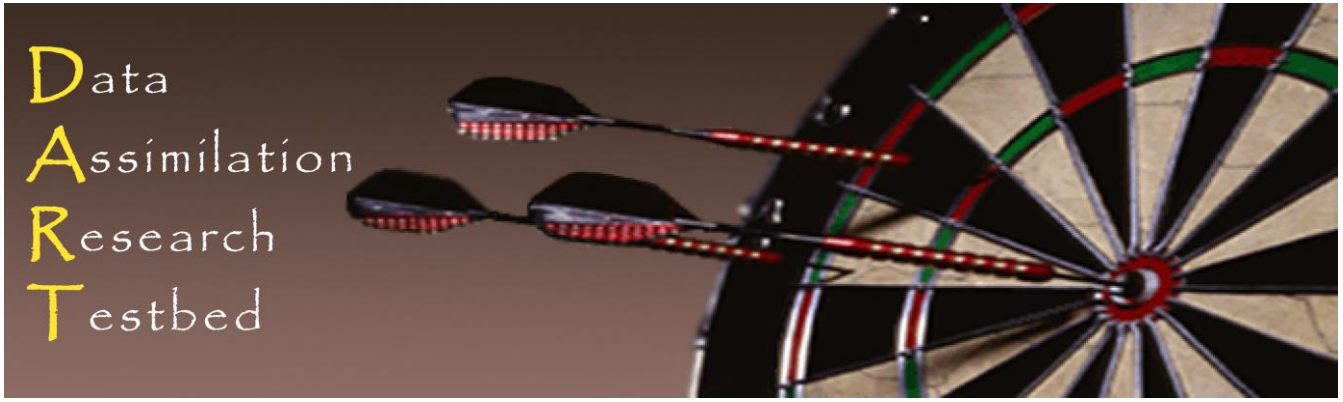

Improving the Representation of Land Surface Processes using the Data Assimilation Research Testbed (DART)

Brett Raczka[1], Xueli Huo[2], Daniel Hagan[3], Andrew M. Fox[4], Moha Gharamti[1], Kevin Raeder[1], Rolf Reichle[4], Emmanuel Dibia[5], Jeffrey Anderson[1]

[1]National Center for Atmospheric, [2]University of Arizona, [3]Nanjing University of Information Science and Technology [4]NASA Goddard Space Flight Center, [5]University of Maryland

American Meteorological Society Annual Meeting
January 12th, 2023

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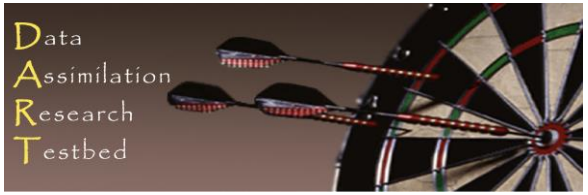
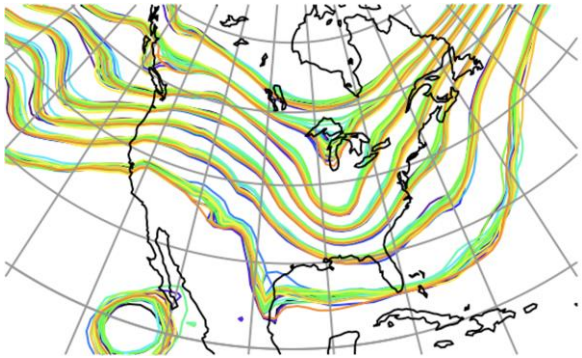
NCAR | National Center for
UCAR | Atmospheric Research

Intro to DART



A flexible suite of software tools to accelerate
Earth system research using ensemble Kalman filters

Educational Resource



User community:

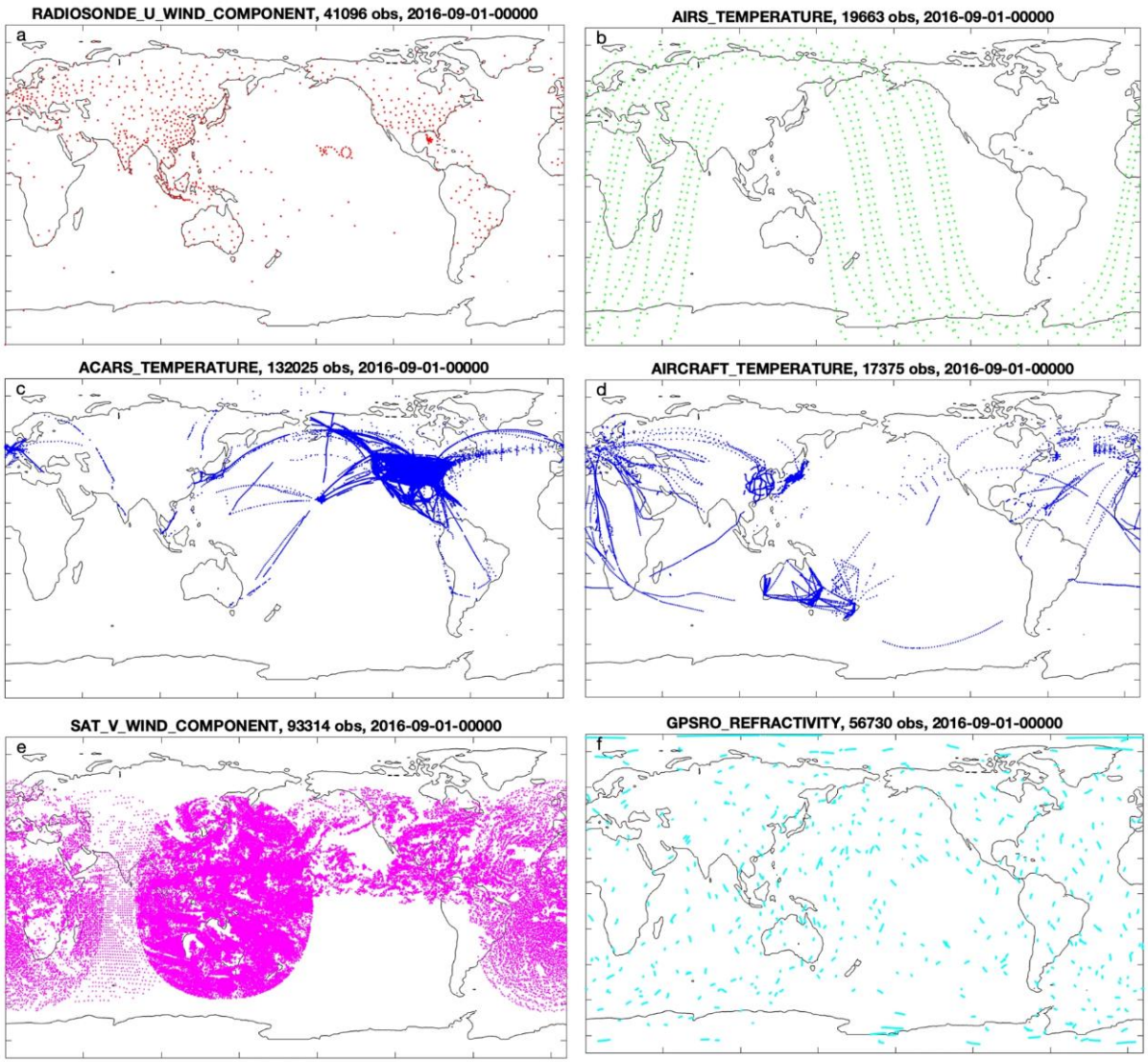
- 50+ Universities
- 100+ other sites
- 1500+ registered users

Open Source. DART team & community members develop:

- Model interfaces (e.g. CLM5, WRF-Hydro, Noah (MP))
- Observation forward operators
- Assimilation algorithms:
  e.g. EnKF, RHF, Quantile Conserving (Anderson; ISDA June 2022)
- Adaptive Inflation

Contributions are reviewed, streamlined and tested
before merging in public DART

CAM-DART (Atmospheric DA)



(Kevin Raeder et al., 2021)

CESM (Atmosphere, Land, Ice, River)

Yrs: 2011-2020

Observations: > 300,000 obs per 6 hour time step

- Radiosondes: Surface balloon launches
- ACARS: NA aircraft
- AIRS: IR Soundings
- CDW: Cloud Drift Winds (satellites)
- GPS Refractivity: occultation

Product: CAM6 Reanalysis

CLM-DART Methodology

- Bayesian Approach

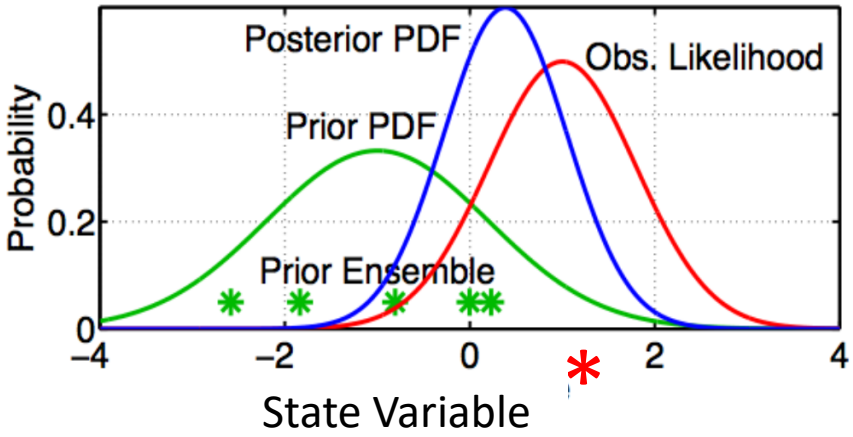
Posterior ~ **Prior** · **Observation Likelihood**

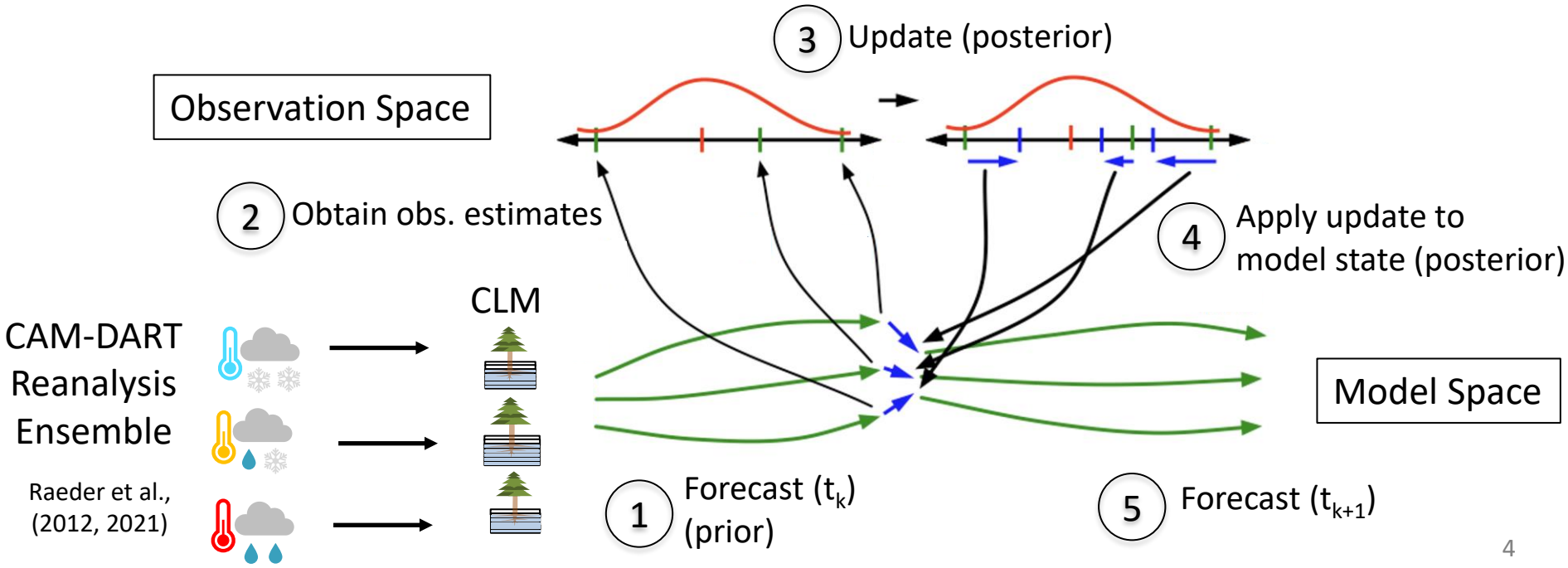
'Analysis' 'Update'

CLM generated forecast

Earth System Observations

e.g. satellite, surface data





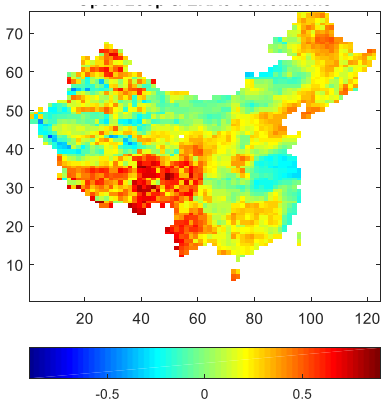
Soil Moisture observations (CLM-DART)

CLM: CLM4.5 free run (no observations)
CLM-DART: CLM4.5 + ECV-CCI observations

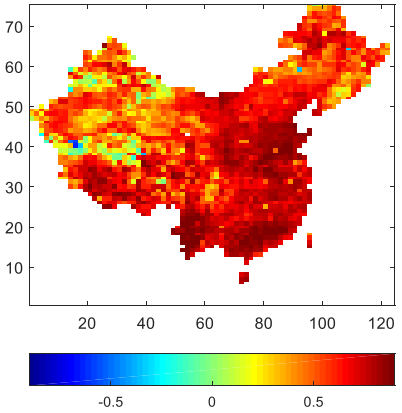
- CLM-DART fills in gaps from ECV-CCI retrievals and improves surface correlation with ERA5 benchmark product

Correlation w/ ERA5 Near Surface Soil Moisture

CLM

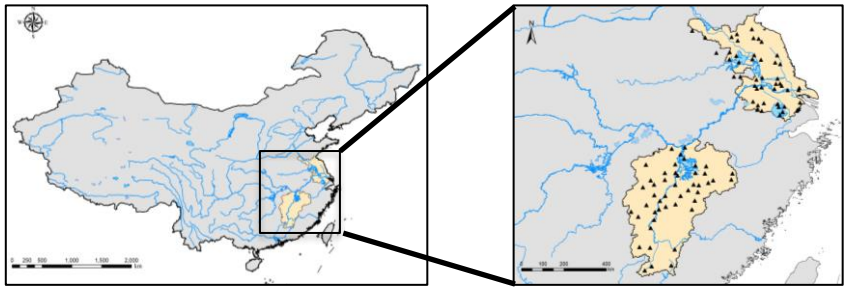


CLM-DART



- CLM-DART also improves subsurface soil moisture correlation with in-situ site observations

D. Hagan et al, (in prep)

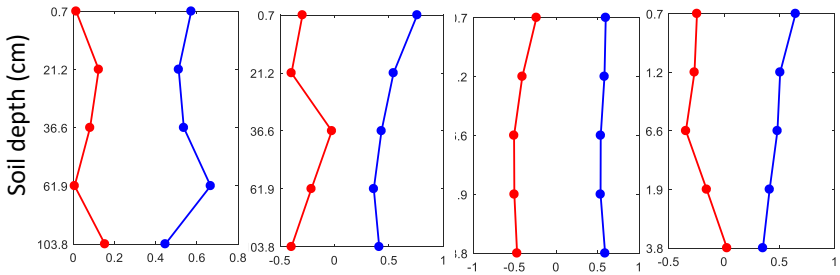


Jiangxi and Jiangsu provinces

Sub-Surface vertical profile
Soil Moisture Correlation (1-100 cm)

CLM

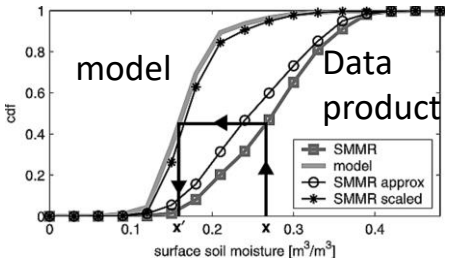
CLM_DART



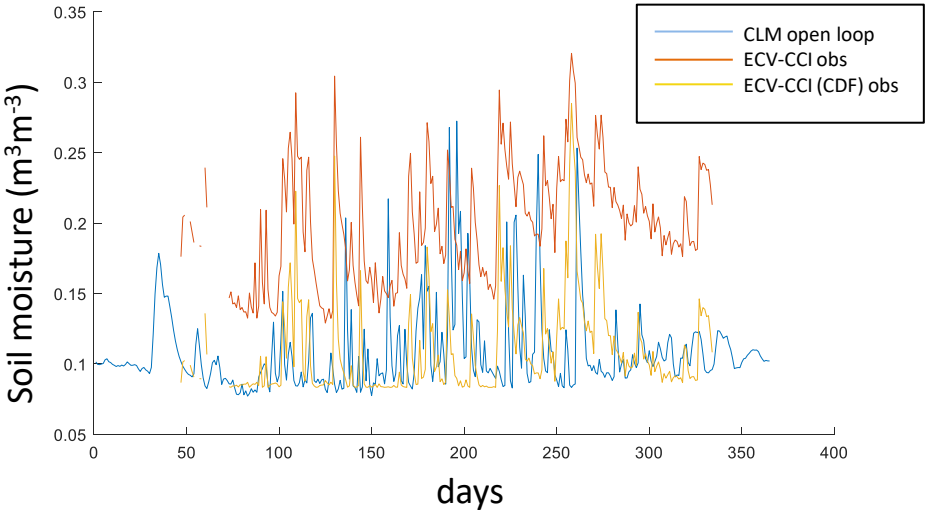
4 different sites

Soil Moisture - CDF matching

- CDF matching re-scales data products to match the bias and variability of the open-loop model



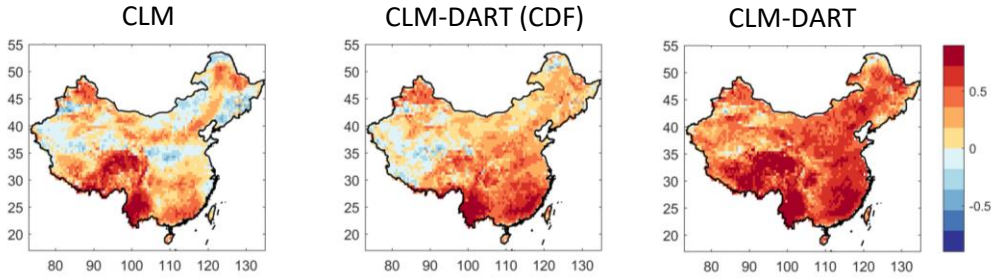
Reichle & Koster 2004 (GRL)



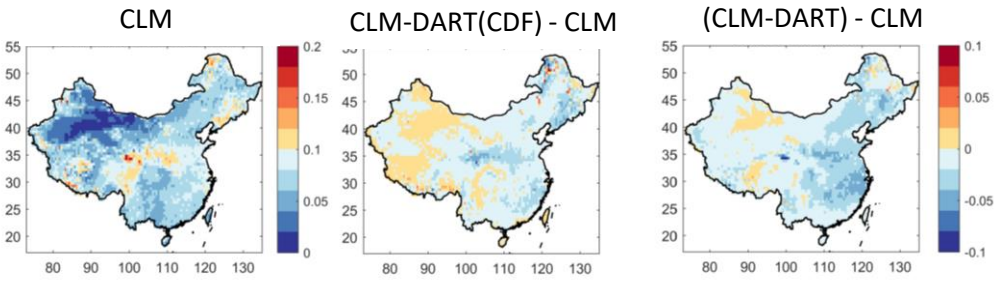
- The CLM-DART soil moisture product using the standard ECV-CCI product shows stronger correlations and reduced RMSD compared to ERA5Land benchmark

- Suggests CDF matched soil moisture product loses information, and inflation helps account for model error & bias

Correlation w/ ERA5



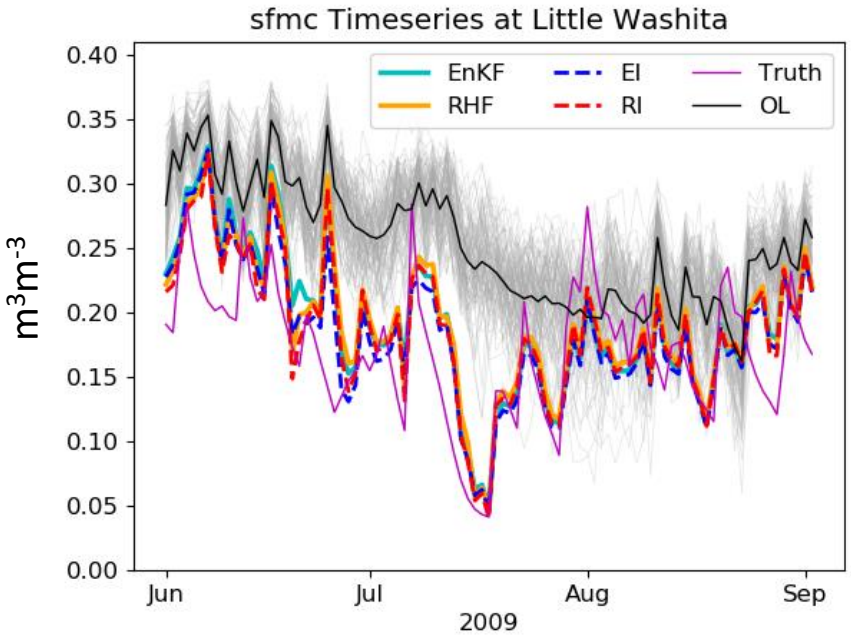
ubRMSD w/ ERA5

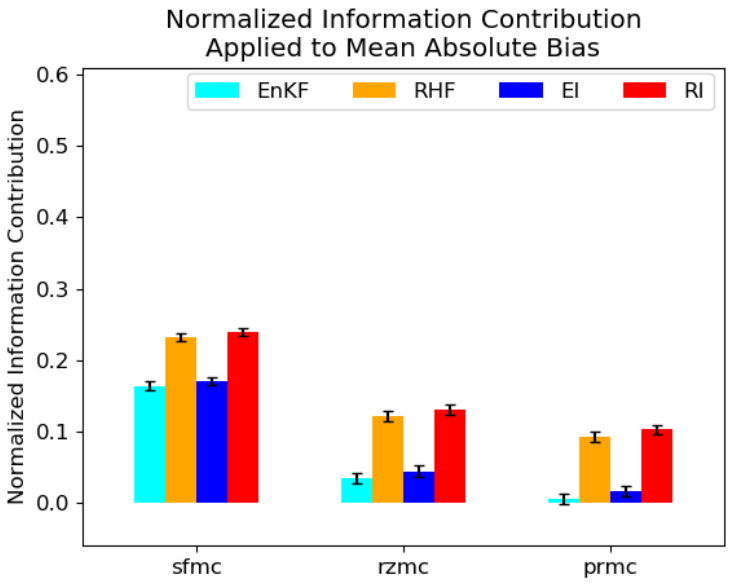


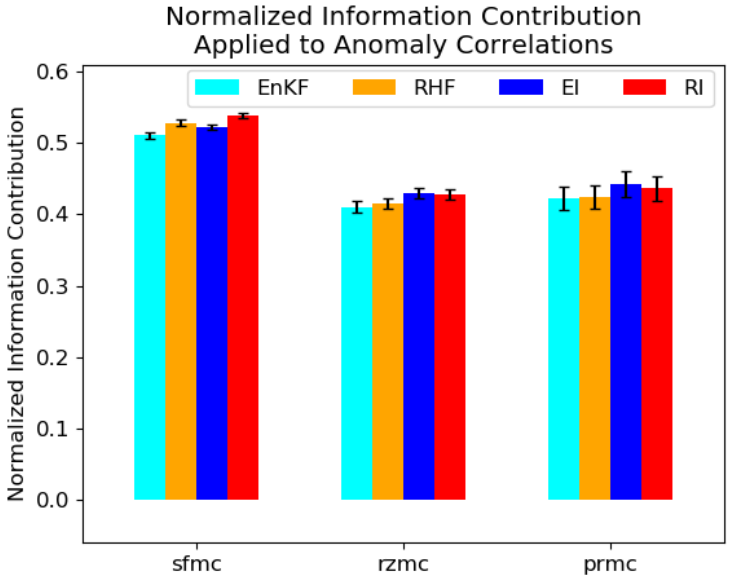
Testing Filter/Inflation Algorithms

Soil Moisture Perfect Model Experiment

- NASA Catchment land surface model
- Merra-2 Met Forcing (AR perturbed)
- 18 global site locations
- EnKF vs Rank Histogram Filter
- Adaptive Inflation (Gharamti, 2018)







Dibia, E., Reichle, Anderson, Liang
(in revision, Journal of Hydrometeorology)

0-5 cm 0-100 cm 0-bedrock

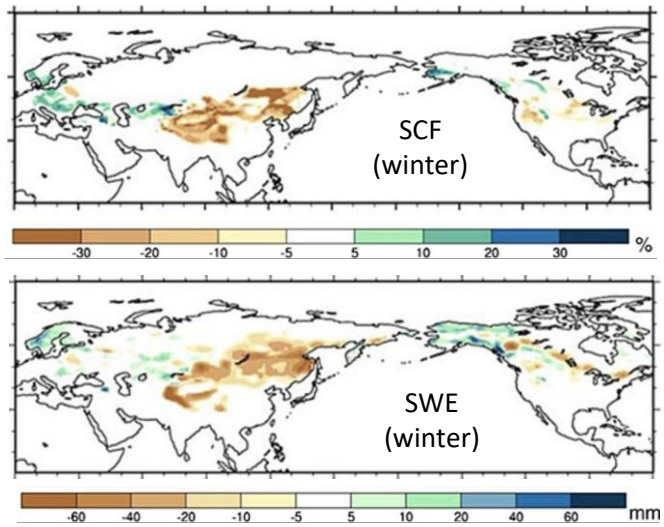
Snow observations (CLM-DART)

Observation:

MODIS
Snow
Cover
Fraction

Zhang et al., (2014)

(CLM4_DART) – CLM4

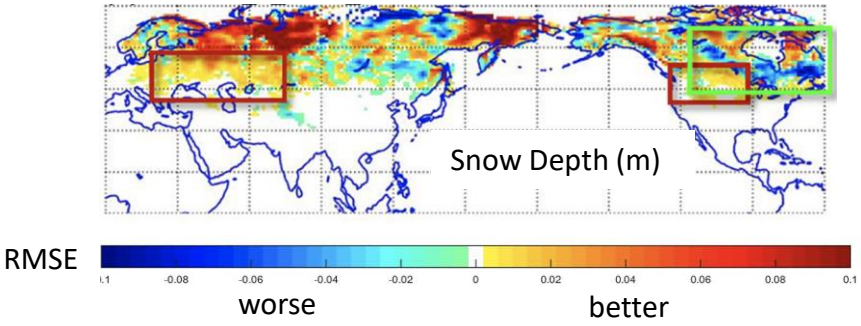


Observation:

MODIS SCF
GRACE TWS

Zhao and Yang (2018)

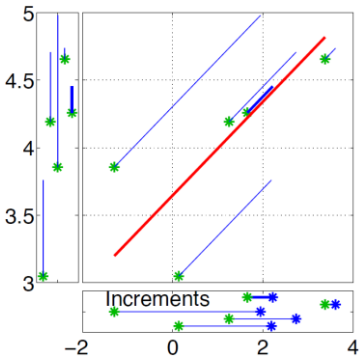
CLM4 – (CLM4_DART)



- Implications for albedo, surface energy balance, soil moisture, carbon cycle

Layer Repartitioning for Snow/Ice

Standard Approach



Model Estimated SWE

Snow Layer Property $_{i = n}$

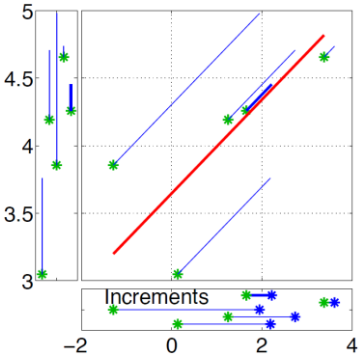
Snow Layer$_i$ + Δ	
" " + Δ	i= 2
" " + Δ	i= 3
" " + Δ	i= n
Ground	

Snow (SWE) Observations

× Snow updates not internally consistent

Δ Total SWE ≠ Σ(ΔLayers)
Δ Total Ice ≠ Σ(ΔLayers)
Δ Total Liquid ≠ Σ(ΔLayers)
Δ Total Depth ≠ Σ(ΔLayers)

Added Snow re-partitioning algorithm



Model Estimated SWE

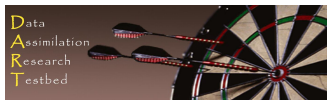
Column SWE

Repartitioning Algorithm

Snow Layer$_i$ + Δ	
" "	i= 2
" "	i= 3
" "	i= n
Ground	

√ Snow updates are internally consistent

Δ Total SWE = Σ(ΔLayers)
Δ Total Ice = Σ(ΔLayers)
Δ Total Liquid = Σ(ΔLayers)
Δ Total Depth = Σ(ΔLayers)

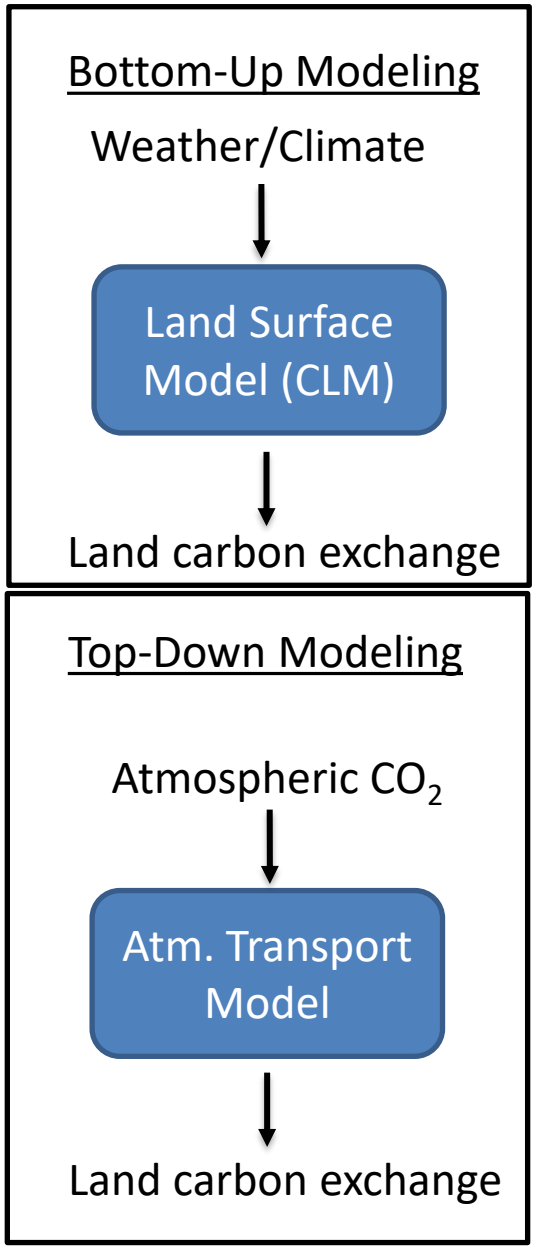


Challenge: Monitoring Terrestrial Carbon Cycle

Carbon stocks vulnerable to climate change, drastic change to landscape and ecosystem functioning

Western US: Fire, Drought, Disturbance

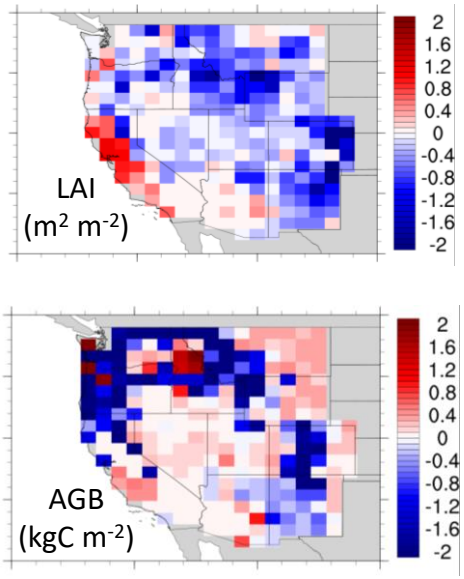
Arctic-Boreal: Greening/Browning, Permafrost Thaw



Improving simulated leaf area and biomass

Western US

(CLM5_DART) – CLM5

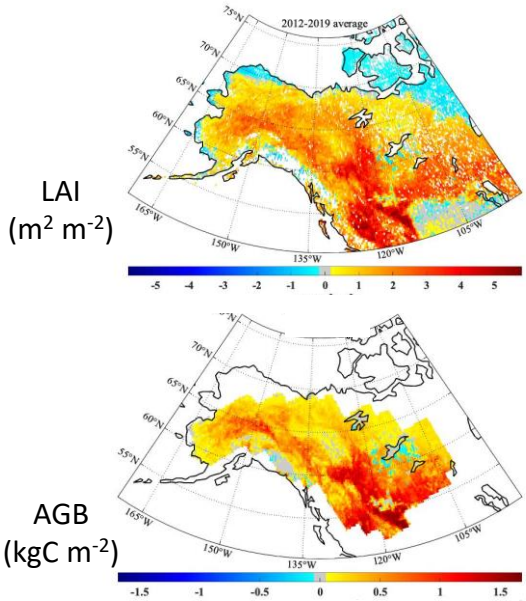


Yrs: 1998-2010 (Raczka et al., 2021)

30 % reduction

Arctic-Boreal

CLM5 – (CLM5_DART)

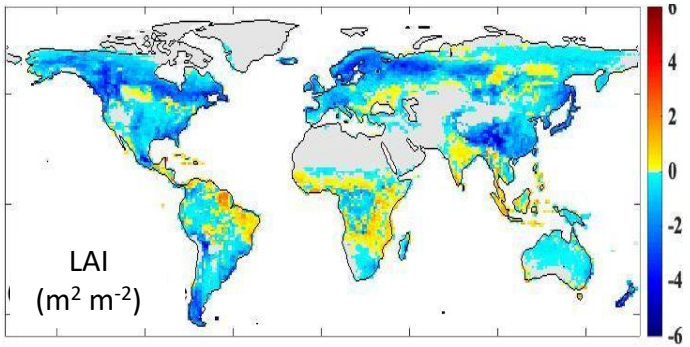


Yrs: 2011-2019, (X. Huo et al., in prep)

30 & 70 % reduction

Globe

(CLM5_DART) – CLM5



(Fox et al., 2022)

Yrs: 2006-2010

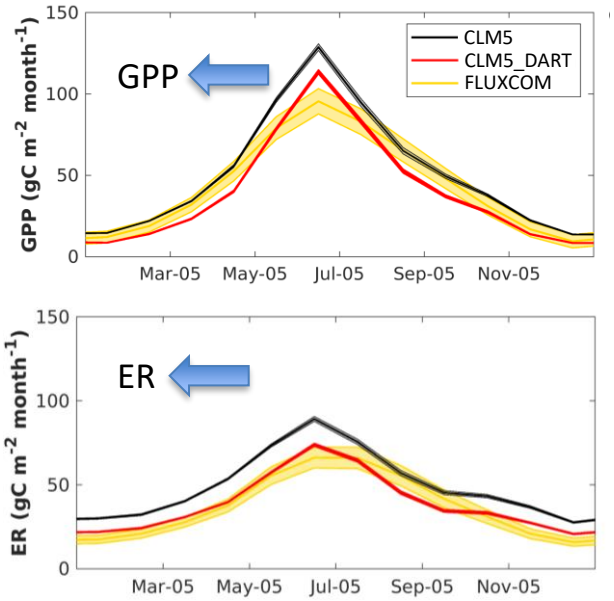
**LAI obs assimilated only

26 % reduction

- Assimilating LAI and biomass observations reduces CLM5 simulated values
- How does this impact component carbon fluxes and net carbon exchange?

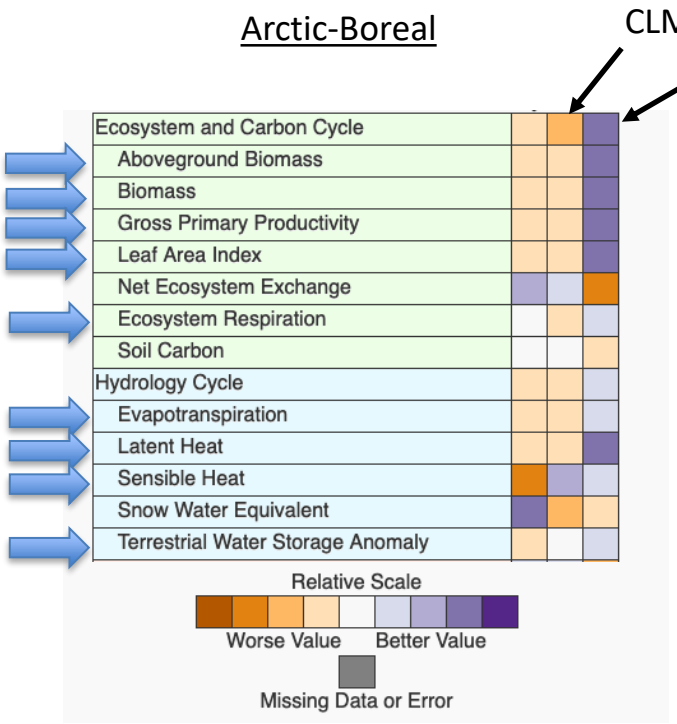
Impact of leaf/biomass on carbon/water cycle

Western US



(Raczka et al., 2021)

Arctic-Boreal



(X. Huo et al., in prep)

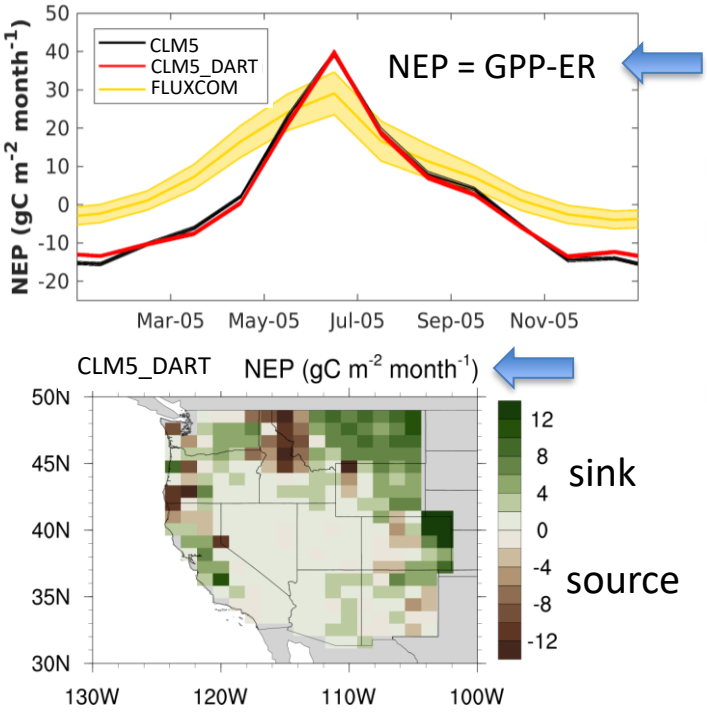
ILAMB Benchmarking Software: Bias and RMSE

(Collier et al., 2018)

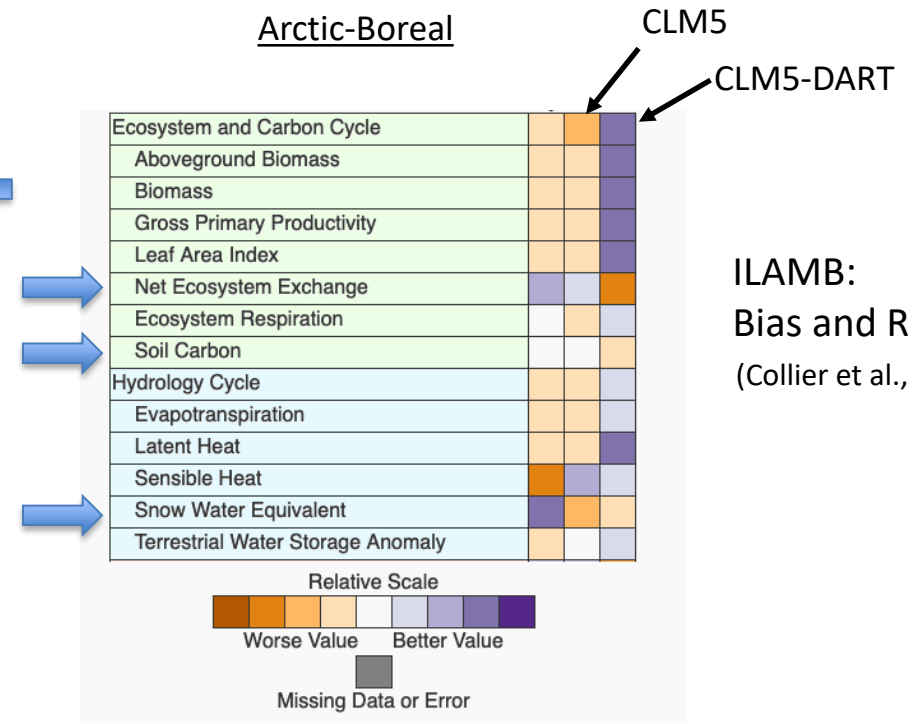
- Assimilating leaf/biomass brings most simulated carbon and water cycling in closer agreement with benchmarks
- What about net carbon exchange?

Impact of leaf/biomass on carbon/water cycle

Western US



Arctic-Boreal



ILAMB:
Bias and RMSE
(Collier et al., 2018)

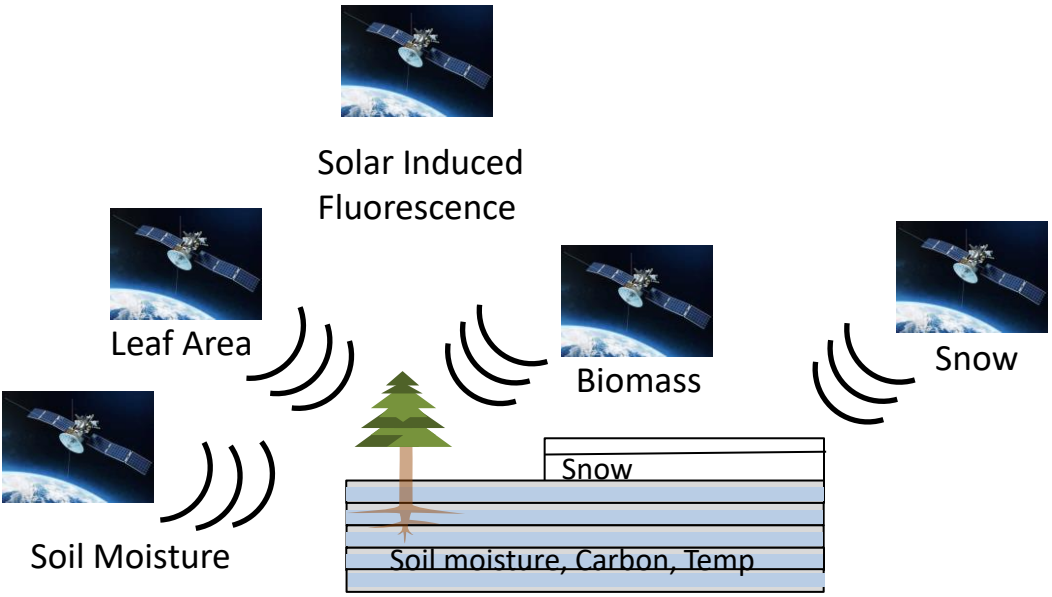
- Simulating NEP, soil carbon and SWE (snow) is more challenging.

Additional Data Streams:

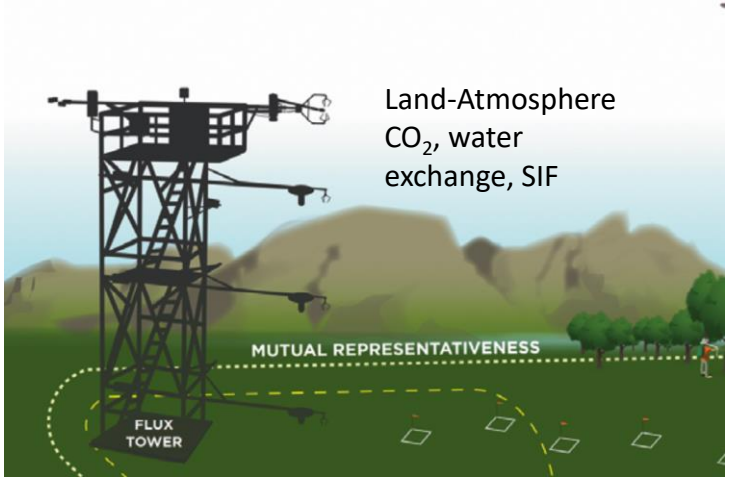
- Soil Moisture, Snow (SWE)
- Soil Carbon data (ER)
- EC flux tower (GPP, ER, NEE)
- Solar-Induced-Fluorescence (SIF-GPP)

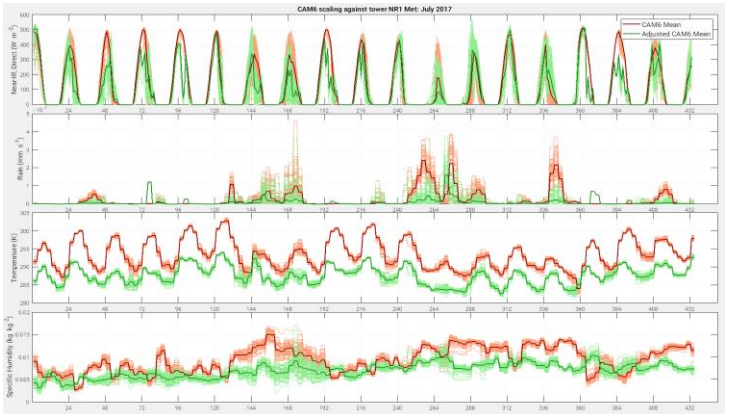
Current and Future Work

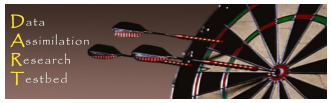
Combine remote biomass, hydrology & emerging observations to constrain land surface processes



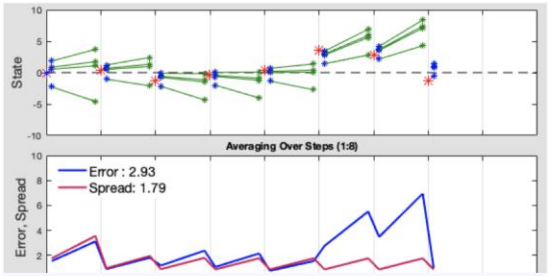
Develop bias-corrected CAM reanalysis to leverage site-based observations (tower fluxes, SIF etc.)







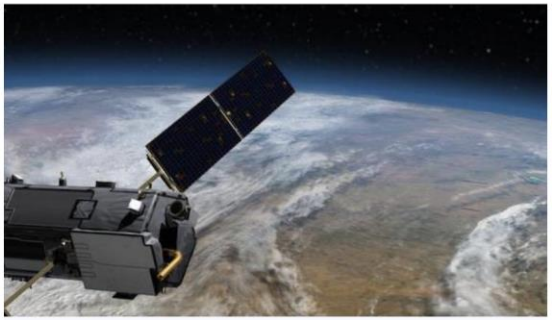
DART Tutorials



MATLAB

DART LAB

An introduction to Data Assimilation using MATLAB DART_LAB is a MATLAB®-based tutorial to demonstrate the principles of ensemble data assimilation. The DART_LAB tutorial begins at a more introductory level than the materials in the tutorial directory, and includes hands-on exercises. ...



Fortran

The DART tutorial

The DART Tutorial is intended to aid in the understanding of ensemble data assimilation theory and consists of step-by-step concepts and companion exercises with DART. ...

Fortran

WRF-DART tutorial

Overview The WRF-DART tutorial steps through a WRF-DART experiment. The experiment covers the continental United States and uses a 50 member ensemble initialized from NCEP's Global Forecast System (GFS) initial conditions at 2017/04/27 00:00 UTC. ...

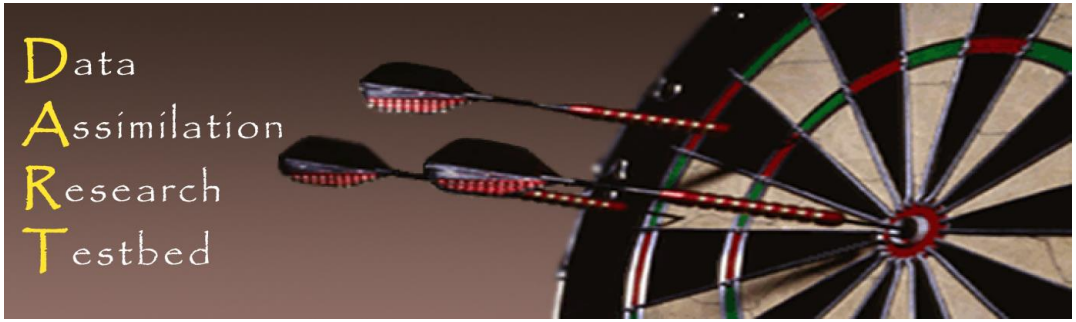
Fortran

CLM5-DART Tutorial

The CLM5-DART tutorial provides a detailed description of the download, setup, executation and diagnostic steps required for a simple global assimilation run using CLM5. It is intended to be performed after the completion of the more general DART tutorial which covers the fundamental concepts of the Ensemble Kalman Filter used within DART. ...

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

For more information:



Thank You !

Questions ?

CISL Computational & Information Systems Lab

We would like to acknowledge high-performance computing support from Cheyenne (doi:10.5065/D6RX99HX) provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation.