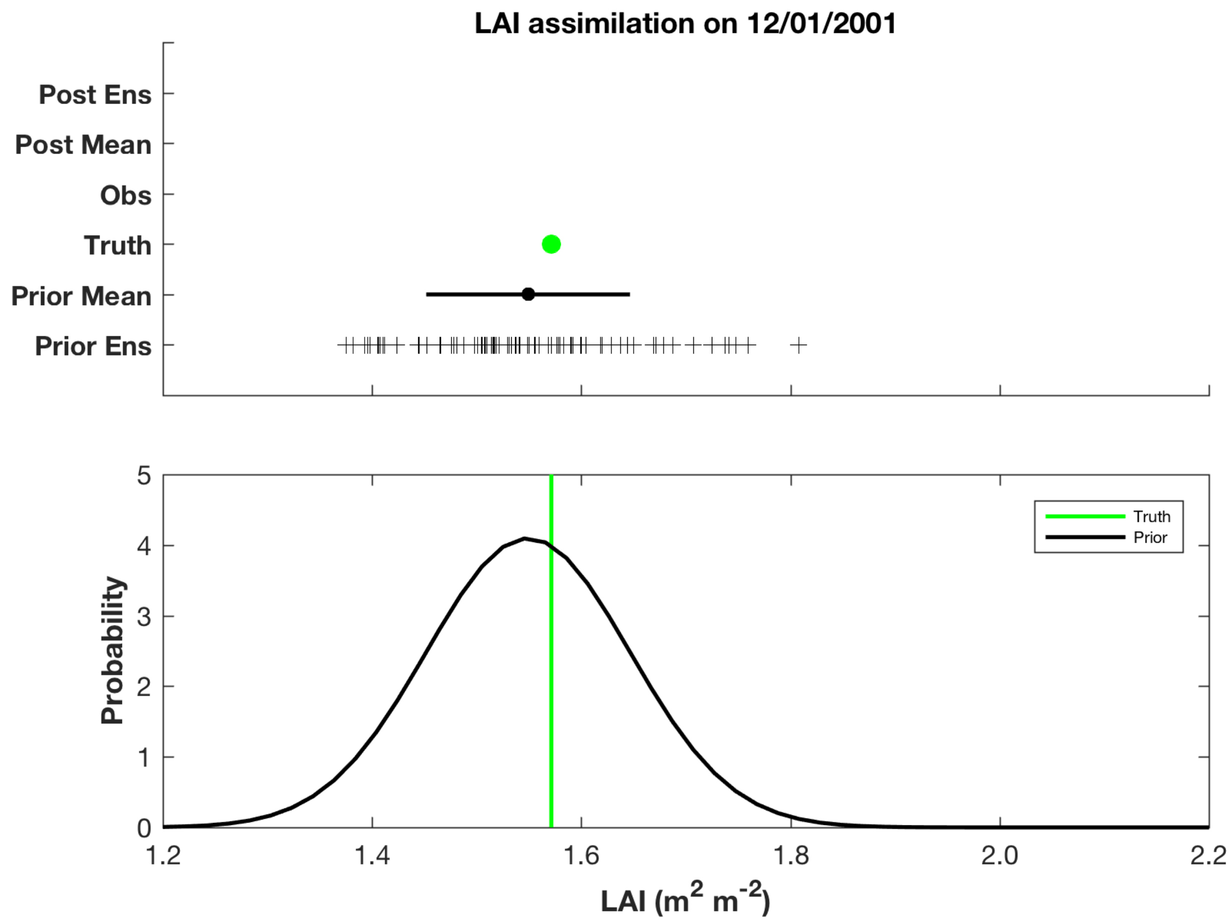


LAI updated by Ens. Adjustment Kalman Filter



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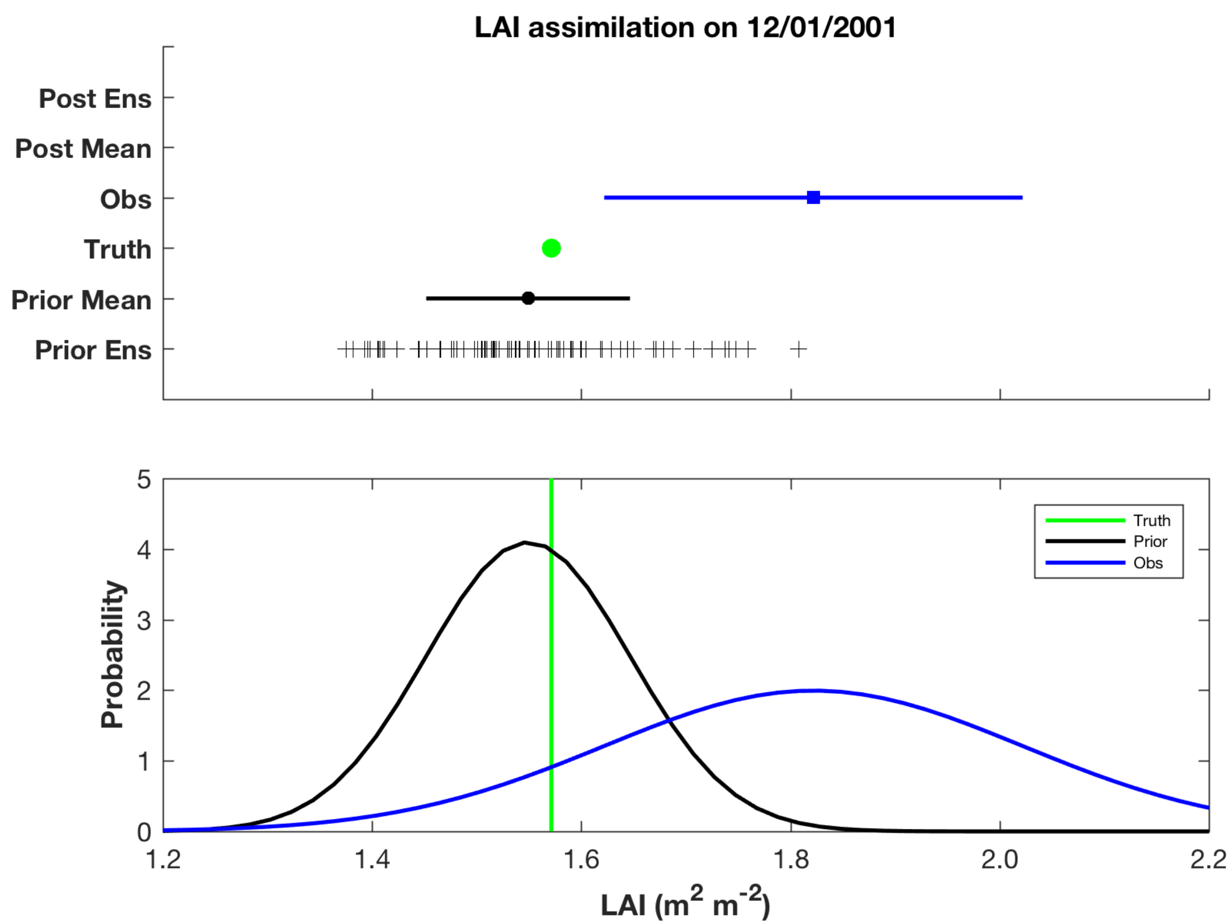

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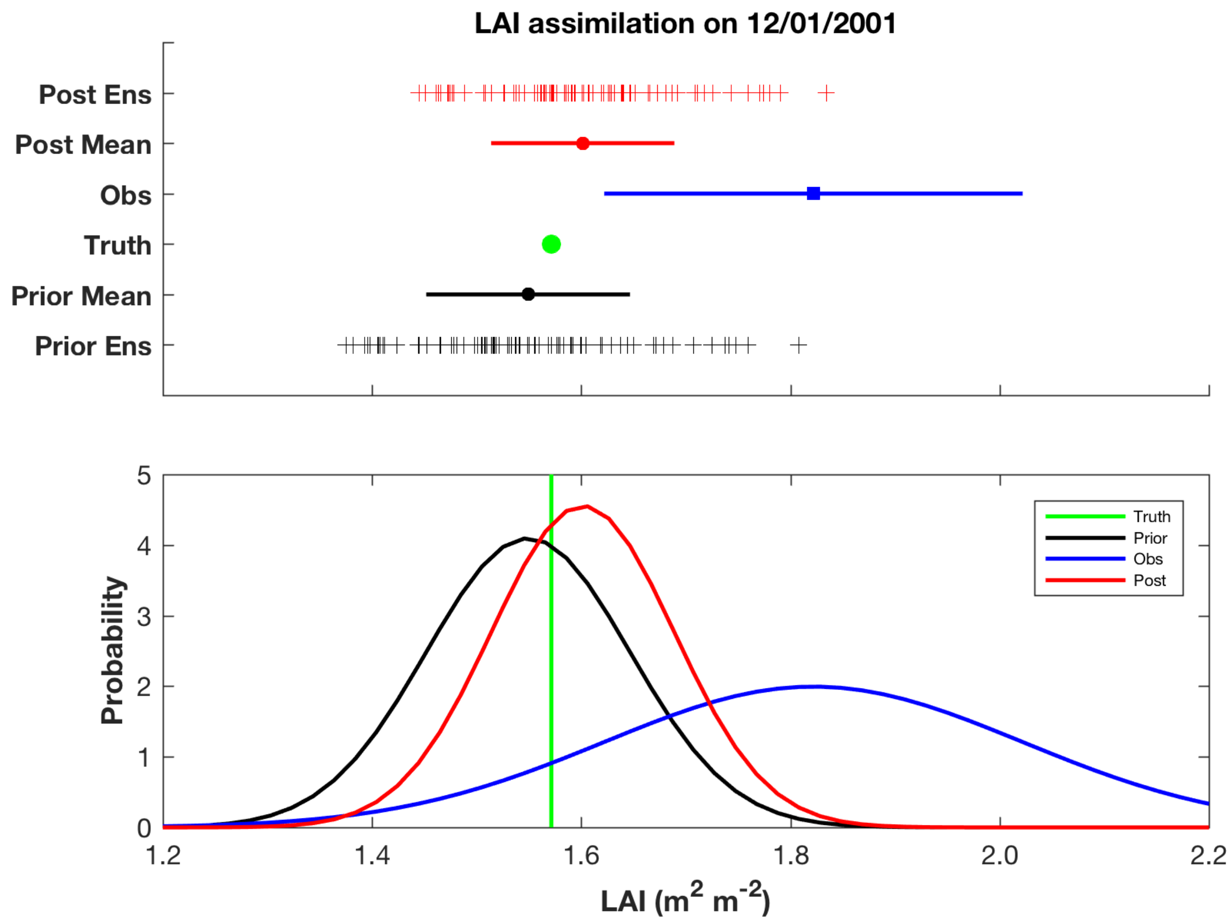

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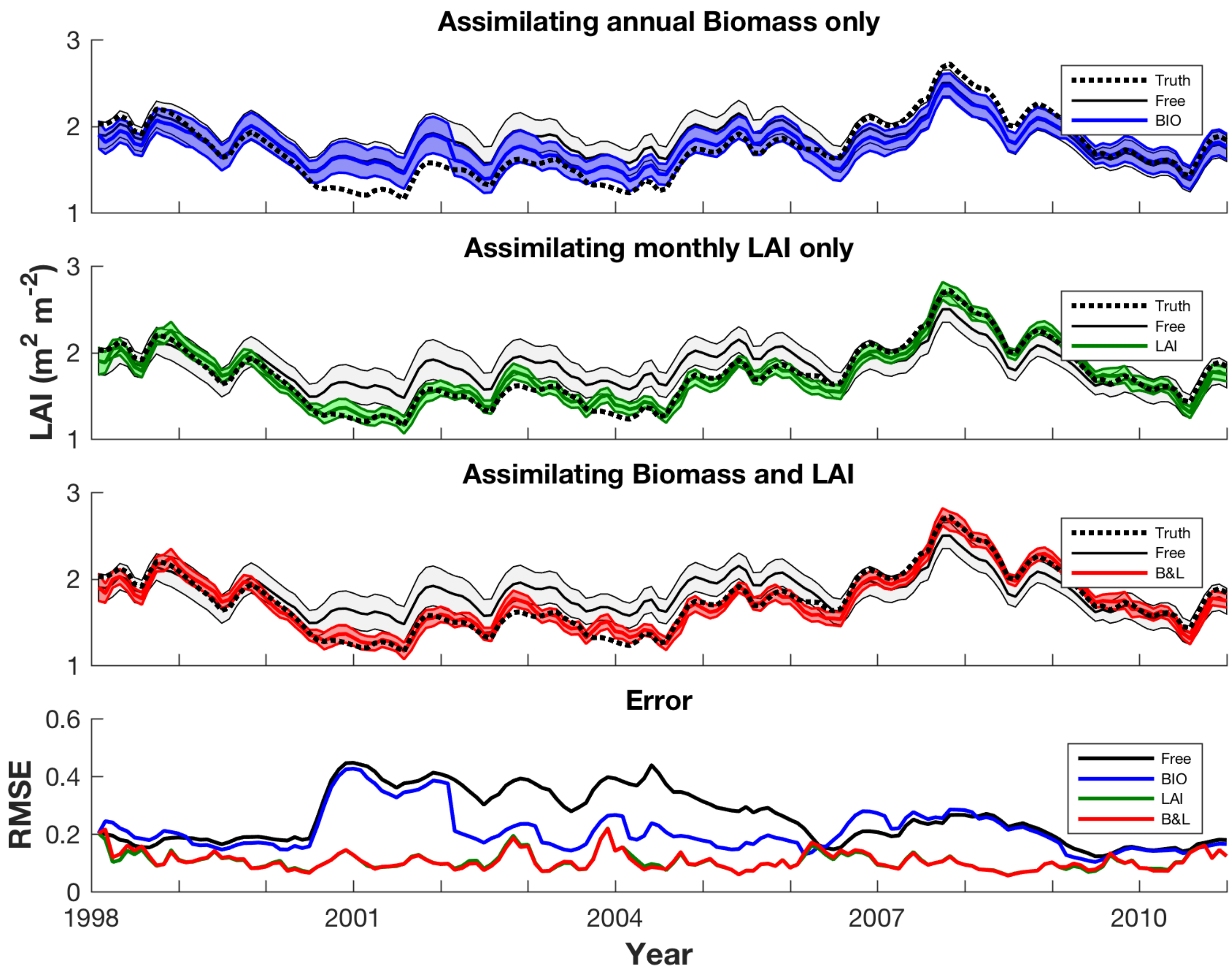
Impact of assimilating LAI, Biomass and both



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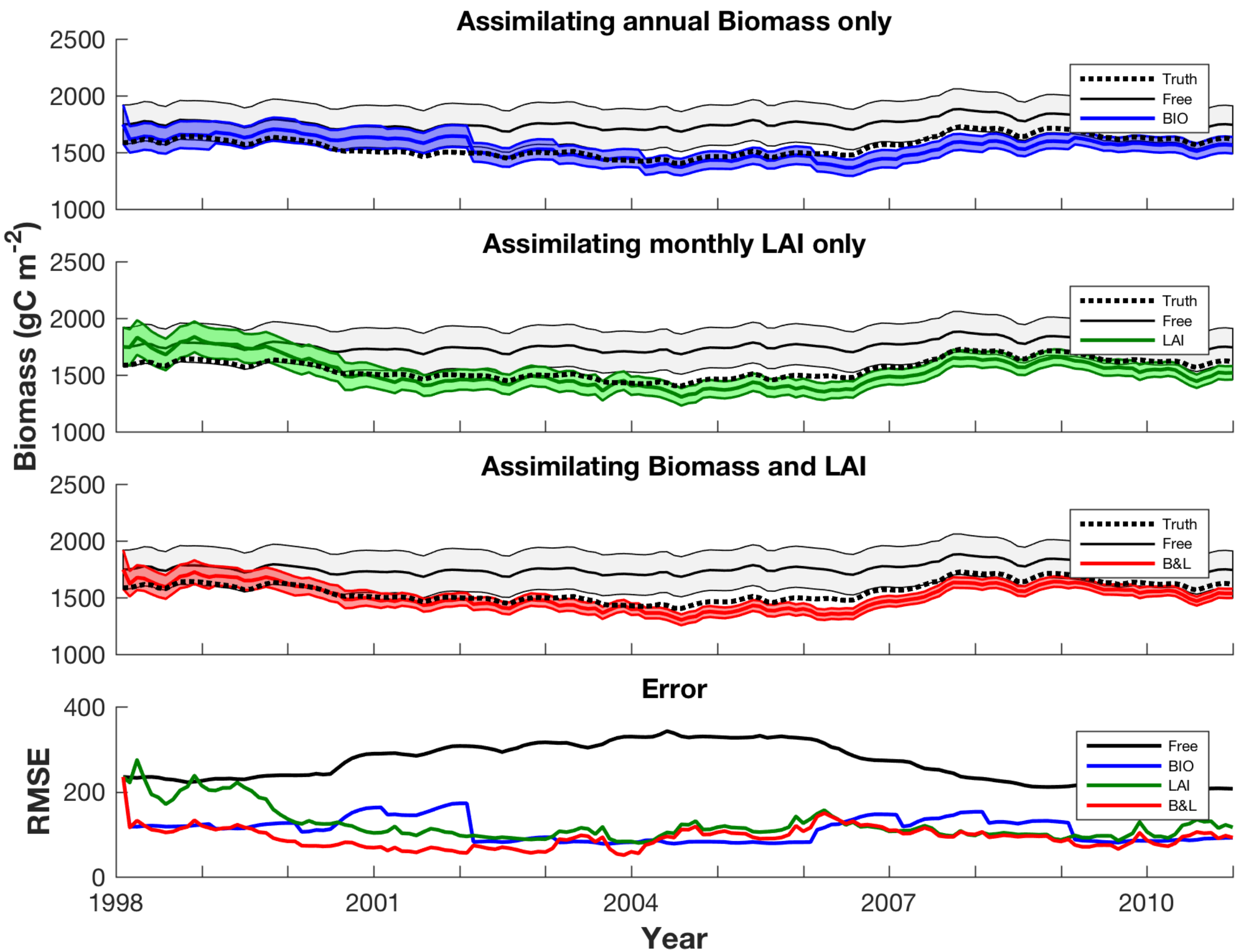
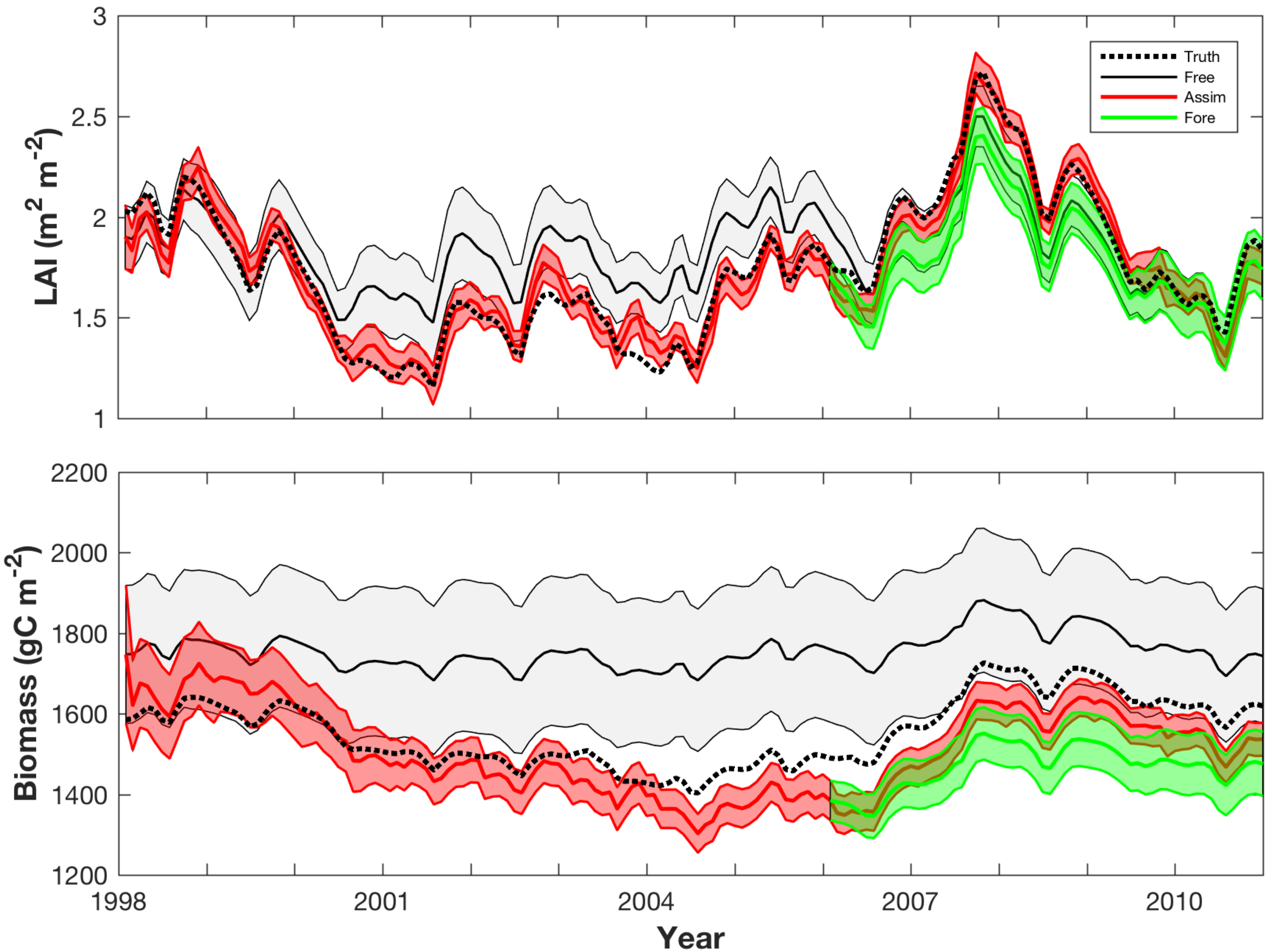


Impact on Forecast



LAI and Biomass – "real" observations

0.5° Aggregated MODIS LAI Observations

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, G01023, doi:10.1029/2006JG000168, 2007

Representing a new MODIS consistent land surface in the Community Land Model (CLM 3.0)

Peter J. Lawrence[1] and Thomas N. Chase[1]

Received 27 January 2006; revised 3 October 2006; accepted 14 November 2006; published 17 March 2007.

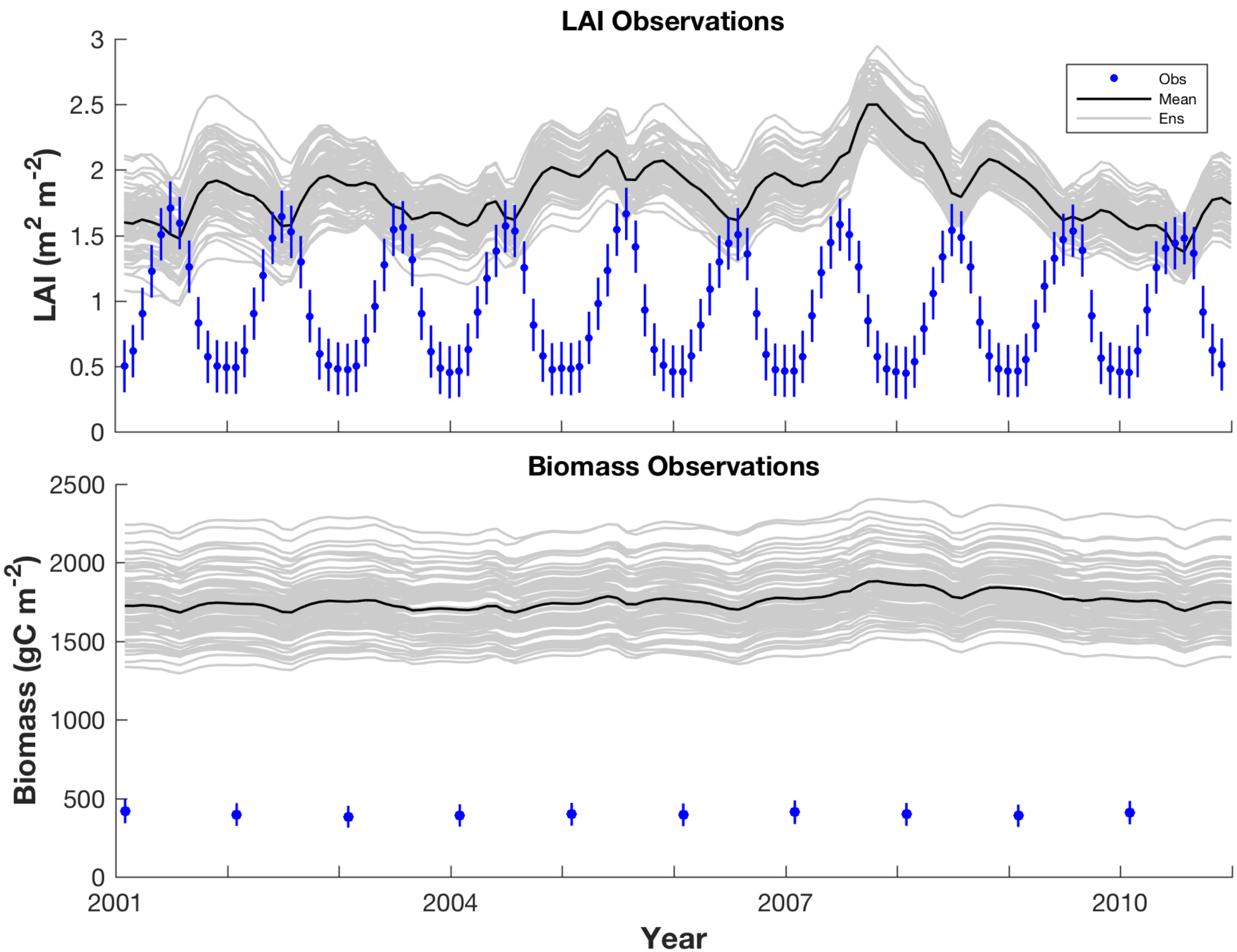
0.25° Vegetation Optical Depth Biomass Observations

nature climate change
LETTERS
PUBLISHED ONLINE: 30 MARCH 2015 | DOI: 10.1038/NCLIMATE2581

Recent reversal in loss of global terrestrial biomass

Yi Y. Liu[1,2*], Albert I. J. M. van Dijk[3,4], Richard A. M. de Jeu[5], Josep G. Canadell[6], Matthew F. McCabe[7], Jason P. Evans[1] and Guojie Wang[8]

LAI and Biomass – "real" observations



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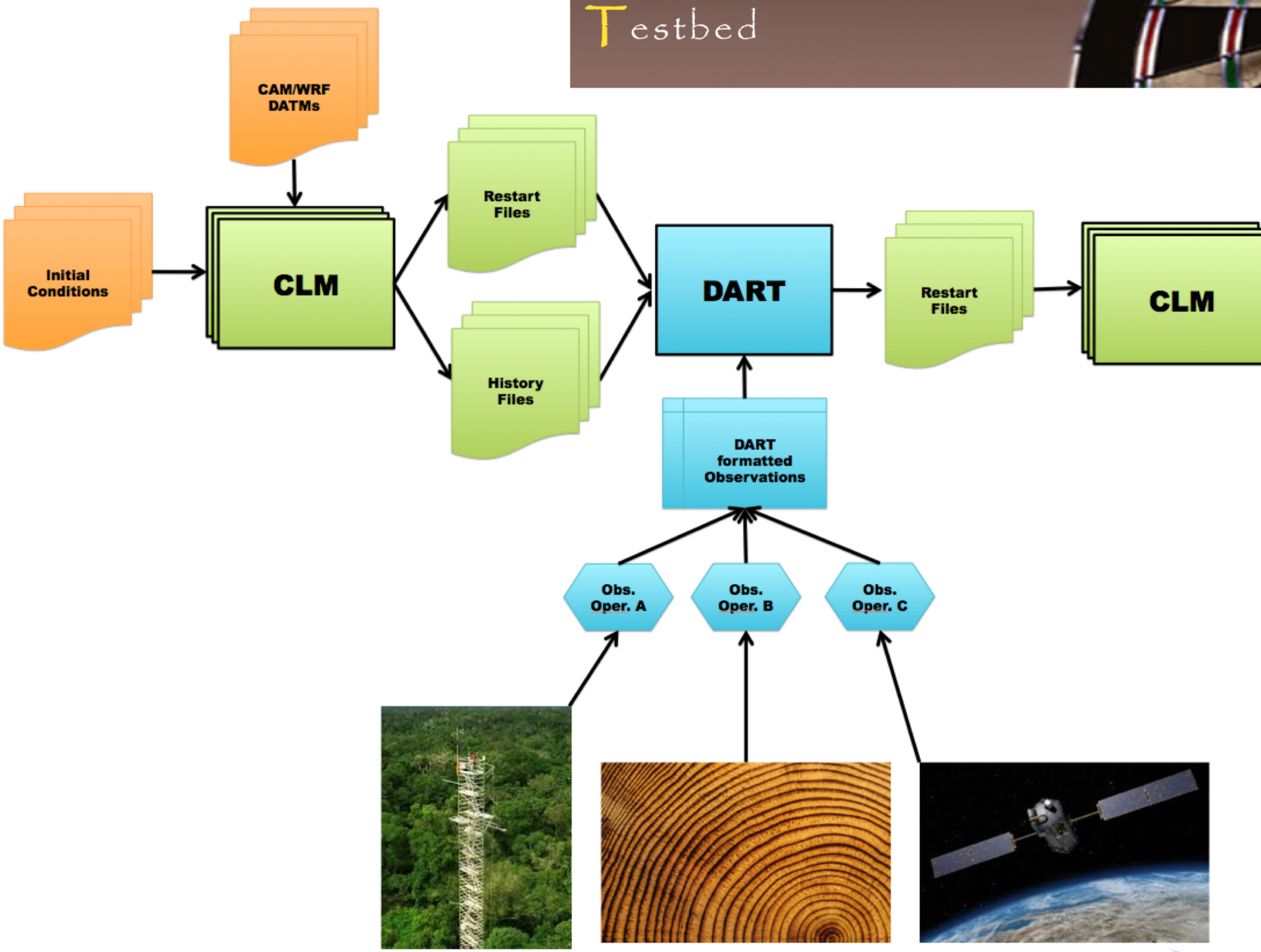
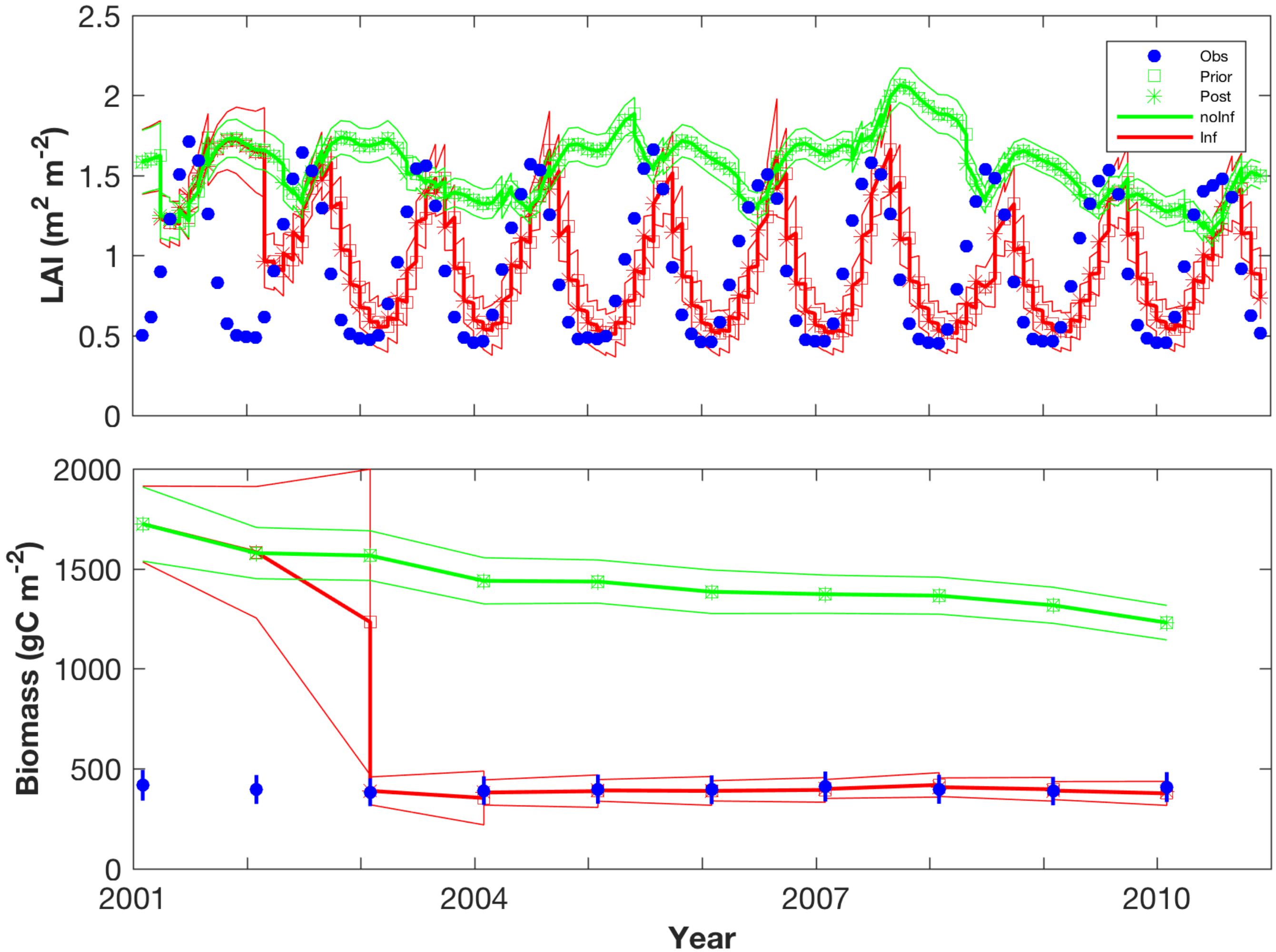
CLM-DART


Data
Assimilation
Research
Testbed


CAM/WRF DATMs
Initial Conditions
CLM
Restart Files
History Files
DART
Restart Files
CLM
DART formatted Observations
Obs. Oper. A
Obs. Oper. B
Obs. Oper. C

Ensemble is updated at observation time



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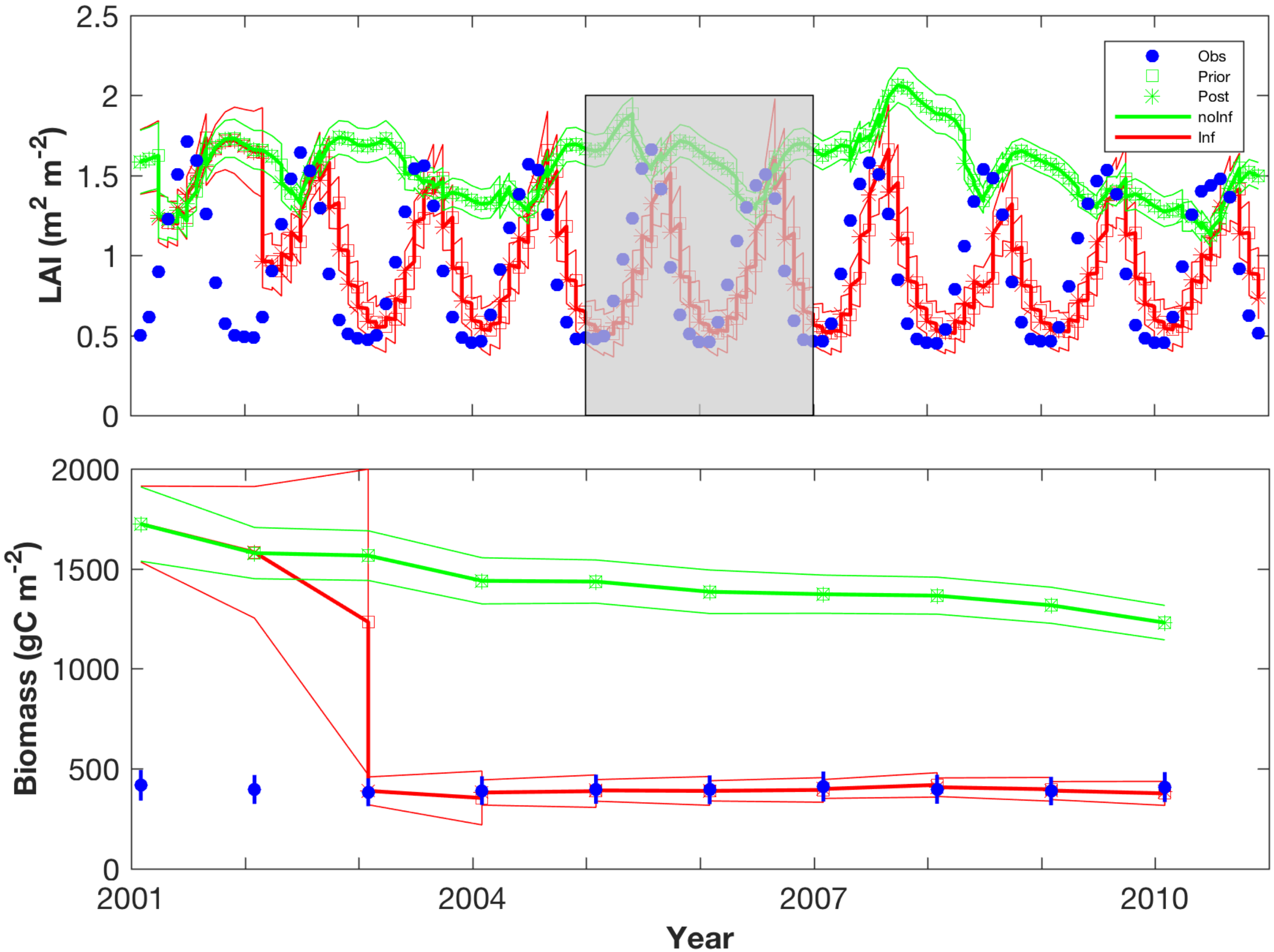

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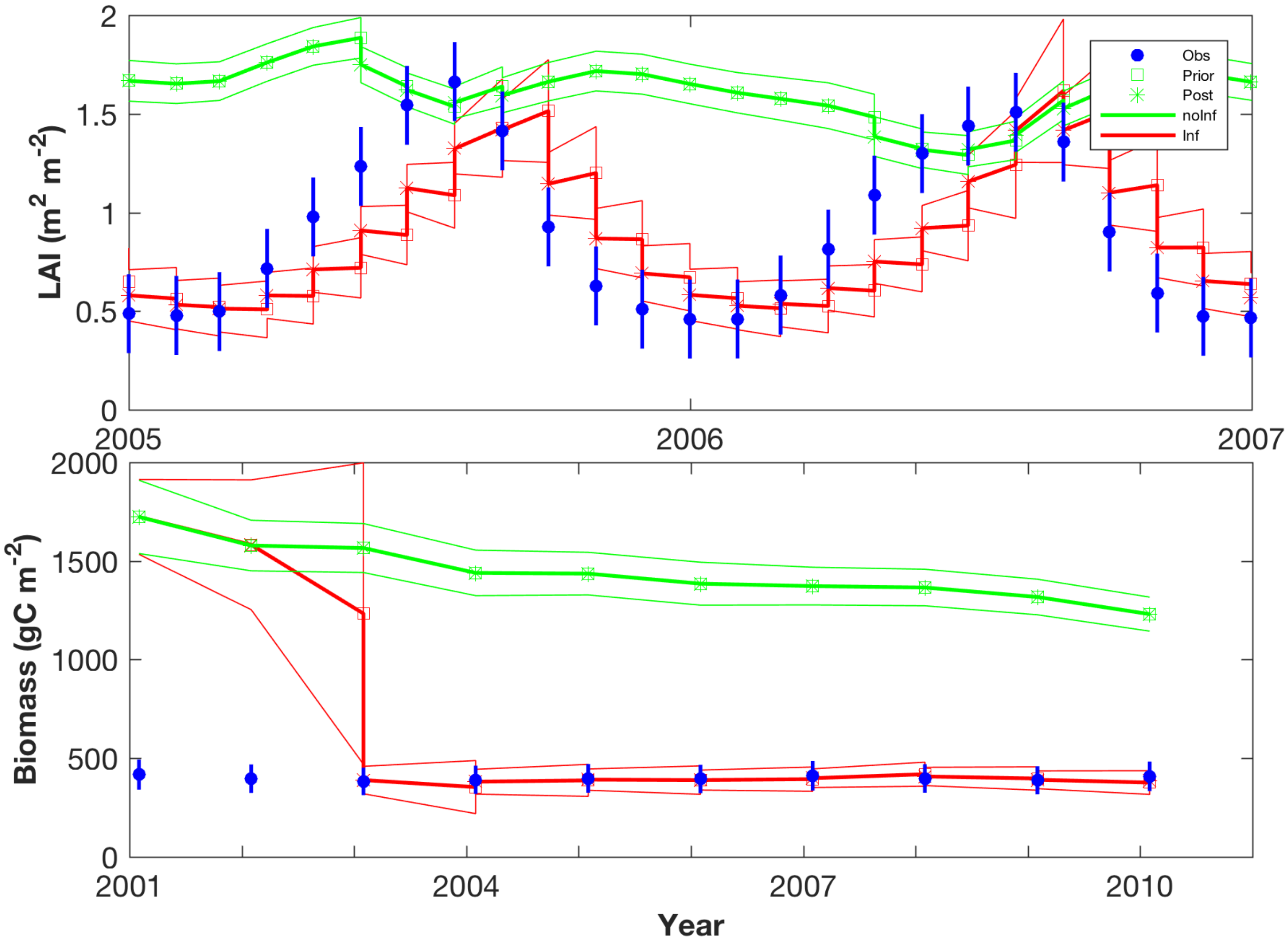
Adaptive inflation compensates for model error



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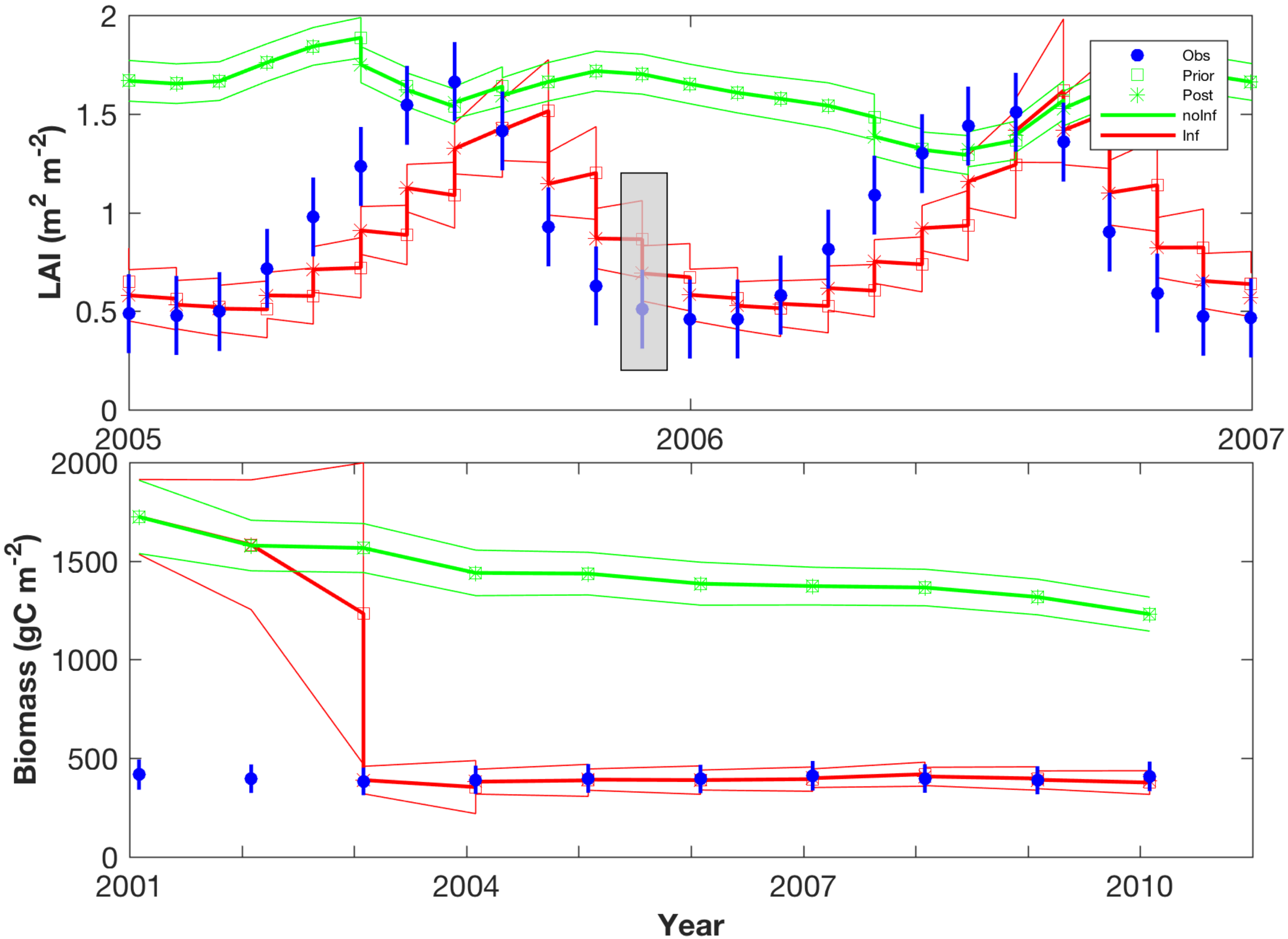
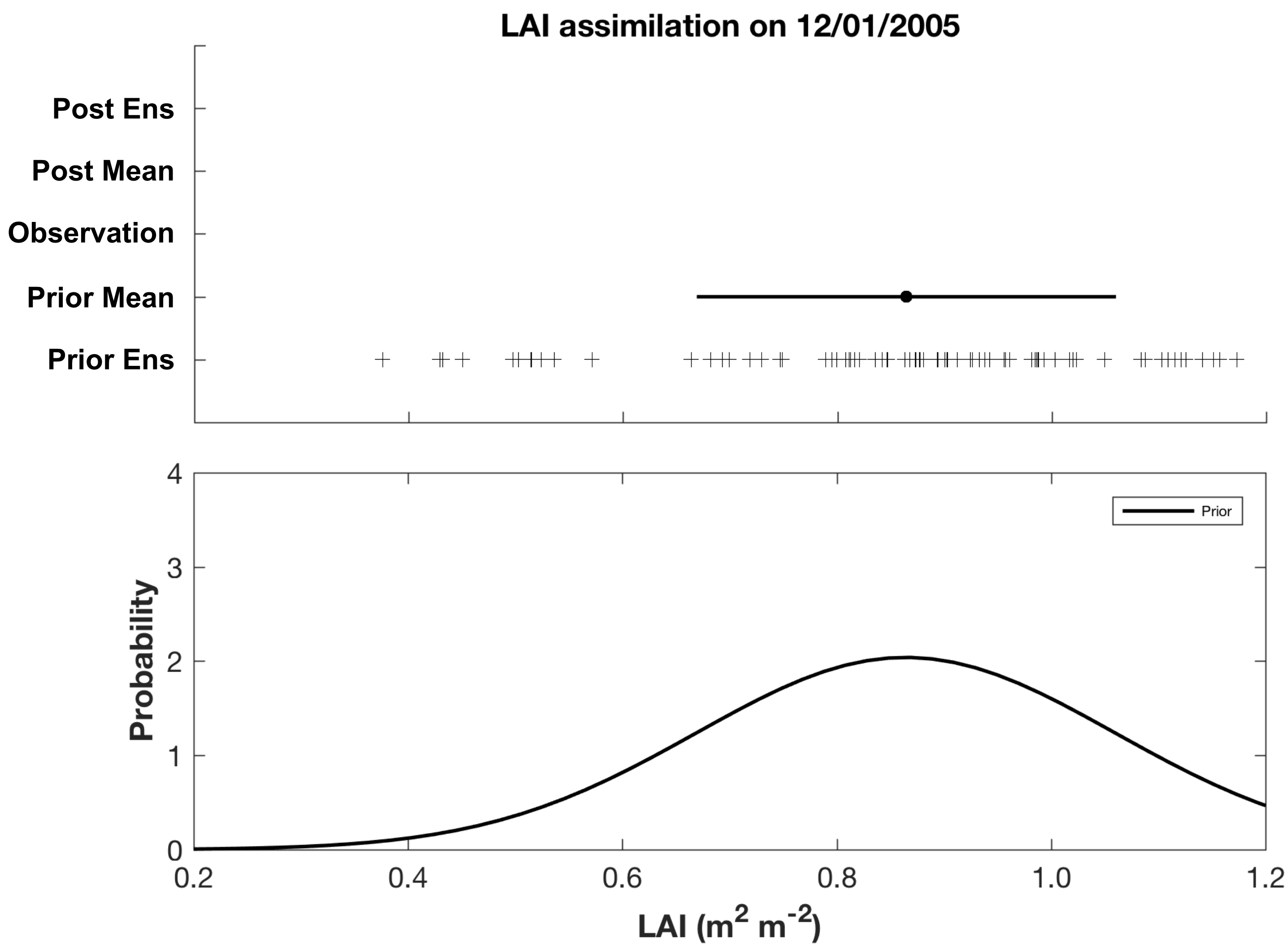
Ensemble is updated at observation time



LAI updated by Ens. Adjustment Kalman Filter



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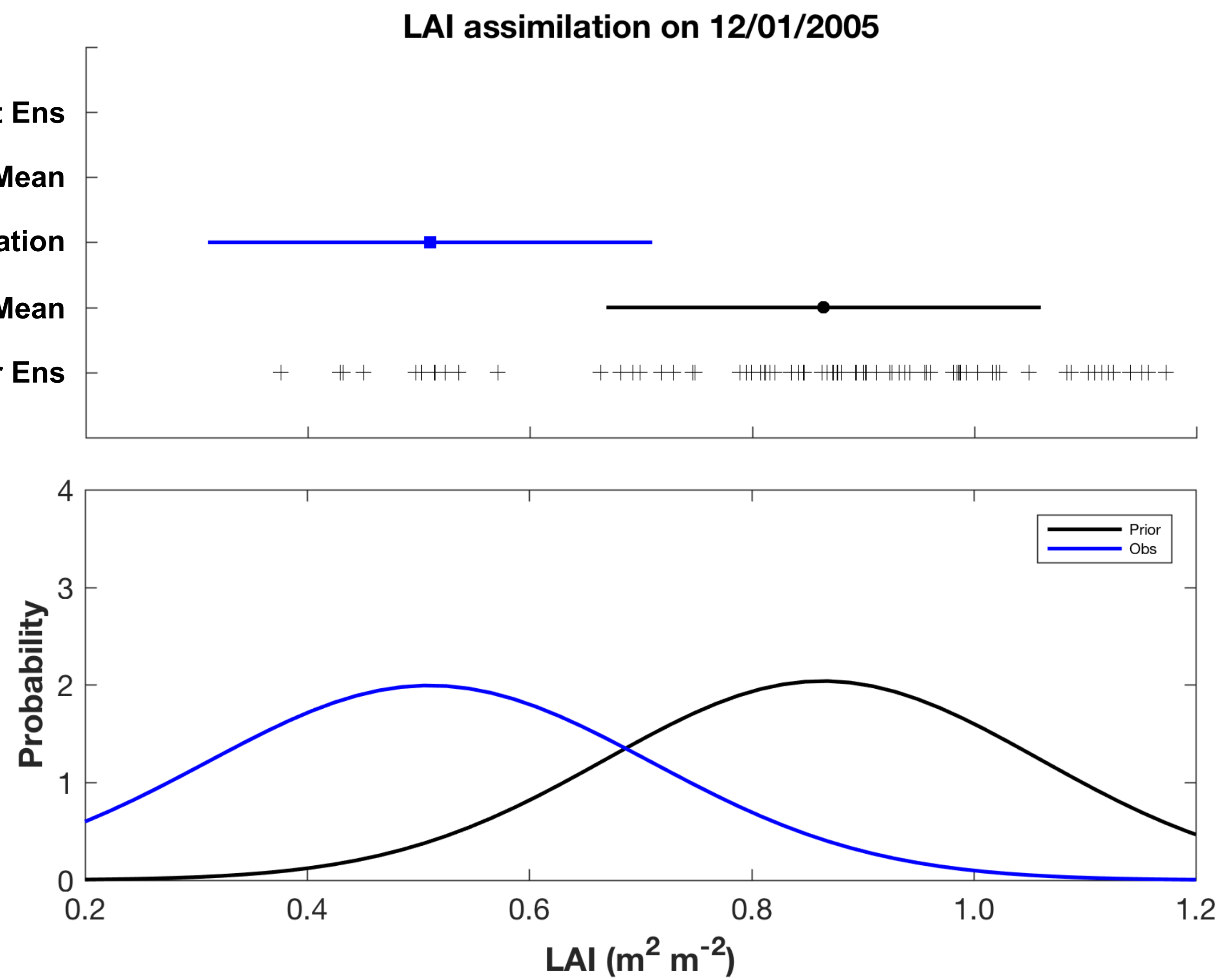

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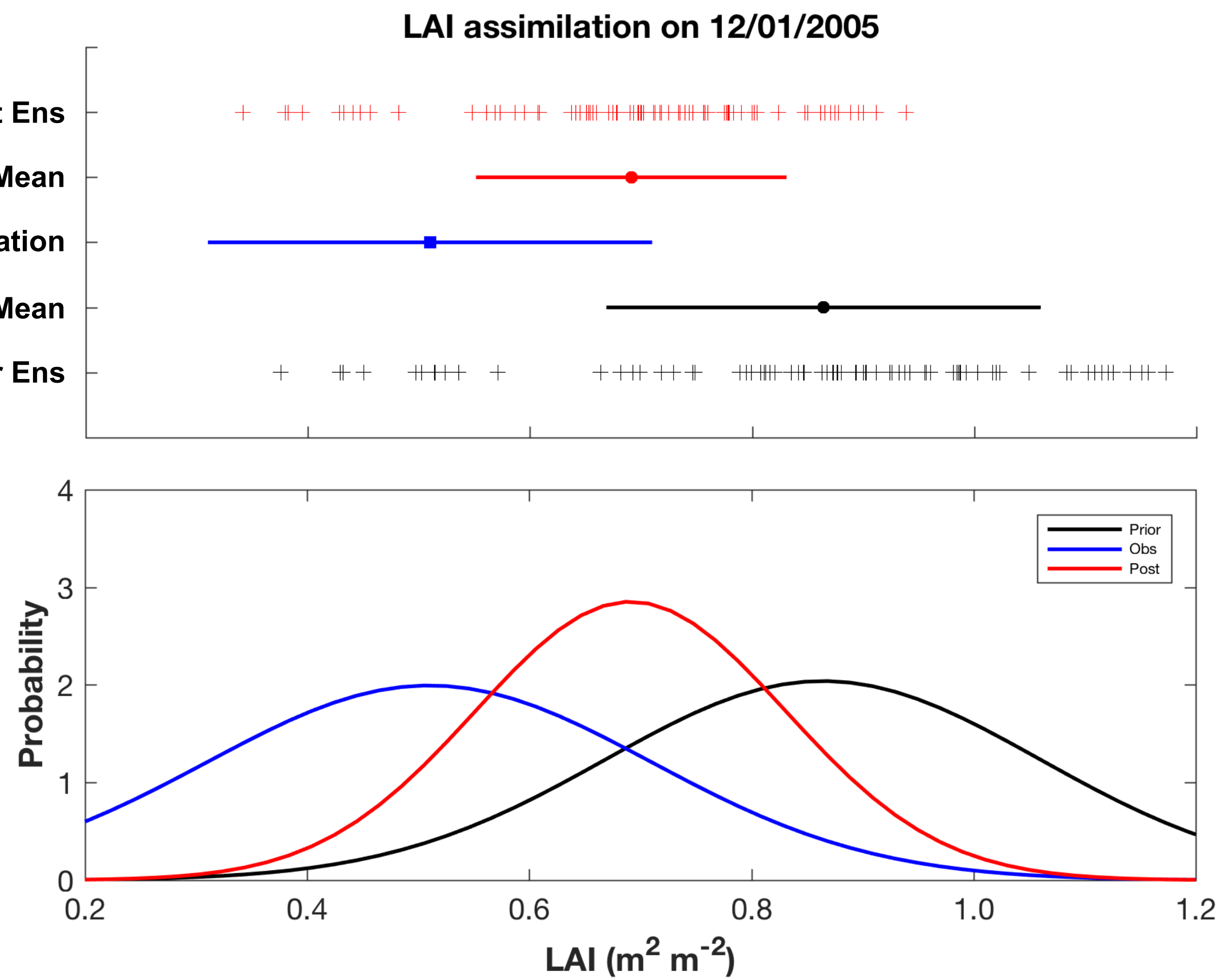
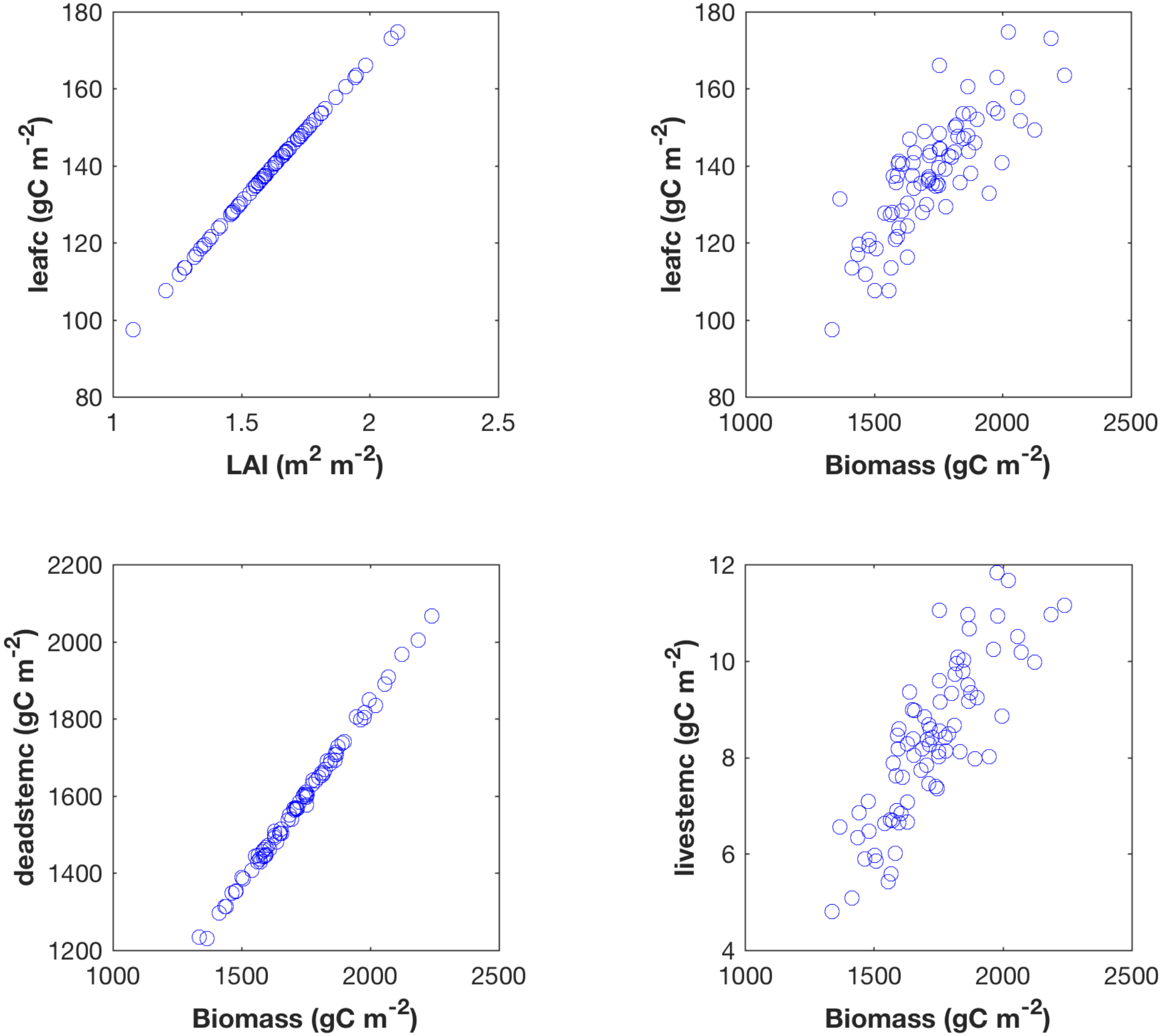


Model state correlations with observations



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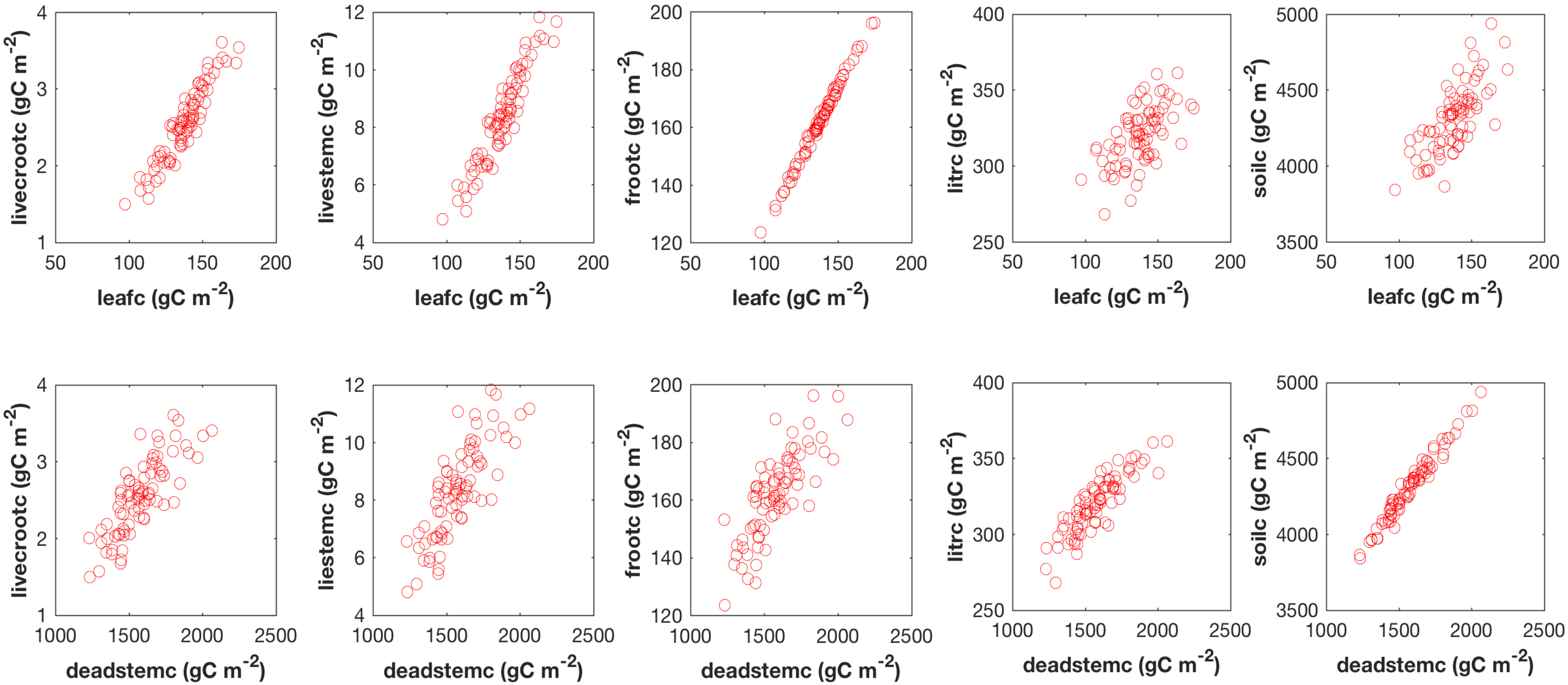
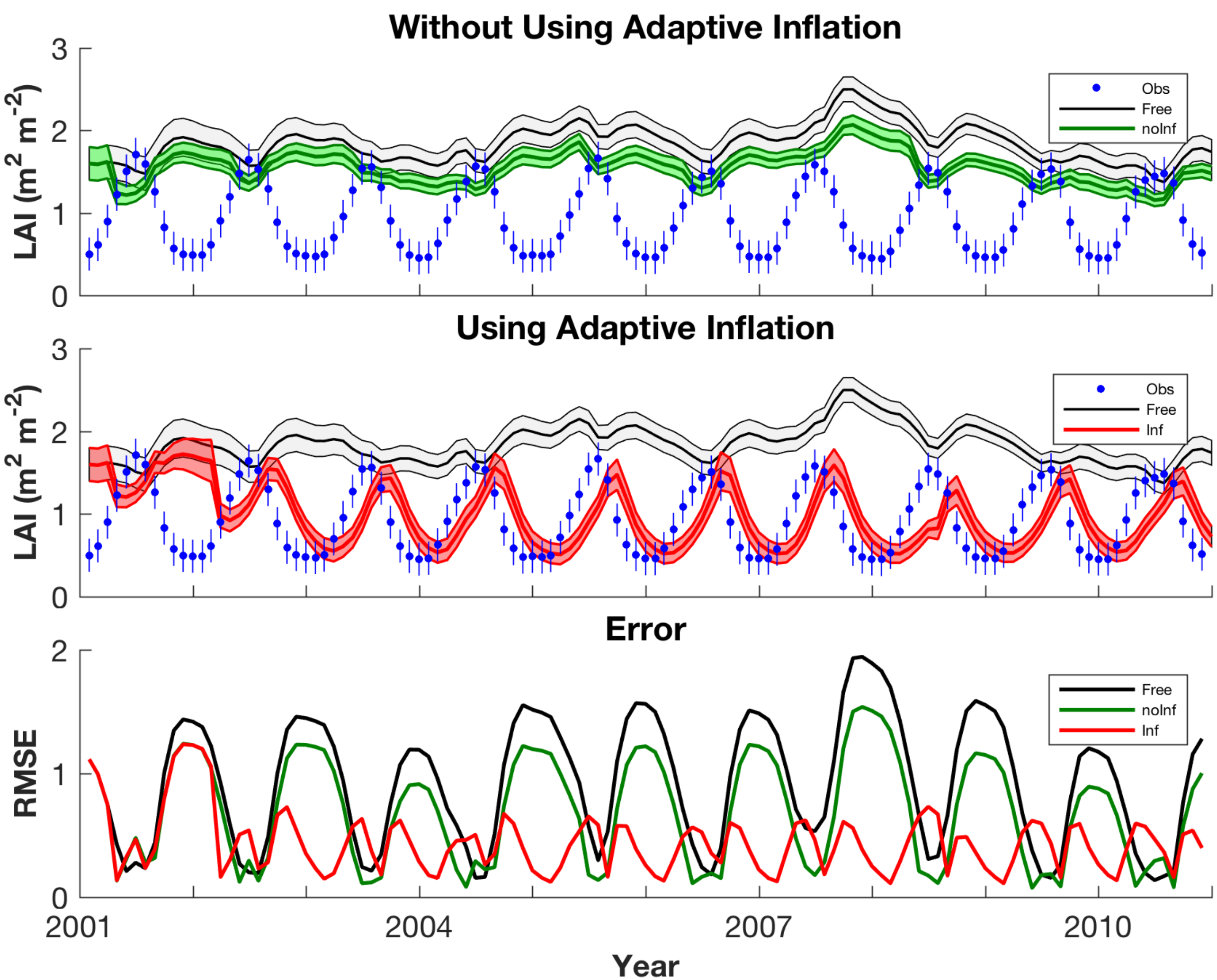
Observed and unobserved states



Assimilating LAI requires adaptive inflation



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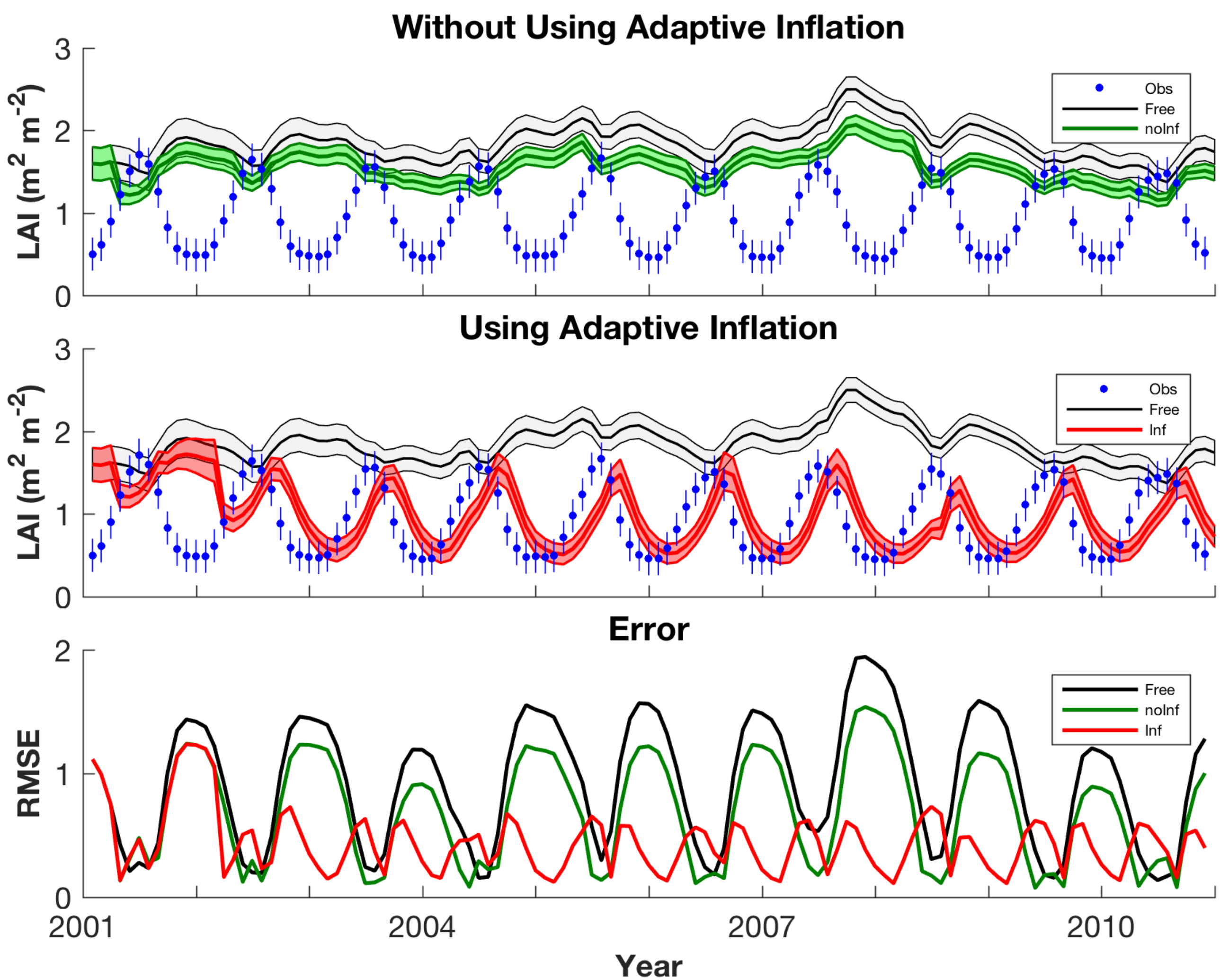

RMSE
0.93
0.70
0.44

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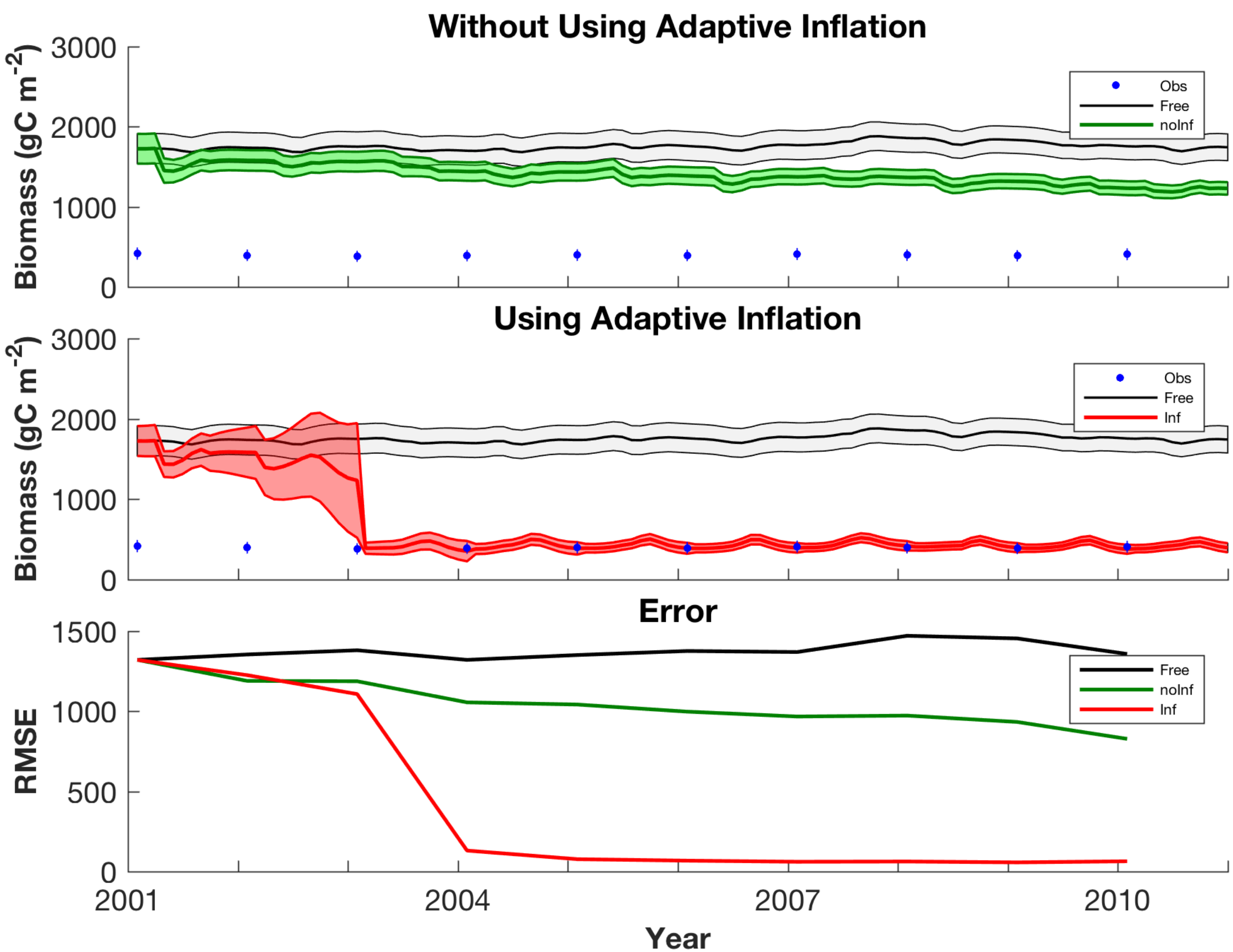
Assimilating Biomass using adaptive inflation



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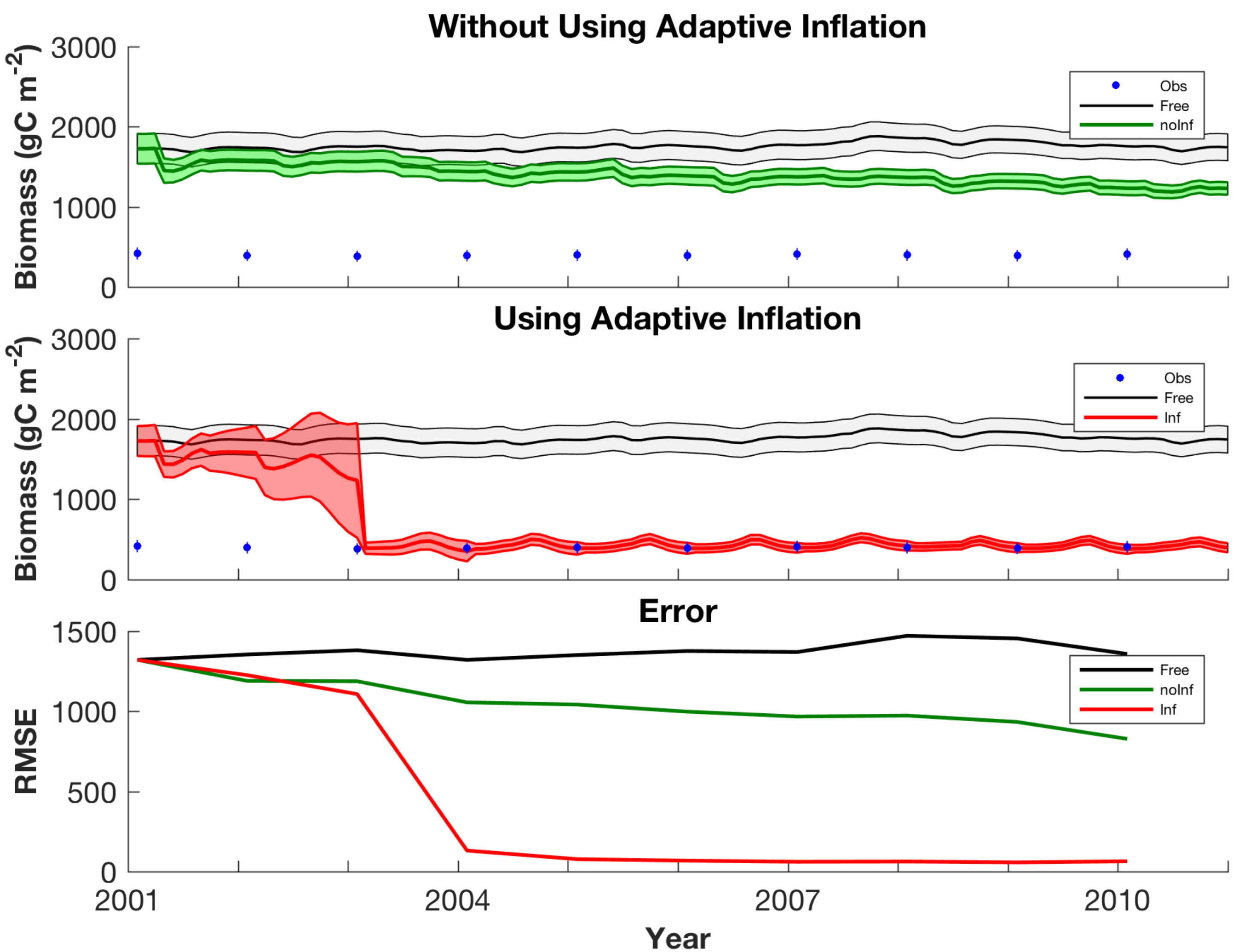
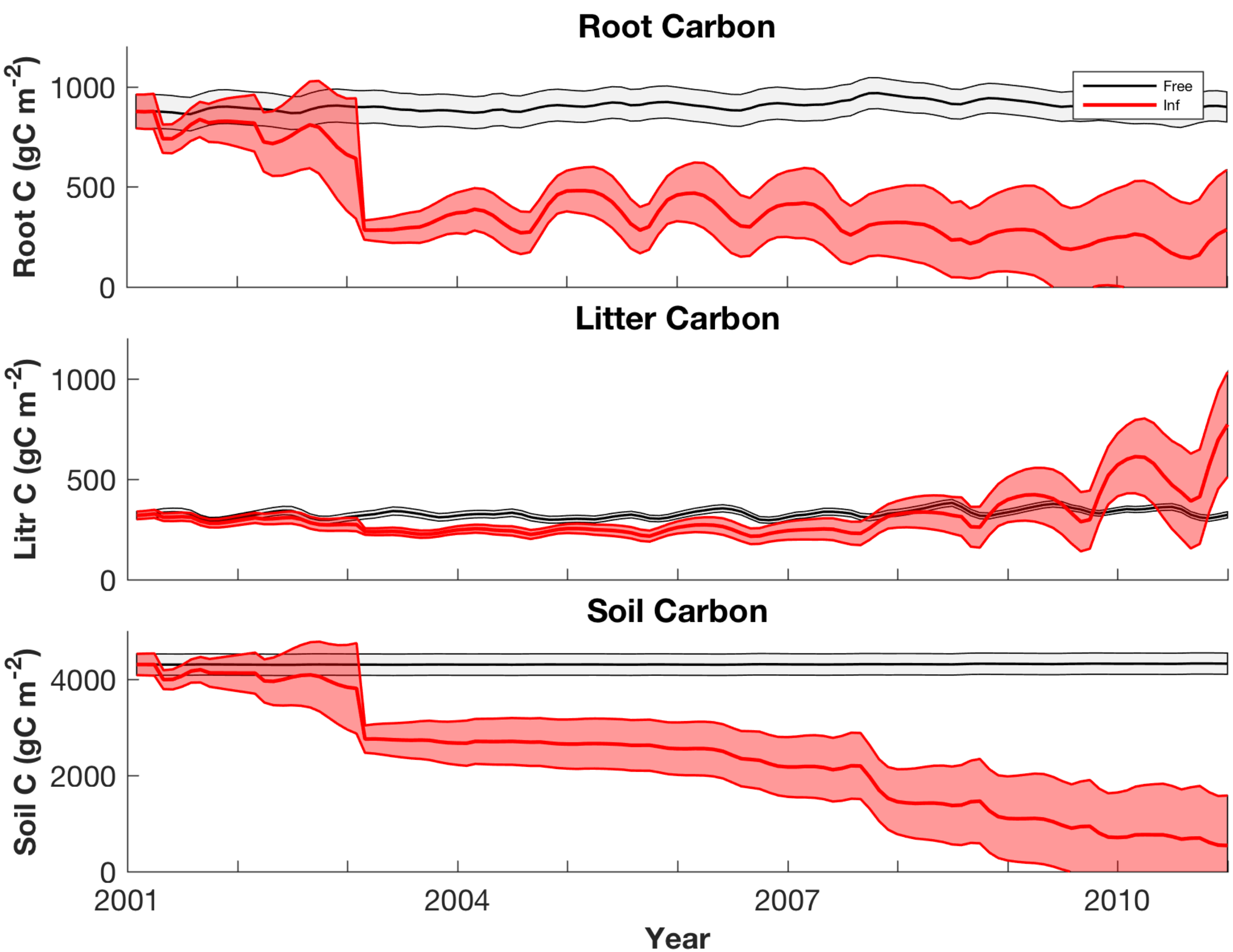
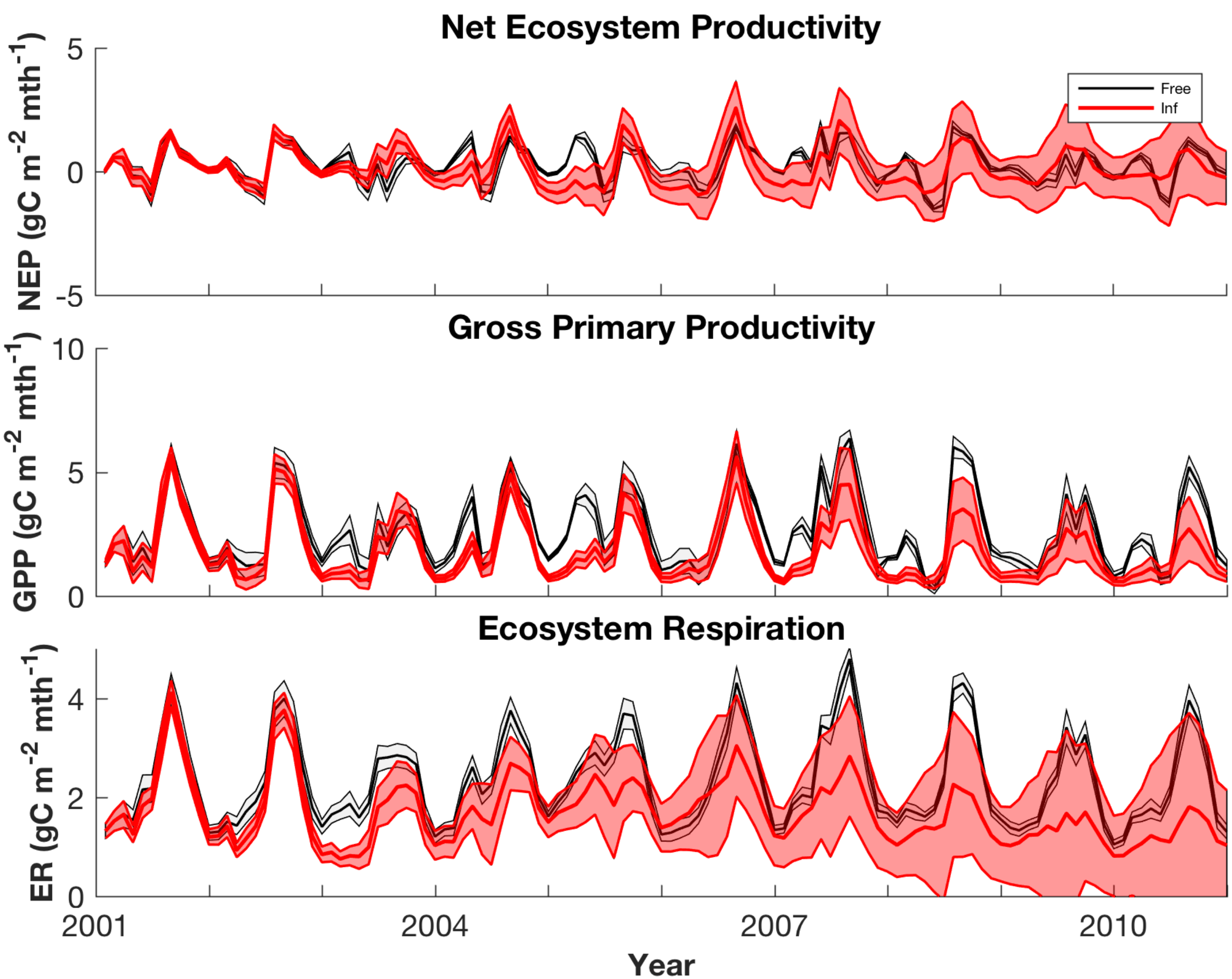


RMSE
1376
1049
417

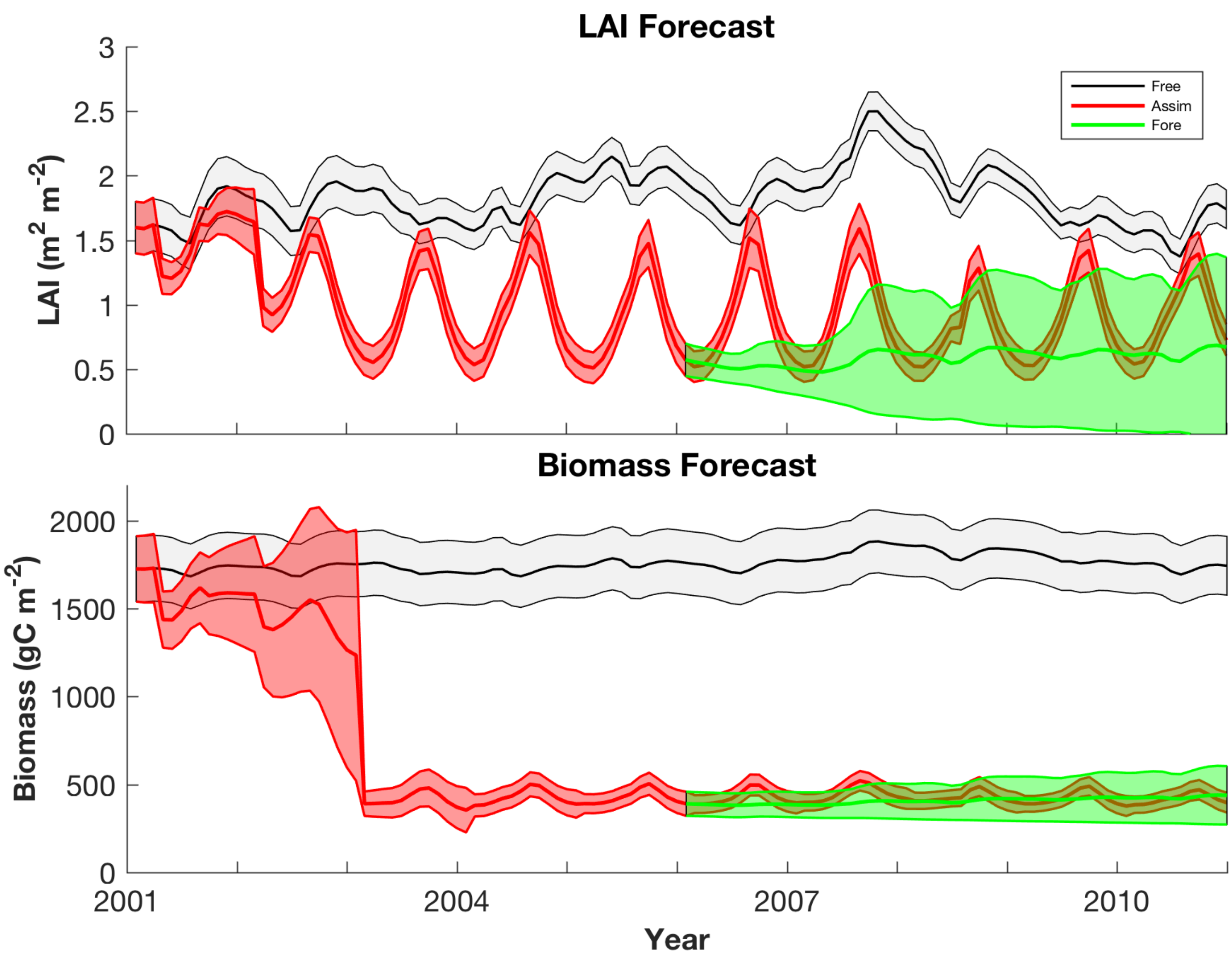
Unobserved State variables



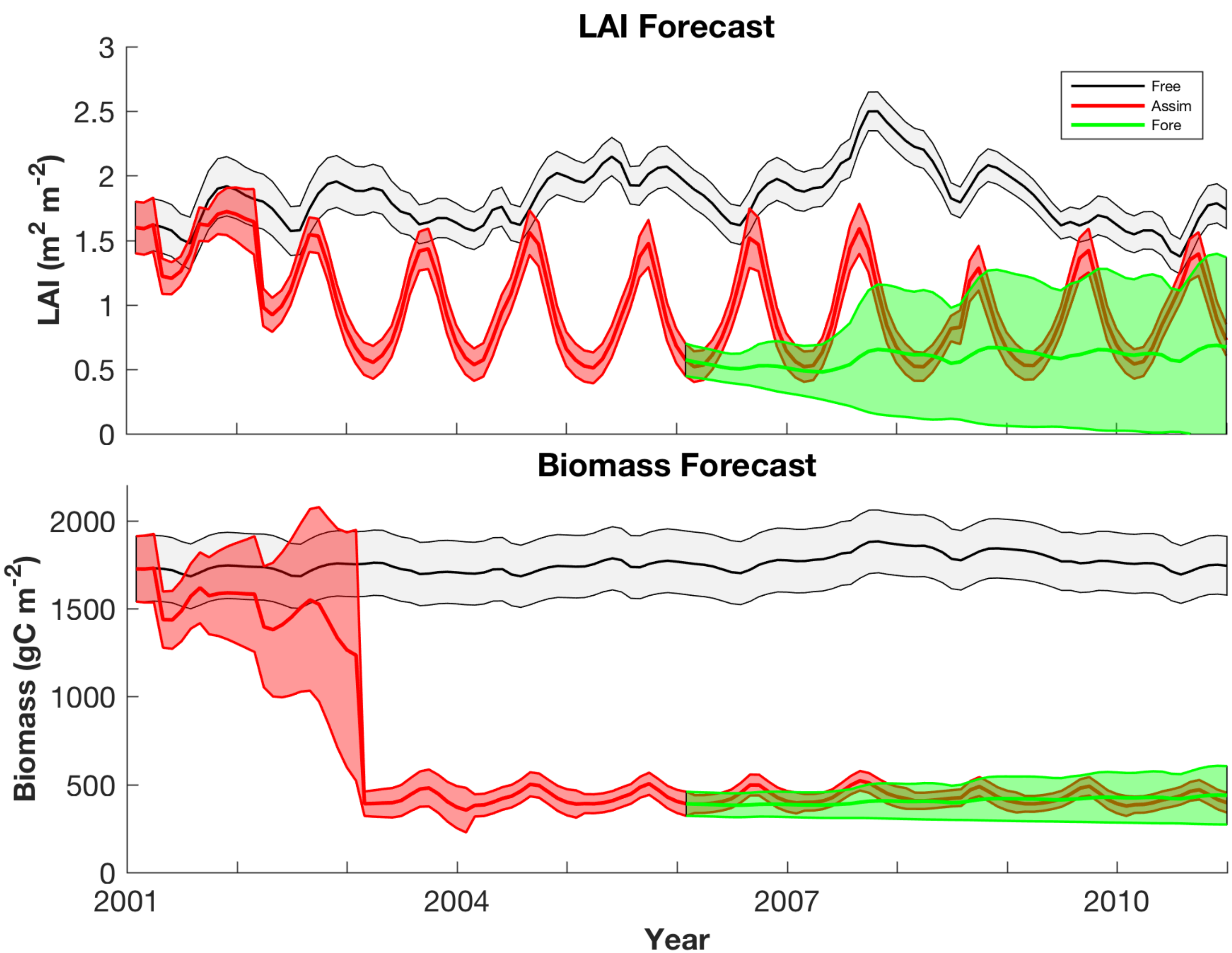
Carbon fluxes



Long-term Forecasts



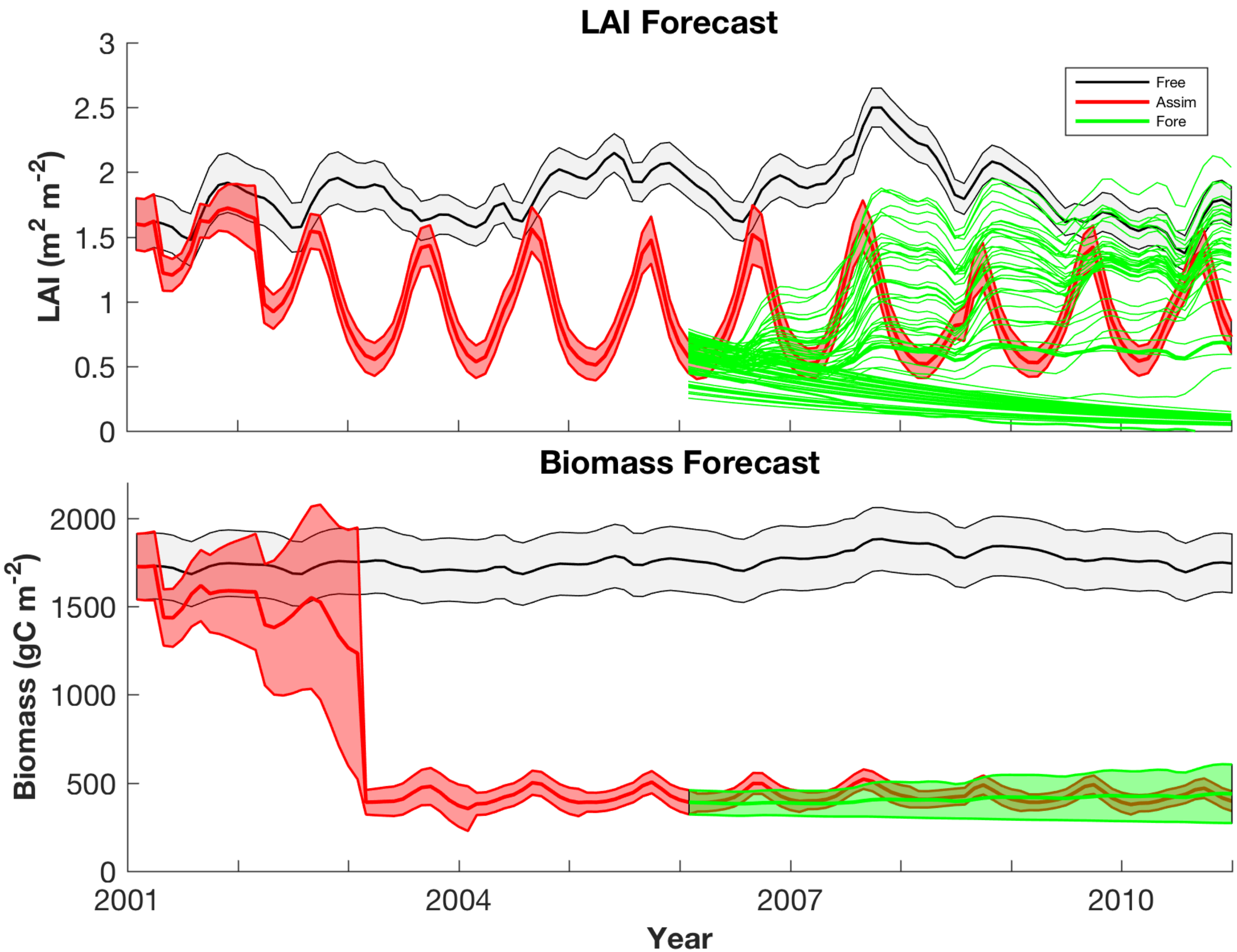
Long-term Forecasts



RMSE
0.96
0.39
0.33

RMSE
1406
62
51

Long-term Forecasts



RMSE
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RMSE
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51

Reductions in RMSE during assimilation

		LAI ($m^2\ m^{-2}$)			
		Free	*No Inf.*	*Inflation*	*Forecast*
RMSE	*2001-2010*	0.93	0.70	0.44	-
	2006-2010	0.96	0.69	0.39	0.33
		Biomass ($gC\ m^{-2}$)			
		Free	*No Inf.*	*Inflation*	*Forecast*
RMSE	*2001-2010*	1376.2	1049.9	417.7	-
	2006-2010	1406.3	940.29	62.8	51.4

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Reductions in RMSE during forecast

		LAI ($m^2\ m^{-2}$)			
		Free	*No Inf.*	*Inflation*	*Forecast*
RMSE	*2001-2010*	0.93	0.70	0.44	-
	2006-2010	0.96	0.69	0.39	0.33
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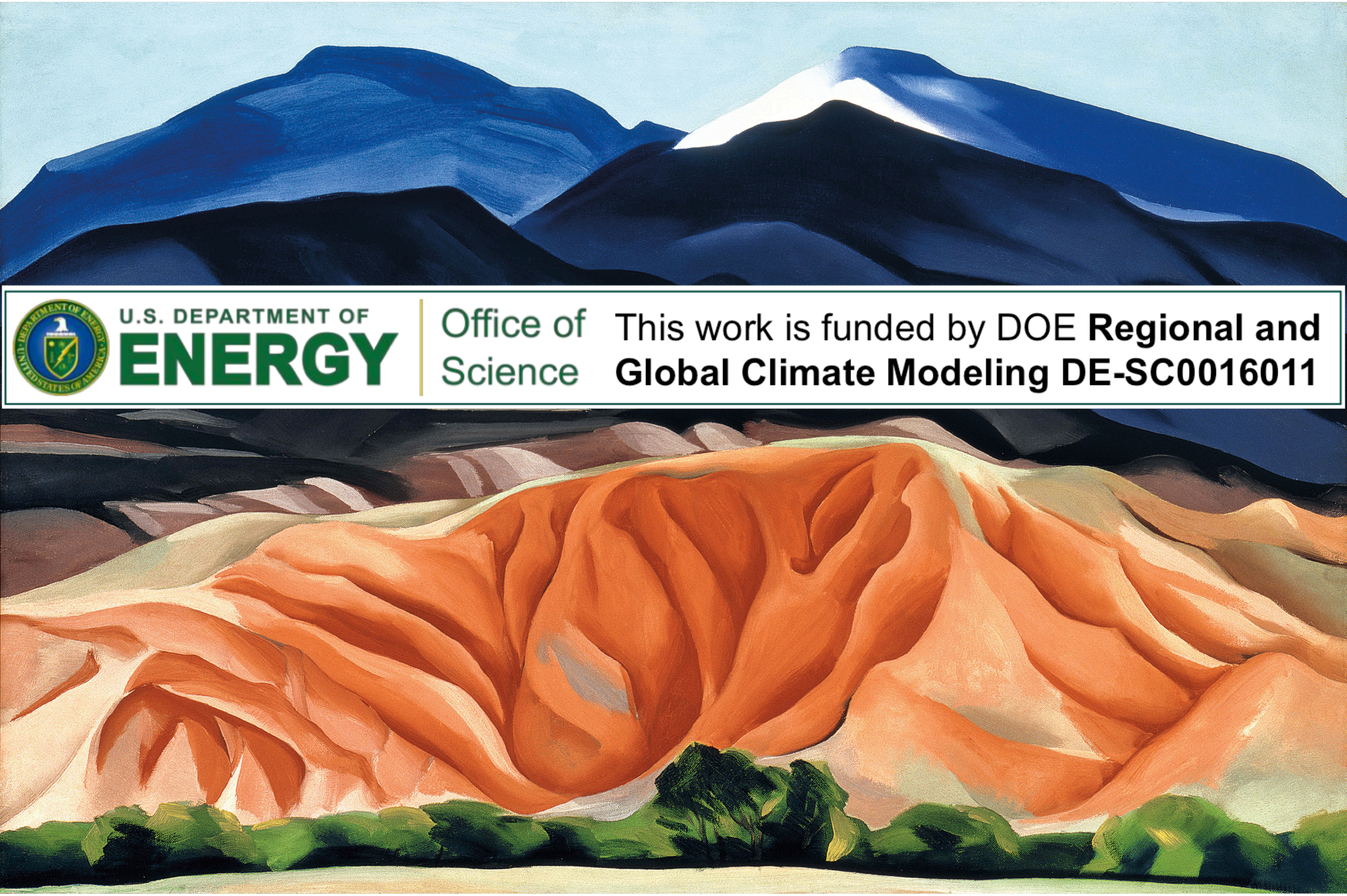
RMSE	*2001-2010*	1376.2	1049.9	417.7	-
	2006-2010	1406.3	940.29	62.8	51.4

Key Points

1) Forecasts benefit from accurate initial conditions
2) Impact persists from years to decades for different C pools
3) Spun-up model had too high biomass, and inaccurate seasonal cycle in LAI
4) Large reductions in error during assimilation and forecast periods
5) Adaptive inflation is required to account for large model error
6) Impact on C fluxes is immediate



U.S. DEPARTMENT OF ENERGY | Office of Science
This work is funded by DOE **Regional and Global Climate Modeling DE-SC0016011**

Georgia O'Keeffe – "Black Mesa Landscape"

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Data Assimilation Research Testbed (DART)

A Forecasting Challenge

- Deterministic knowledge of complex processes and feedbacks = complex models
- Present day stocks and fluxes are very dependent on disturbance history
- Actually disturbance history is “unknowable” – replace this by updating states based on observations
- Ensemble data assimilation can account for uncertainties in model and observations
- Provides probabilistic estimates of future states

AND THEN WHAT?

IAV from Semi-arid Ecosystems?

LETTER

doi:10.1038/nature13376

Contribution of semi-arid ecosystems to interannual variability of the global carbon cycle

Benjamin Poulter[1,2], David Frank[3,4], Philippe Ciais[2], Ranga B. Myneni[5], Niels Andela[6], Jian Bi[5], Gregoire Broquet[2], Josep G. Canadell[7], Frederic Chevallier[2], Yi Y. Liu[8], Steven W. Running[9], Stephen Sitch[10] & Guido R. van der Werf[6]

CARBON CYCLE

The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink

Anders Ahlström,[1,2*] Michael R. Raupach,[3†] Guy Schurgers,[4] Benjamin Smith,[1] Almut Arneth,[5] Martin Jung,[6] Markus Reichstein,[6] Josep G. Canadell,[7] Pierre Friedlingstein,[8] Atul K. Jain,[9] Etsushi Kato,[10] Benjamin Poulter,[11] Stephen Sitch,[12] Benjamin D. Stocker,[13,14] Nicolas Viovy,[15] Ying Ping Wang,[16] Andy Wiltshire,[17] Sönke Zaehle,[6] Ning Zeng[18]

LETTER

doi:10.1038/nature20780

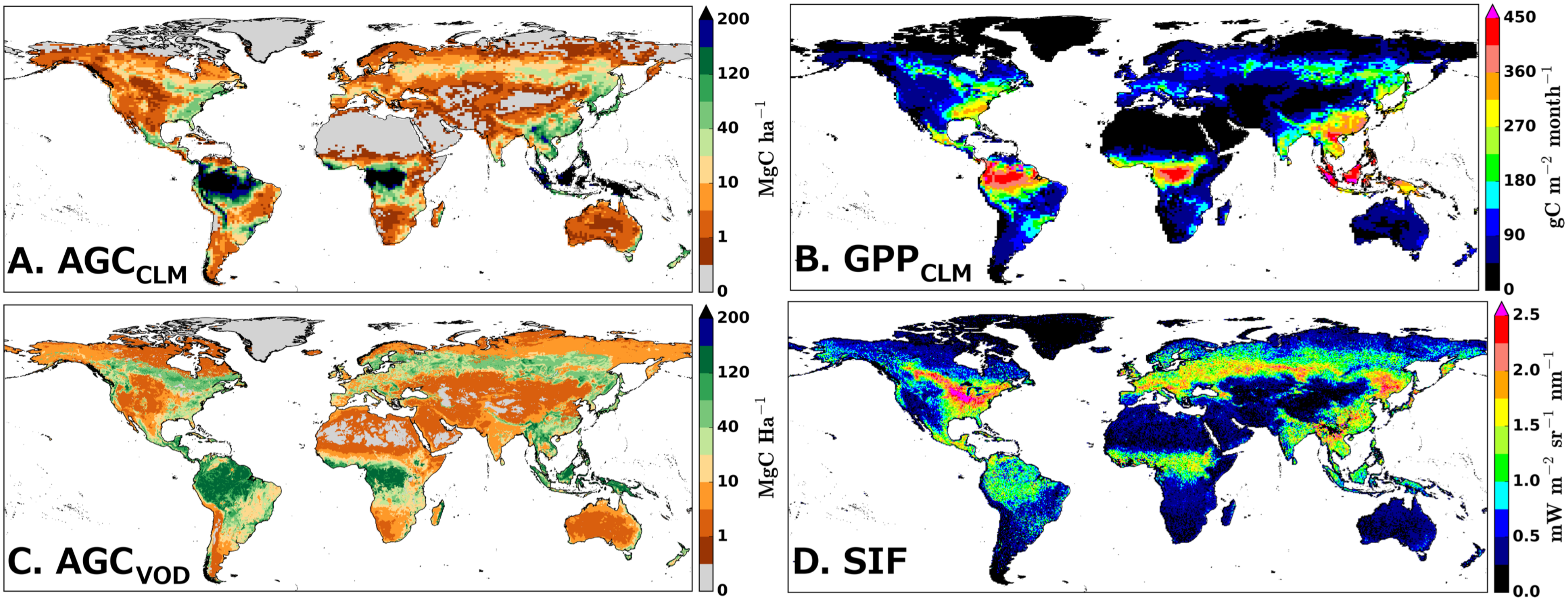
Compensatory water effects link yearly global land CO_2 sink changes to temperature

Martin Jung[1], Markus Reichstein[1,2], Christopher R. Schwalm[3], Chris Huntingford[4], Stephen Sitch[5], Anders Ahlström[6,7], Almut Arneth[8], Gustau Camps-Valls[9], Philippe Ciais[10], Pierre Friedlingstein[11], Fabian Gans[1], Kazuhito Ichii[12,13], Atul K. Jain[14], Etsushi Kato[15], Dario Papale[16], Ben Poulter[17], Botond Raduly[16,18], Christian Rödenbeck[19], Gianluca Tramontana[16], Nicolas Viovy[10], Ying-Ping Wang[20], Ulrich Weber[1], Sönke Zaehle[1,2] & Ning Zeng[21,22]

Sources of Uncertainty

- Model Structure
- Model Parameter
- Initial Conditions/Model States
- Spin Up
- Boundary Conditions

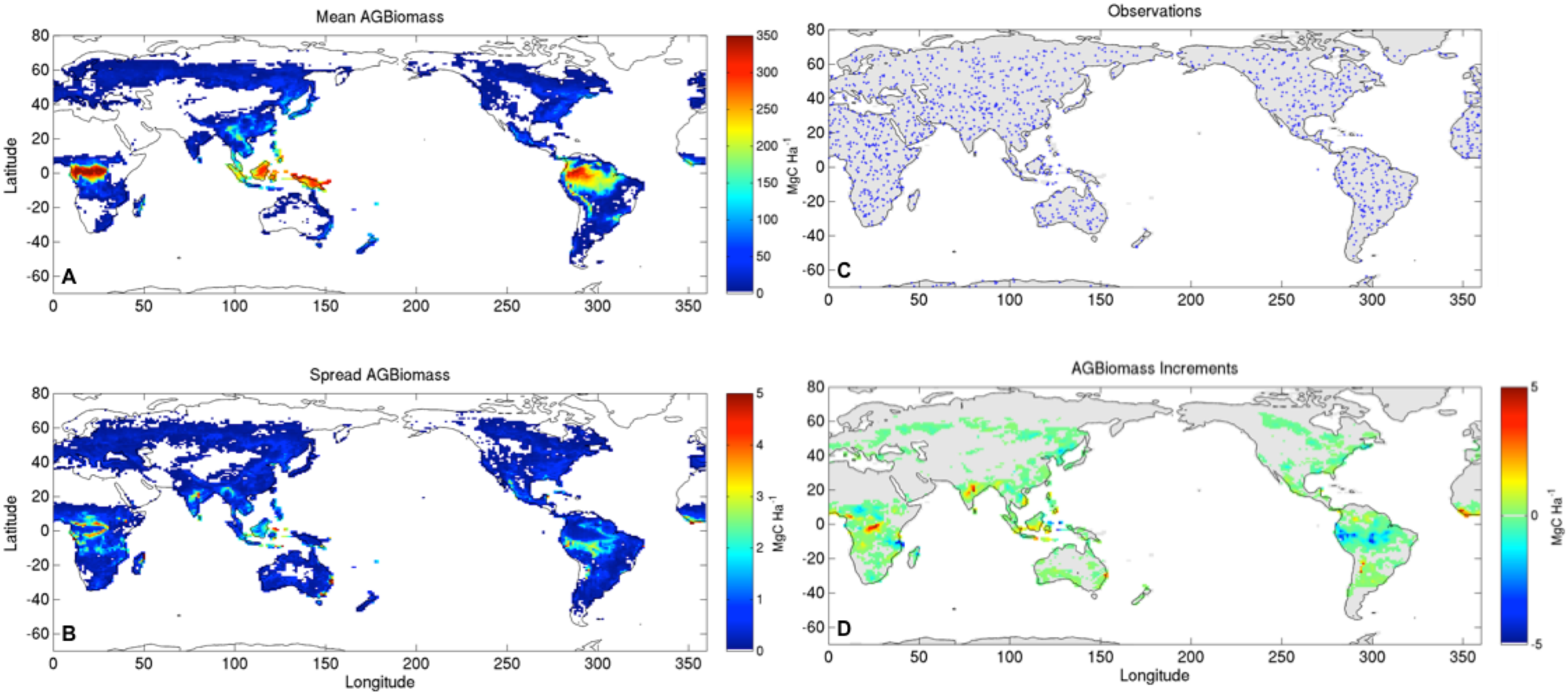
Vegetation Optical Depth and SIF



Courtesy Bill Kolby-Smith, UA

Data
Assimilation
Research
Testbed

Global Biomass OSSE

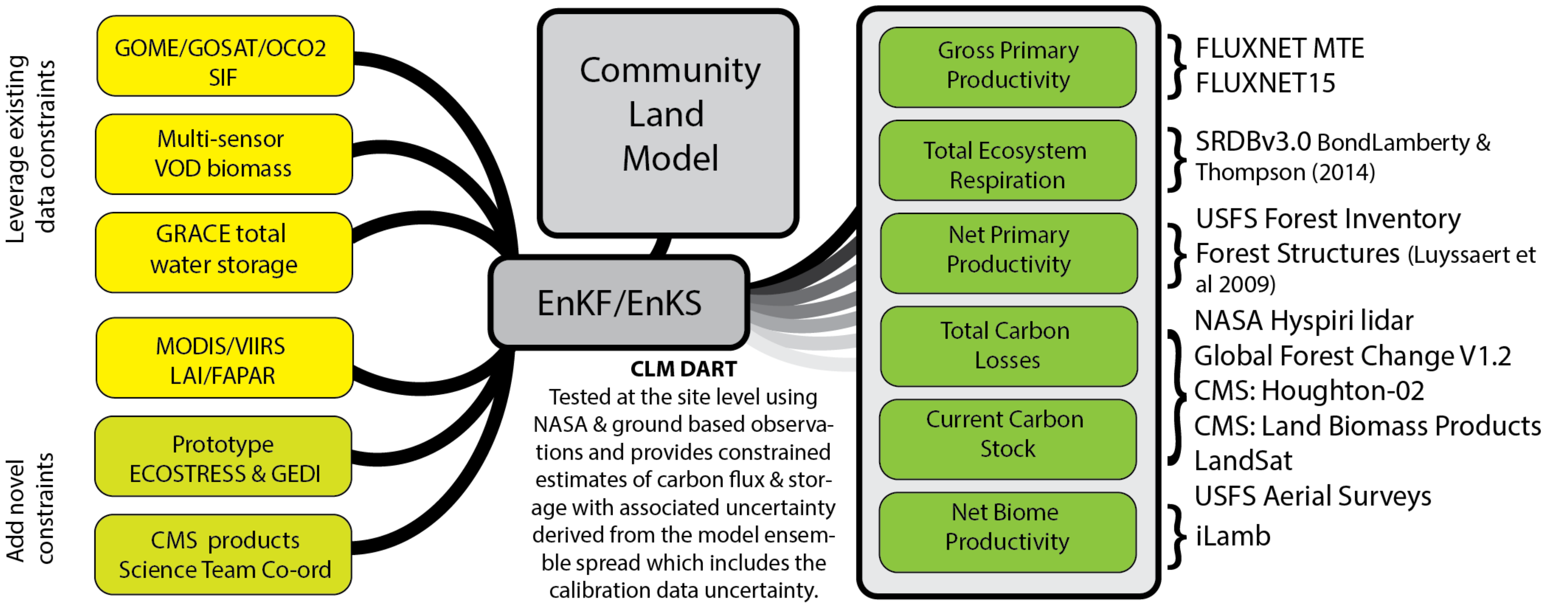


Data Assimilation Research Testbed

NCAR

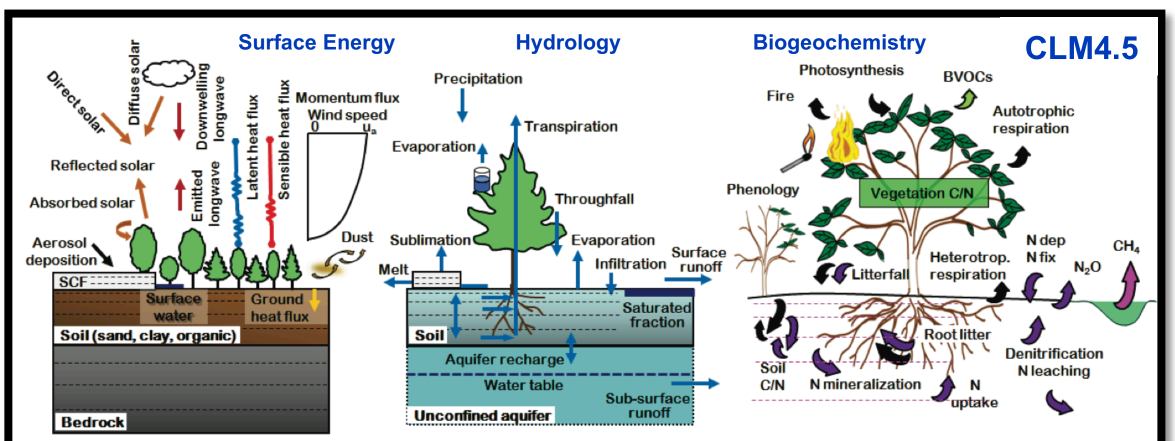
The University of Arizona

Calibration datasets and Data Assimilation **Ensemble Data Products Production and Validation**



Community Land Model set up

- Multi-instance CLM4.5 BGC set up for a location in central New Mexico, USA
- PFT fractions of Bare, C4 grass, shrub and Needleleaf Evergreen – Temperate
- Spun up by cycling 12 years of ensemble atmospheric reanalysis data



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