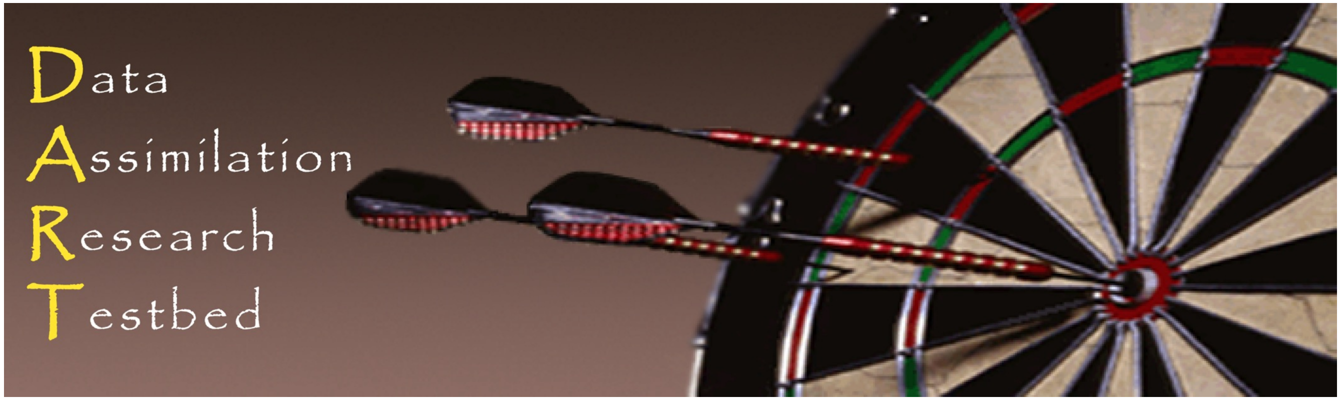
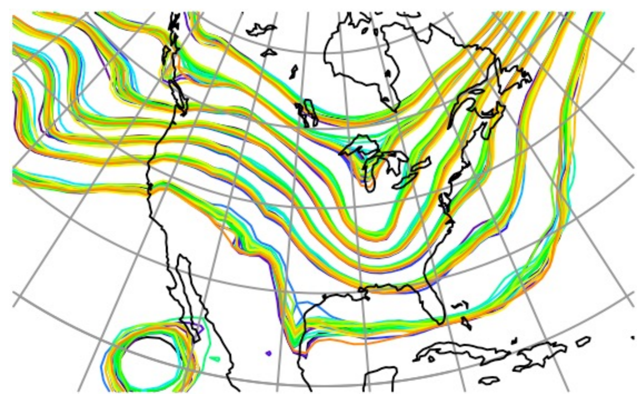


Applying the Data Assimilation Research Testbed to improve the Representation of Earth System Carbon, Water and Energy Cycling

Brett Raczka, NCAR, Data Assimilation Research Section (DAReS)



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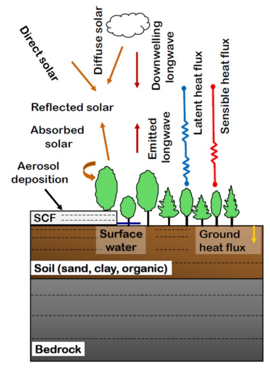
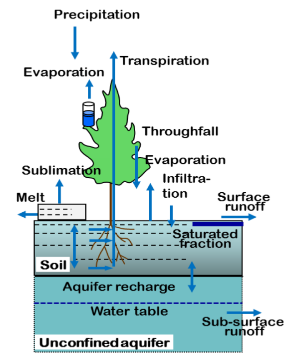
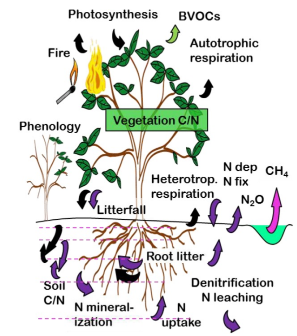
Approaches to reduce CLM uncertainty

Energy balance ***Hydrology*** ***Carbon and nitrogen cycles***

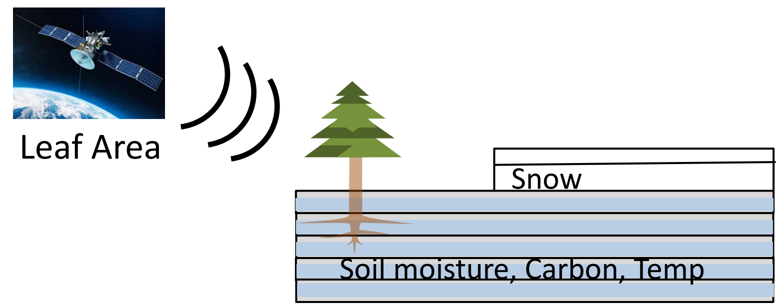




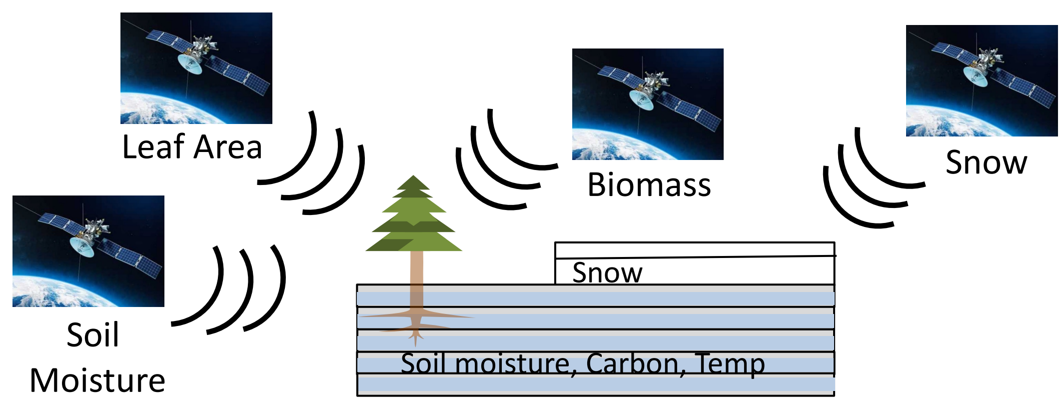


CLM-BGC (Biogeochemistry)
- No external constraints
- Prognostic
- Initial & boundary conditions, parameter/structural error

CLM-SP (Satellite Phenology)
- Prescribed Leaf Area/Vegetation



CLM-DART
- 'Any' observed land surface property
- Uncertainty estimates



Data Assimilation Research Testbed

Expanding Earth System Observations

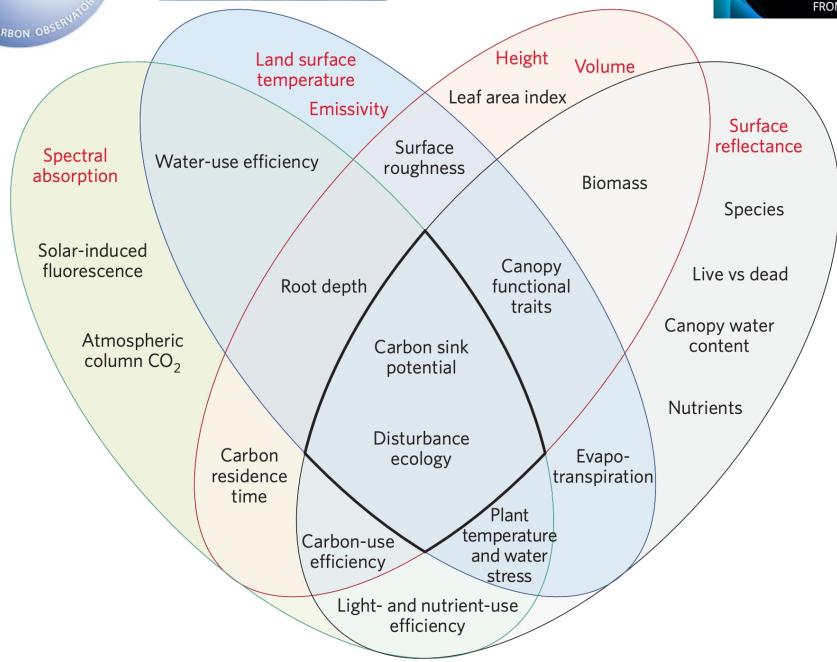
Remote Sensing Satellites

2019

2018

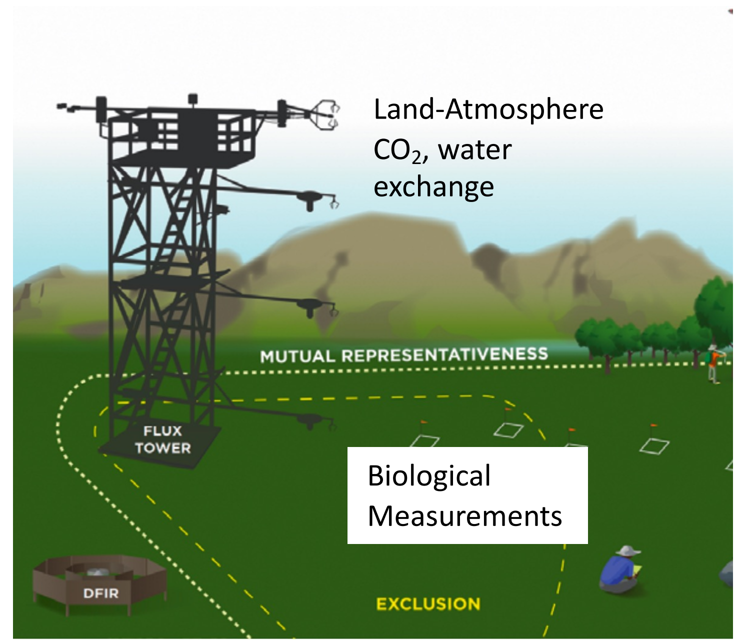
2018

2020



Stavros et al., (2017)

Ground Based Ecological Observation Networks: NEON, Ameriflux



Metzger et al., (2019)

Data Assimilation Research Testbed

CLM-DART Methodology

- Bayesian Approach

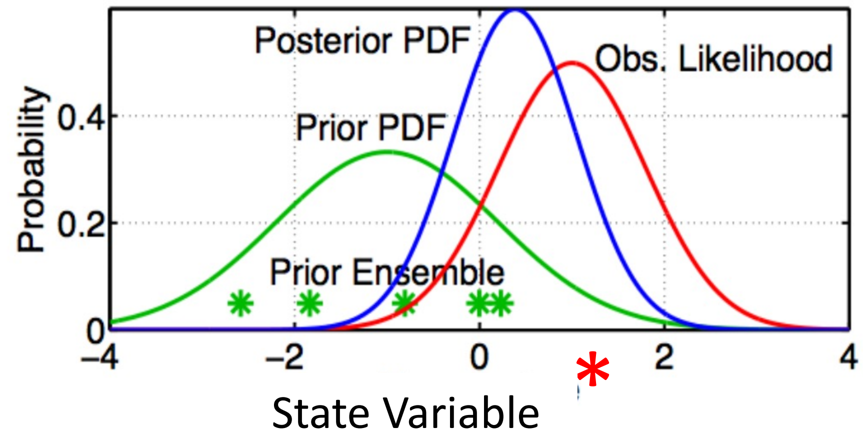
Posterior ~ **Prior** · **Observation Likelihood**

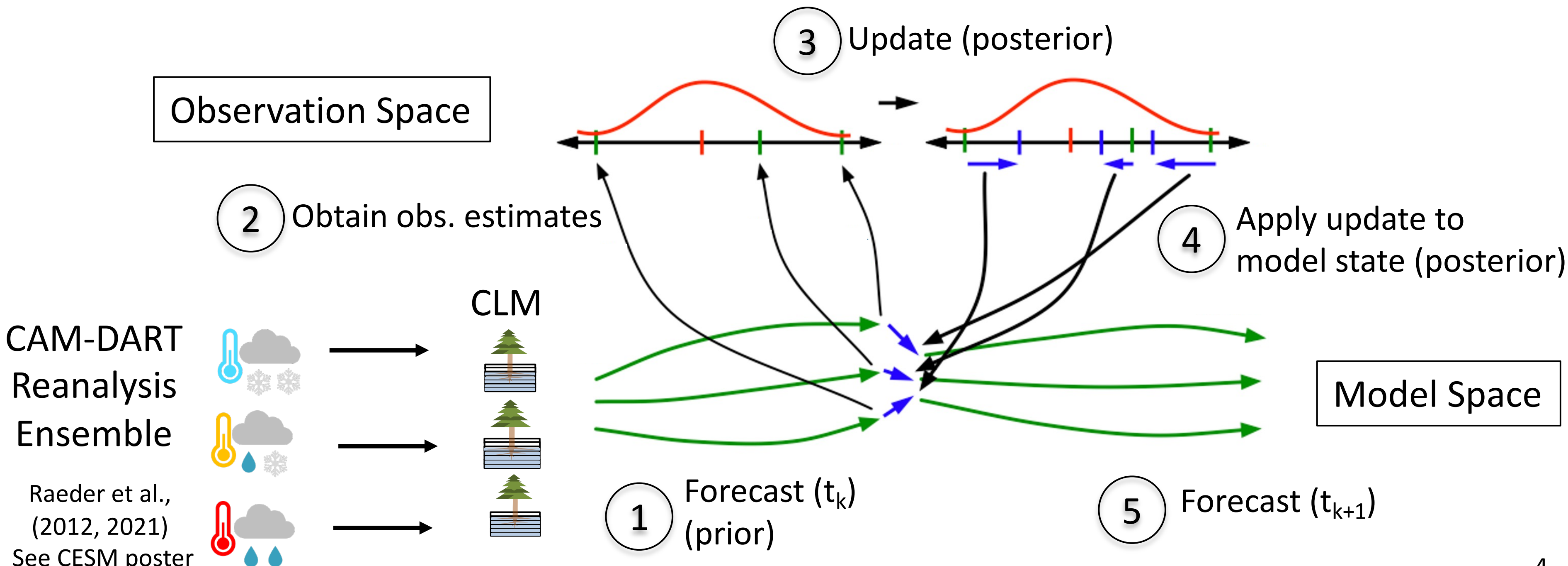
'Analysis'
'Update'

CLM generated forecast

Earth System Observations

e.g. satellite, surface data



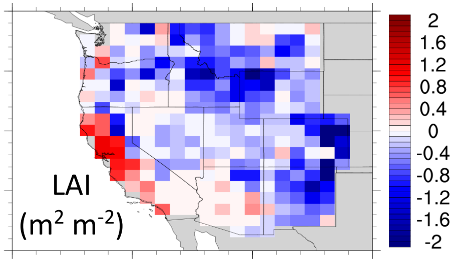


Improving simulated leaf area and biomass

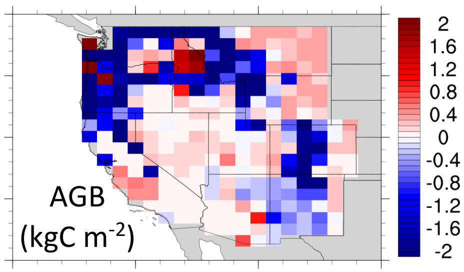
Western US

(CLM5_DART) – CLM5

LAI (m^2 m^{-2})



AGB (kgC m^{-2})



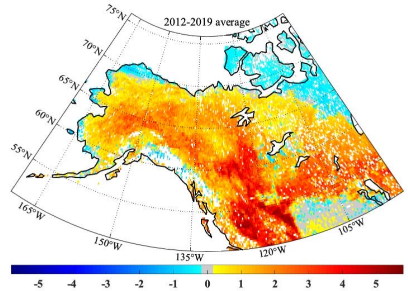
Yrs: 1998-2010 (Raczka et al., 2021)

30 % reduction

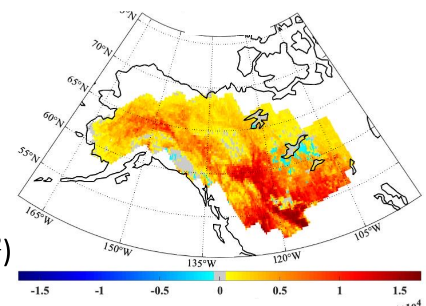
Arctic-Boreal

CLM5 – (CLM5_DART)

LAI (m^2 m^{-2})



AGB (gC m^{-2})



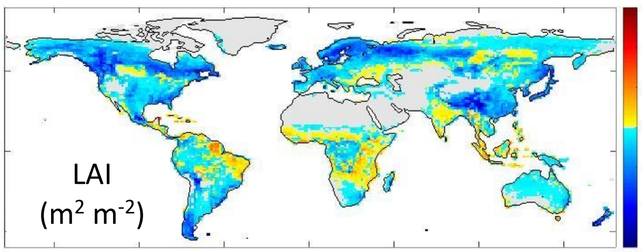
Yrs: 2011-2019, (X. Huo et al., in prep)

30 & 70 % reduction

Globe

(CLM5_DART) – CLM5

LAI (m^2 m^{-2})



(Fox et al., in revision)

Yrs: 2006-2010

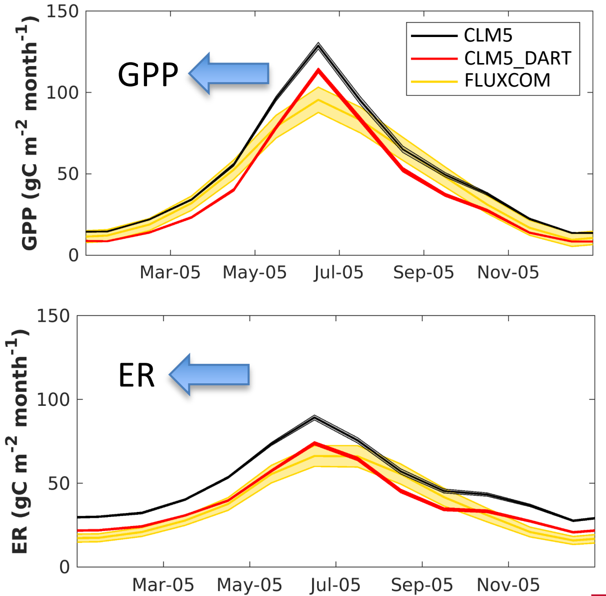
**LAI obs assimilated only

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

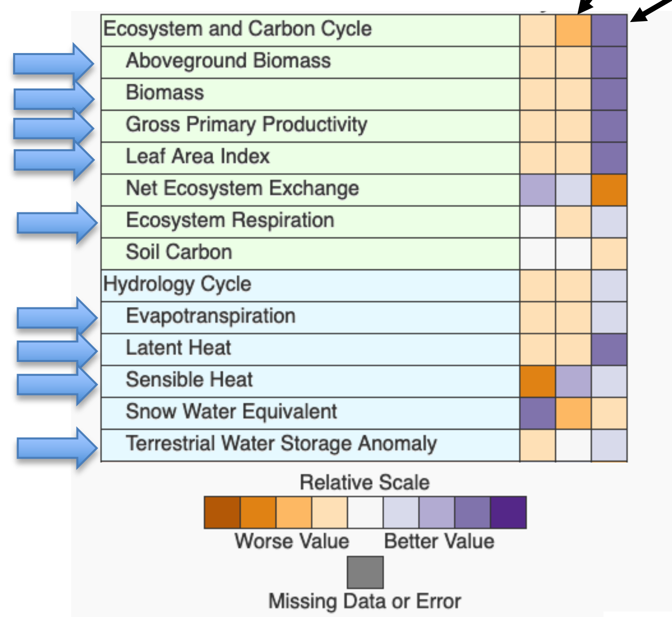


(Raczka et al., 2021)

Arctic-Boreal

CLM5

CLM5_DART



(X. Huo et al., in prep)

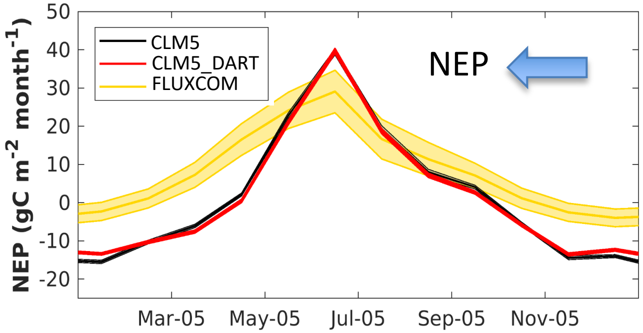
ILAMB Benchmarking Software: Bias and RMSE

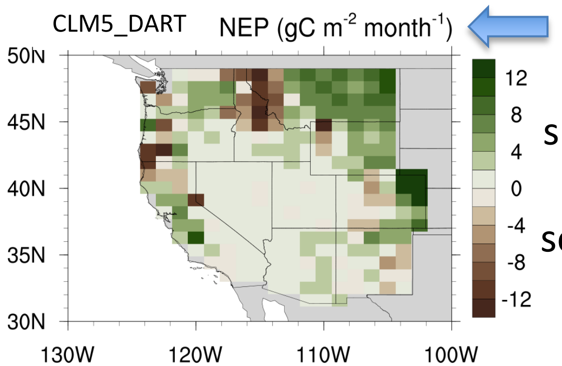
(Collier et al., 2018)

- Assimilating leaf/biomass brings simulated carbon and water cycling metrics in closer agreement with benchmarks

Impact of leaf/biomass on carbon/water cycle

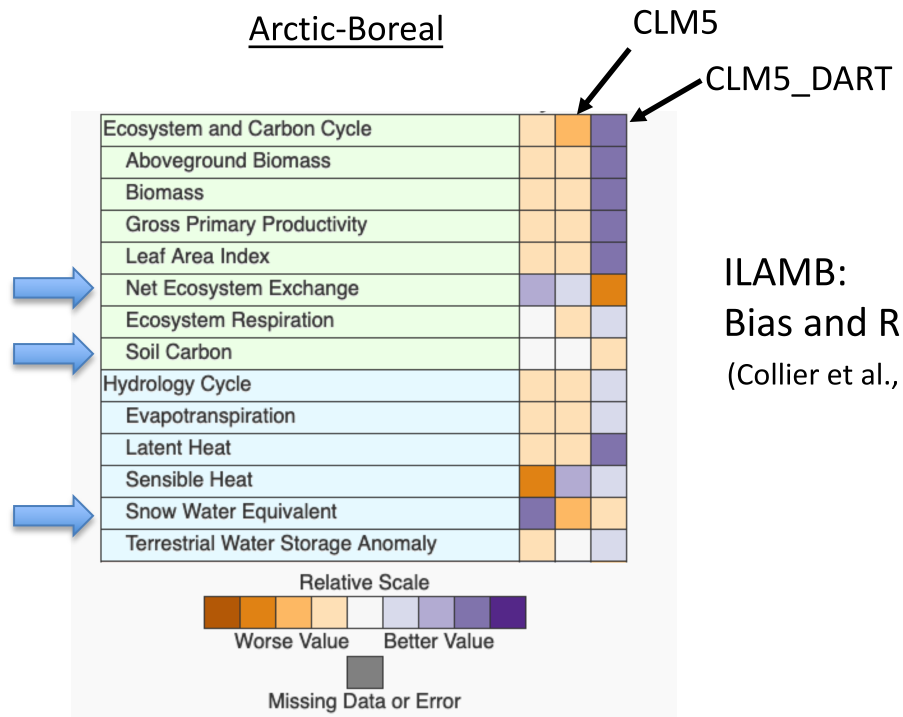
Western US





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

Arctic-Boreal



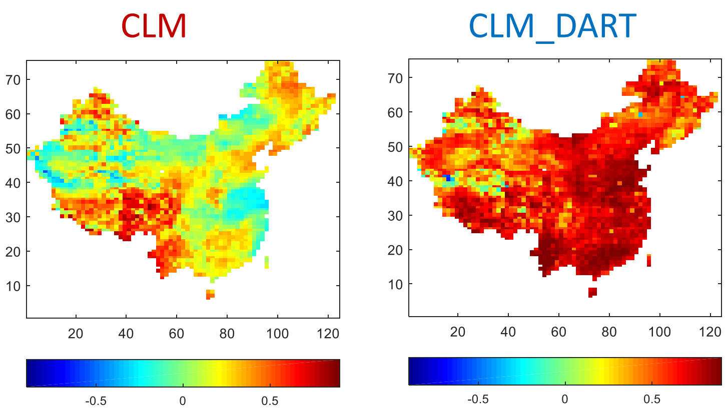
ILAMB:
Bias and RMSE
(Collier et al., 2018)

Additional Data Streams:

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

Impact of Soil Moisture observations

Correlation w/ ERA5 Near Surface Soil Moisture



D. Hagan et al, (in prep)

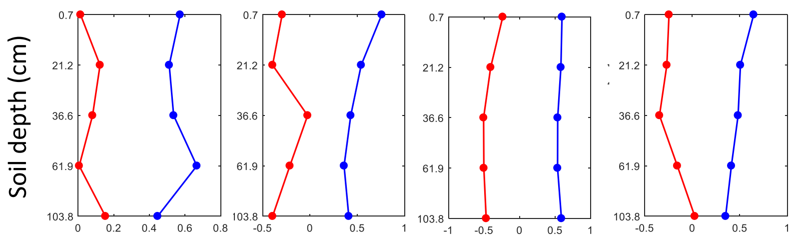
CLM:	CLM4.5 free run (no observations)
CLM_DART:	CLM4.5 + ECV-CCI observations

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

Site Level Sub-Surface Soil Moisture Correlation (1-100 cm)

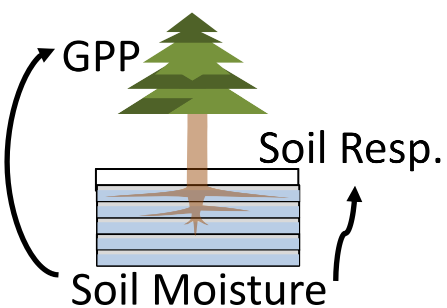
CLM

CLM_ DART

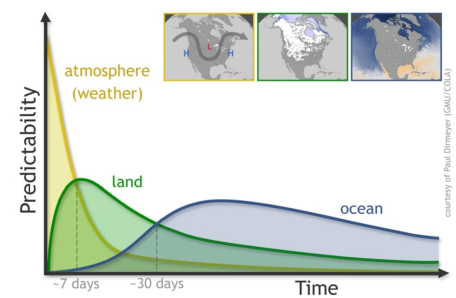


- CLM_DART also improves subsurface soil moisture correlation with in-situ site observations

- Impact upon land-atmosphere carbon cycling?



- Earth System Prediction Working Group (S2S Prediction)



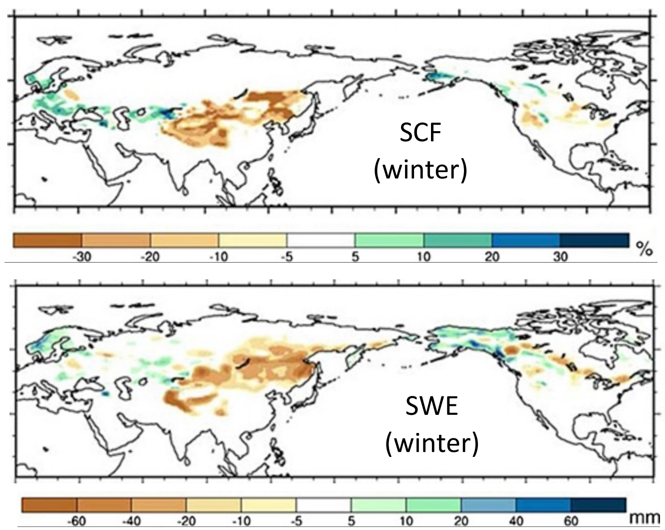
Snow observations

<u>Observation:</u>

MODIS
Snow
Cover
Fraction

Zhang et al.,
(2014)

(CLM4_DART) – CLM4

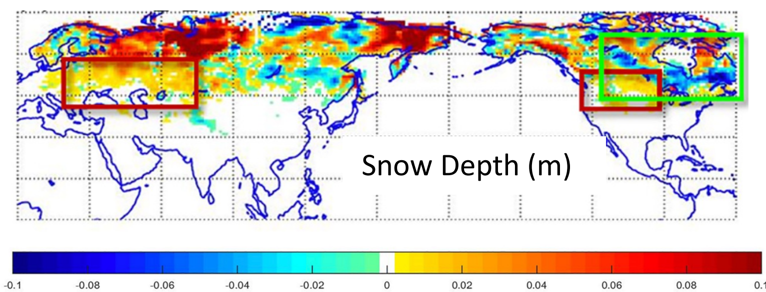


<u>Observation:</u>

MODIS SCF
GRACE TWS

Zhao and Yang
(2018)

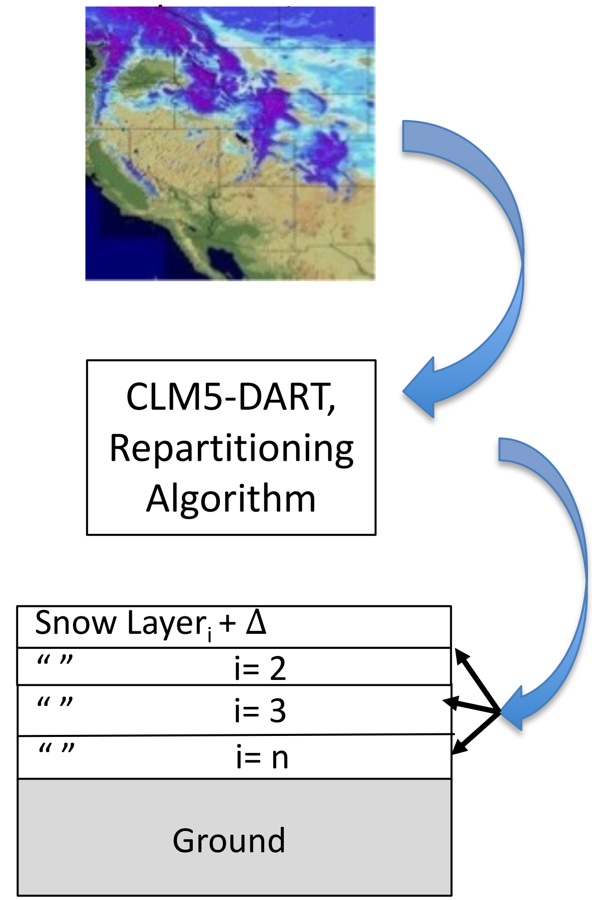
CLM4 – (CLM4_DART)



RMSE

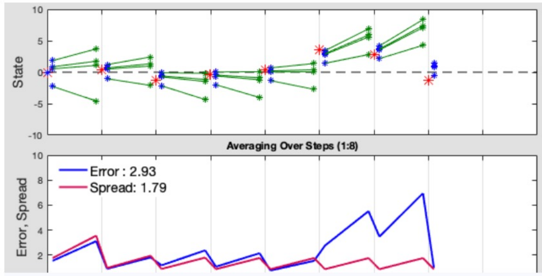
worse better

Snow Water
Equivalent (SWE)



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

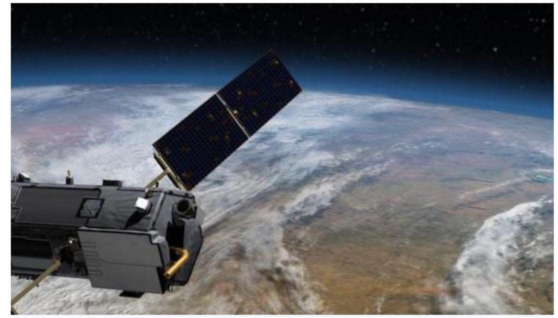
DART Tutorials



MATLAB

DART LAB

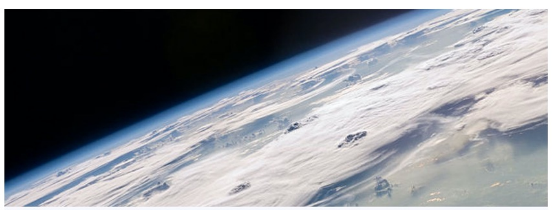
An introduction to Data Assimilation using MATLAB DART_LAB is a MATLAB®-based tutorial to demonstrate the principles of ensemble data assimilation. The DART_LAB tutorial begins at a more introductory level than the materials in the tutorial directory, and includes hands-on exercises. ...



Fortran

The DART tutorial

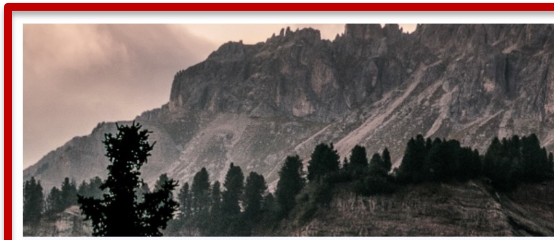
The DART Tutorial is intended to aid in the understanding of ensemble data assimilation theory and consists of step-by-step concepts and companion exercises with DART. ...



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. ...

Data Assimilation Research Testbed

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

CLM5-DART Tutorial

Downloading, setup, run, diagnostic steps:

- Step 1: Download CLM5
- Adding CLM5 SourceMods
- Compiling CLM5
- Step 2: Download DART
- Step 3: Navigating DART Scripts
- Step 4: Compiling DART
- Step 5: Setting up the atmospheric forcing
- Step 6: Setting up the initial conditions for land earth system properties
- **Step 7: Setting up the observations to be assimilated**
- Step 8: Setting up the DART and CLM states
- Step 9: Set the spatial localization
- Step 10: Set the Inflation
- Step 11: Complete the Assimilation Setup
- Step 12: Execute the Assimilation Run
- Step 13: Diagnose the Assimilation Run

Instructions, script examples, and definitions:

In this tutorial we have several observation types that are to be assimilated, including `SOIL_TEMPERATURE`, `MODIS_SNOWCOVER_FRAC`, `MODIS_LEAF_AREA_INDEX` and `BIOMASS`. To enable the assimilation of these observations types they must be included within the `&obs_kind_nml` within the `input.nml` file as:

```
&obs_kind_nml
  assimilate_these_obs_types = 'SOIL_TEMPERATURE',
                               'MODIS_SNOWCOVER_FRAC',
                               'MODIS_LEAF_AREA_INDEX',
                               'BIOMASS',
  evaluate_these_obs_types   = 'null'
  /
```

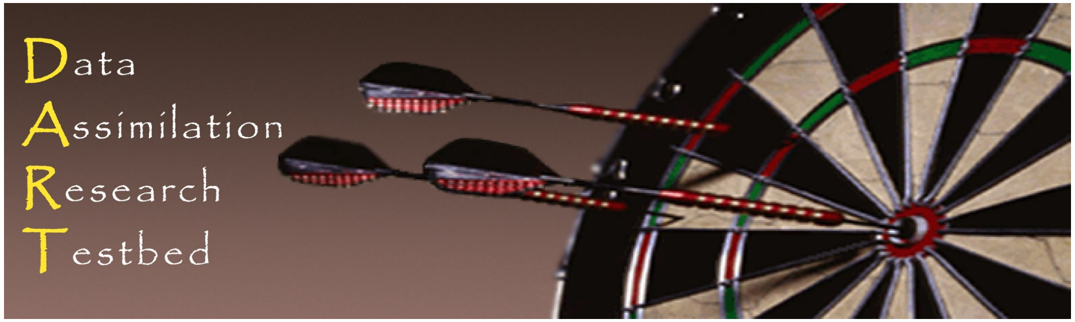
Observation Sequence File Variable	Description
observation sequence number	The chronological order of the observation within the observation sequence file. This determines the order in which the observation is assimilated by DART for a given time step.
observation value	The actual observation value that the DART `filter` step uses to update the CLM model. This is derived from the true observation value generated from CLM model output with uncertainty added.
true observation value	The observation generated from CLM output. In this case the observation was generated as part of a perfect model experiment (OSSE; Observing System Simulation Experiment), thus the 'true' value is known.
observation quality control	The quality control value provided from the data provider. This can be used as a filter in which to exclude low quality observations from the assimilation.

For more information:

CAM GCOM CAM-Chem FESOM ROMS WRF

GITM CABLE WRF-Hydro WACCM

CLM



POP

AM2

BGRID

SQG

https://dart.ucar.edu

COAMPS NOAH

https://docs.dart.ucar.edu

dart@ucar.edu

NCOMMAS PE2LYR

MITgcm_ocean COAMPS_nest

WRF-Chem

NAAPS TIEGCM MPAS_ATM

MPAS_OCN

WACCM-X PBL_1d NOAH-MP

CISL Computational & Information Systems Lab

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