Next-Generation Data Assimilation Capabilities to Increase the Value of Terrestrial Observations

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Project Description

- **Objectives:**

  1. Implement in the NASA Land Information System a method to use remote sensing (RS) observations to understand systematic deficiencies in dynamic predictions. TRL 2 to 3

  2. Perform a SMAP OSSE

- **Broader questions to keep in mind:**
  - ✦ What kinds of information do we need?
  - ✦ What kinds of information do we currently extract from RS observations?
  - ✦ How to better address information requirements?

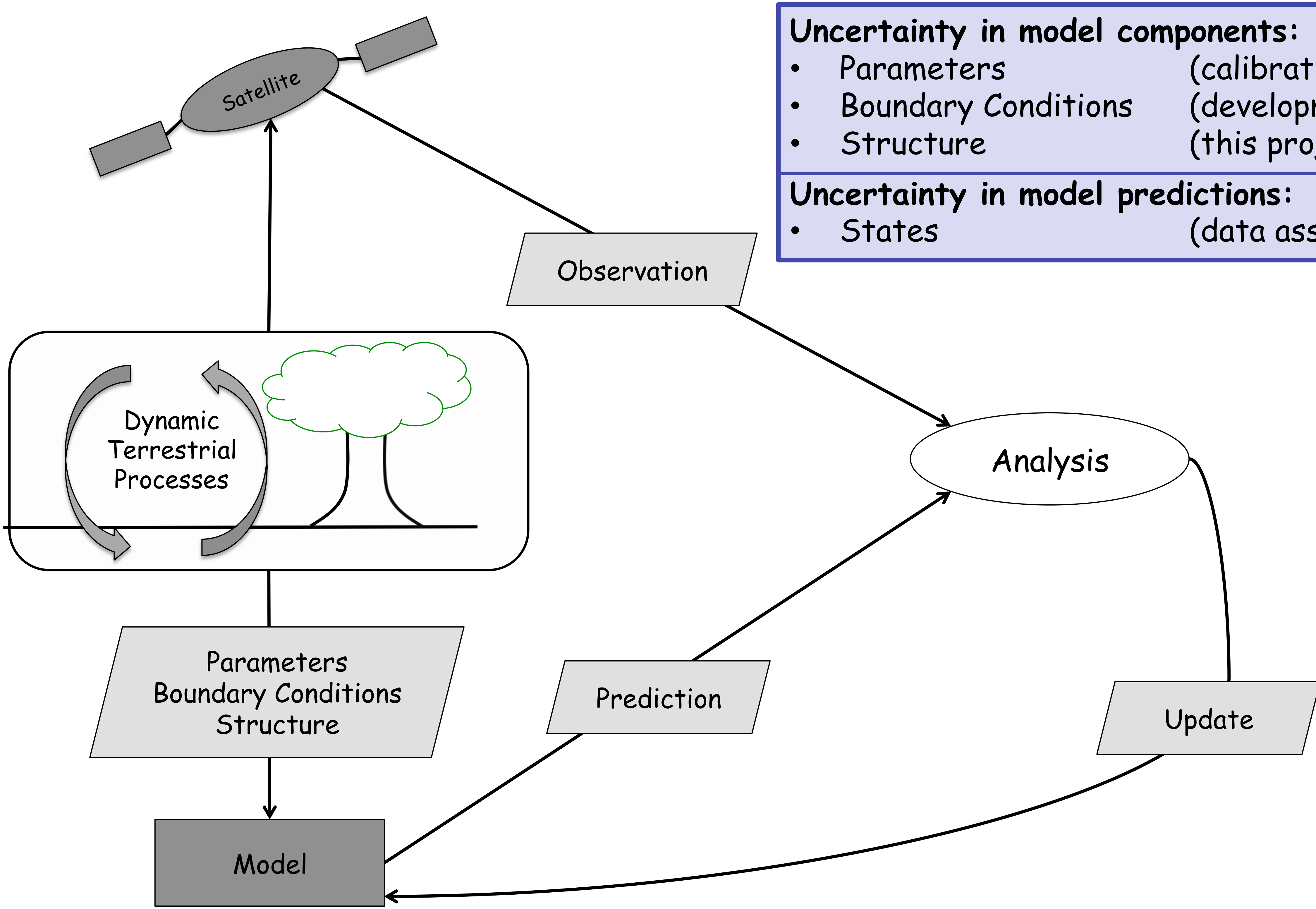
What Information Do We Need?

Uncertainty in model components:

- Parameters (calibration)
- Boundary Conditions (developmental)
- Structure (this project)

Uncertainty in model predictions:

- States (data assimilation)



How We Use Observations

Background

- Prior Information

$$p(\mathcal{S}, \theta, U)$$

- Predictions

$$p(X|\mathcal{S}, \theta, U)$$

- Parameters (θ)
- Boundary Conditions (U)
- Structure (S)
- States (X)
- Observations (Y)

- Bring in Observations (Data Assimilation)

Incorrect!

$$p(X|\mathcal{S}, \theta, U, Y) \propto p(Y|X, \mathcal{S}, \theta, U)p(X|\mathcal{S}, \theta, U)$$

- But we learned nothing about the system!

$$p(\mathcal{S}, \theta, U|Y)$$

- Better predictions are:

Correct!

$$p(X|Y) = \int p(X|\mathcal{S}, \theta, U, Y)d\mu(\mathcal{S}, \theta, U|Y)$$

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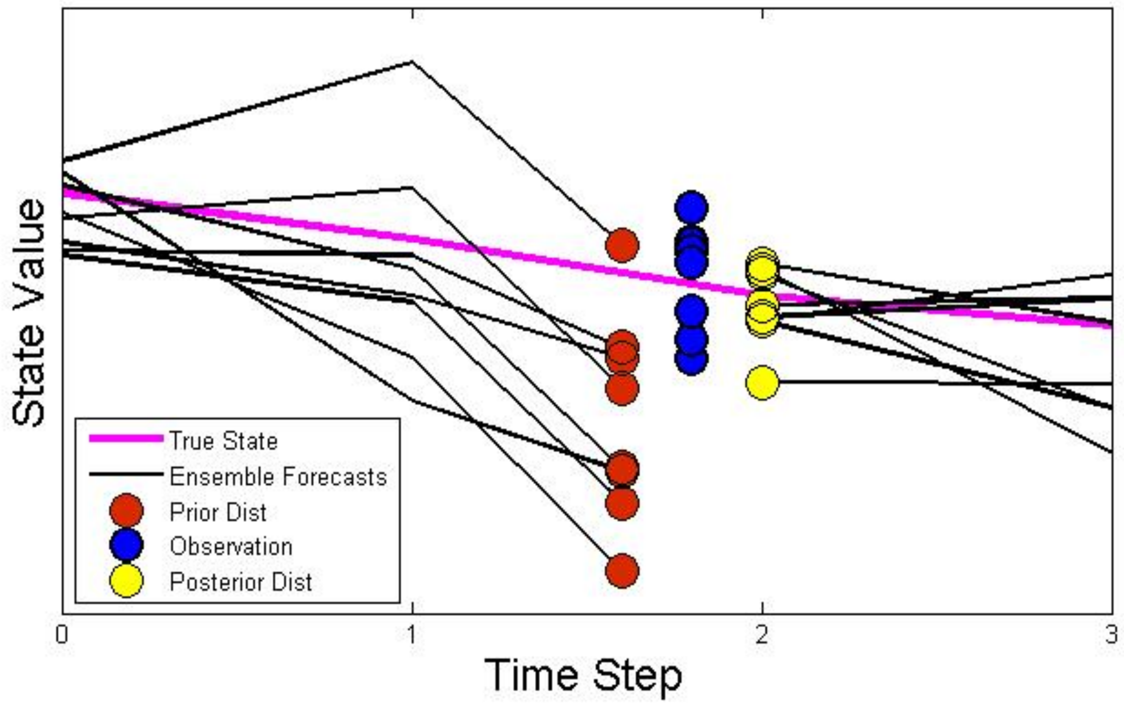
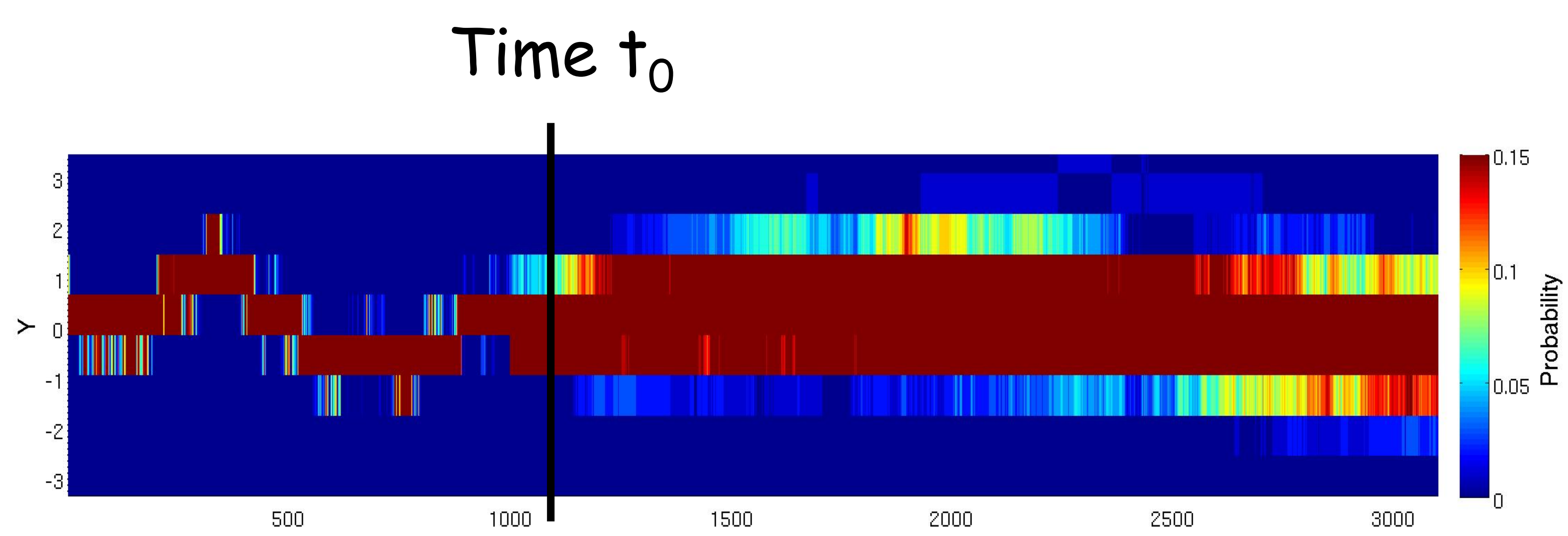
Data Assimilation Shortcomings

The Ensemble Kalman Filter



Does not address underlying issues that cause uncertainty!

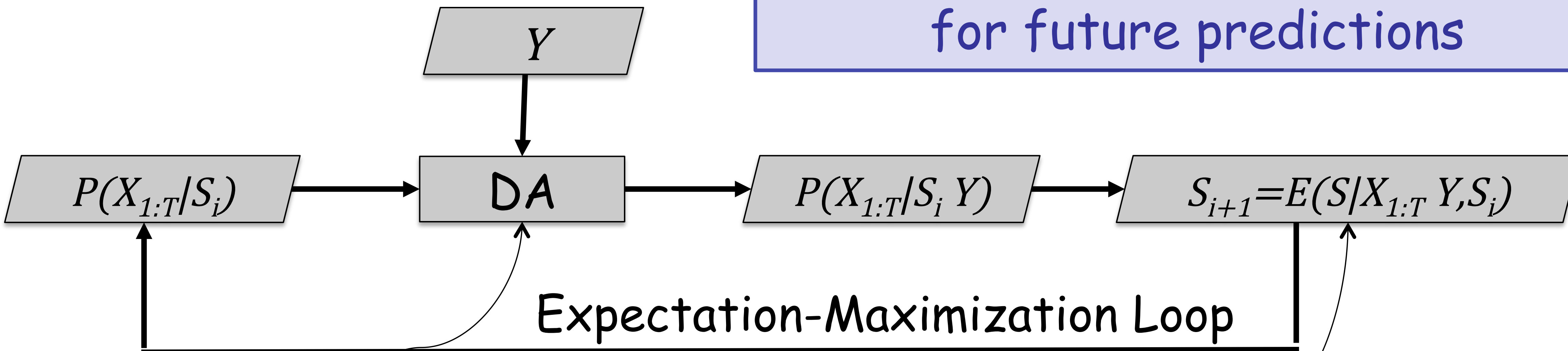
Reverts back to model prior during prediction period

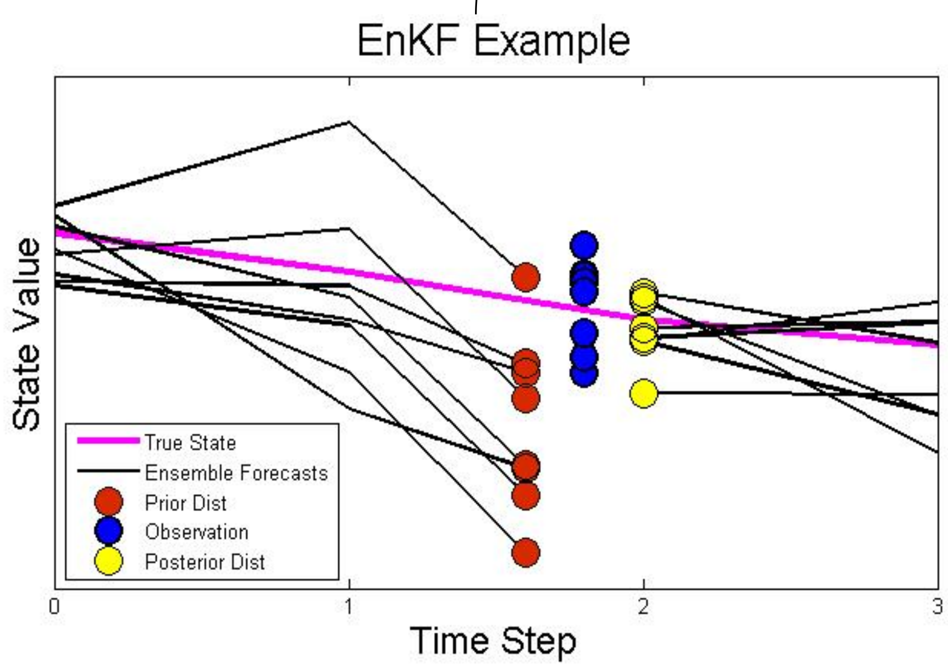


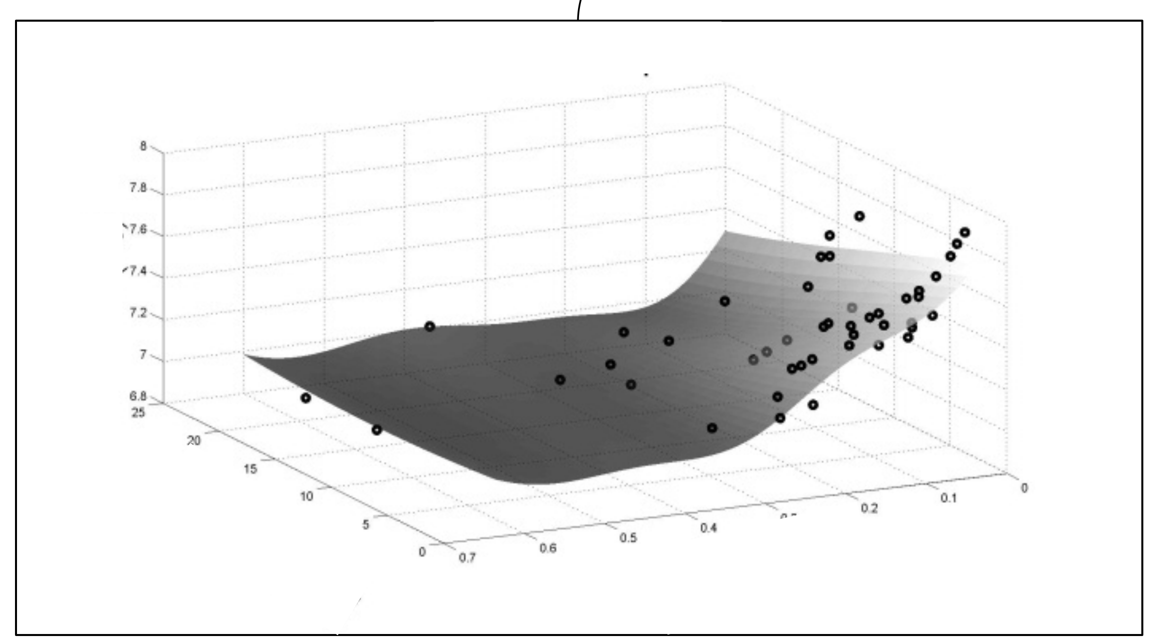
Use Observations to Improve Model Structure

Methods

Allows us to store information from RS obs in model structure for future predictions







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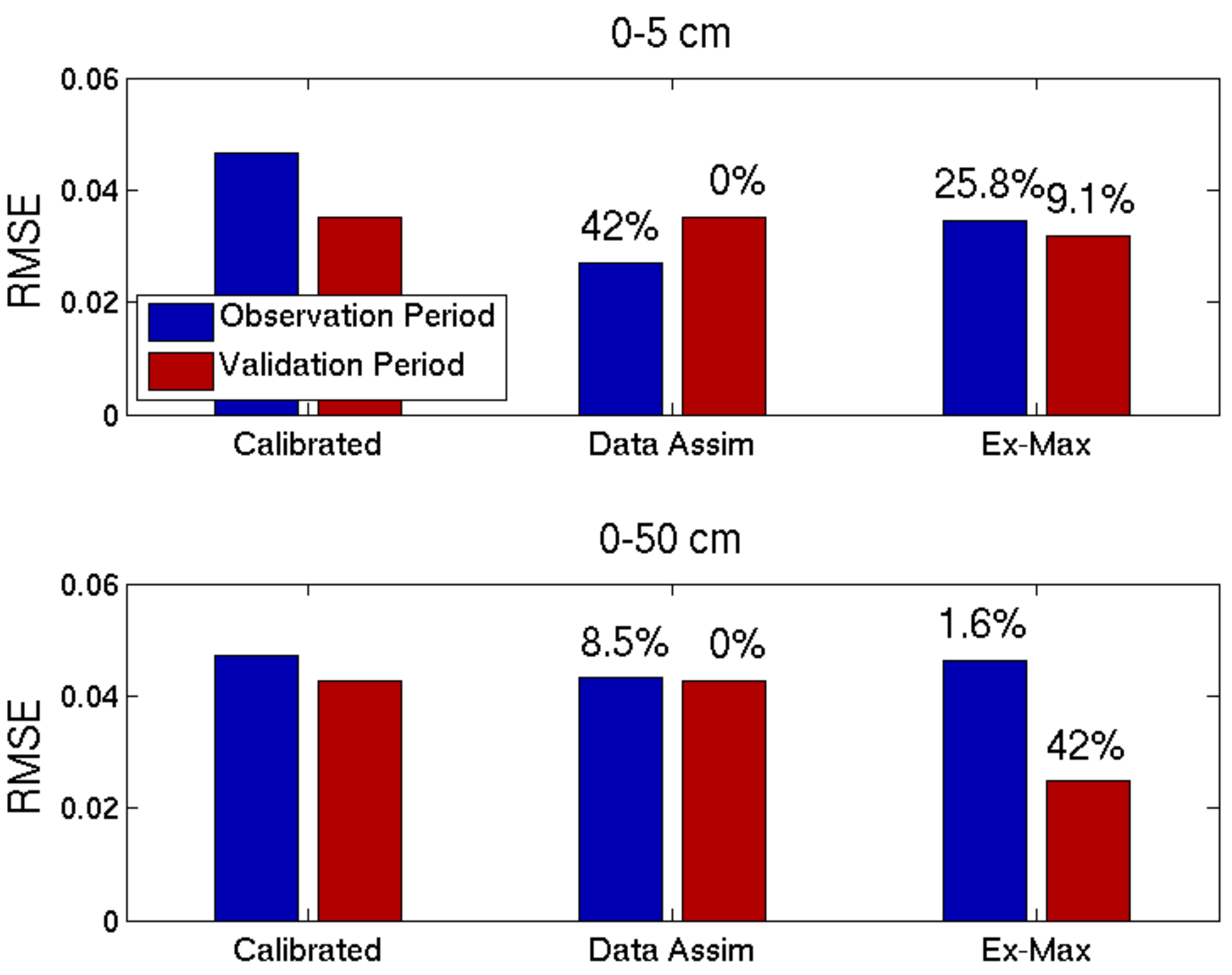
SMAP OSSE - Structure Estimation

Results

- **OSSE Parameters:**
  - NOAH land surface model
  - Synthetic obs from in situ soil moisture sensors Delta Peach Orchard, Alabama
    - 5 cm depth
    - 3 day obs frequency
    - σ = 0.04
  - Obs period: 2 years (hourly obs freq)
  - Val period: 2 years (hourly obs freq)

1. **Calibrate the model** – extract obs info about parameters.
2. **Perform DA** – extract obs info about structural error and errors in boundary conditions.
3. **Perform Ex-Max System Identification** – isolate systematic improvements from DA.

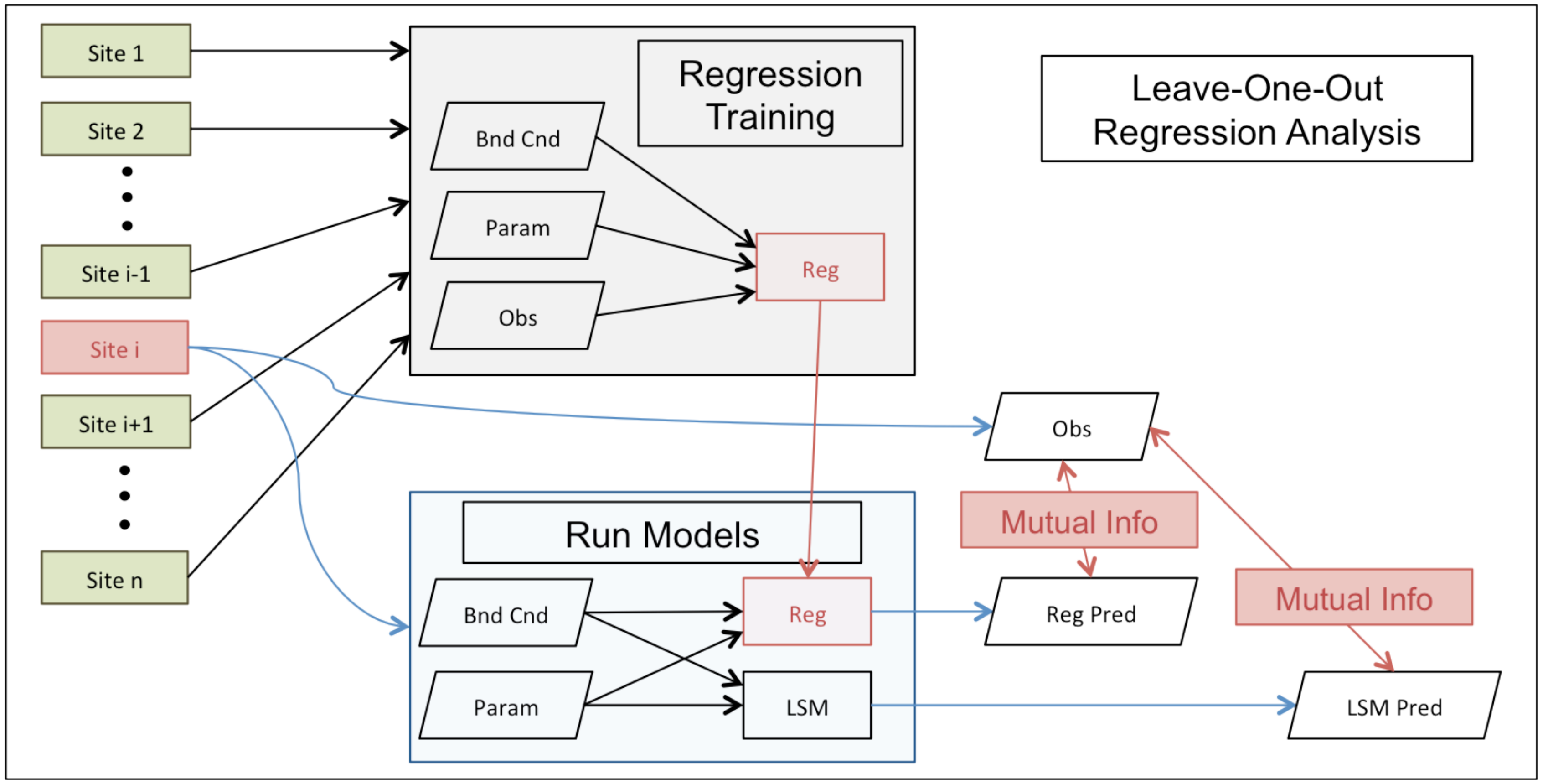


Ex-Max System Identification can:
- Isolate obs info about systematic model structural errors
- Use this info to update the model in a way that provides long-term improvements in model predictions.

- **We can measure information missing from all three model components:**
- **Boundary Conditions:** Create a Kernel Density Function using data from a single site that maps boundary conditions to observations of the quantity we want to predict. Errors in predictions made by this model represent uncertainty caused by information missing from B.C.s.
- **Parameters:** Using data from multiple sites, create a KDF that maps parameters + B.C.s to observations. Errors made by this model represent uncertainty caused by information missing from parameters + B.C.s.
- **Model Structure:** The extent to which the physics model does better or worse than the multi-site KDF represents information added or lost (due to model error) or added by the model's physics.

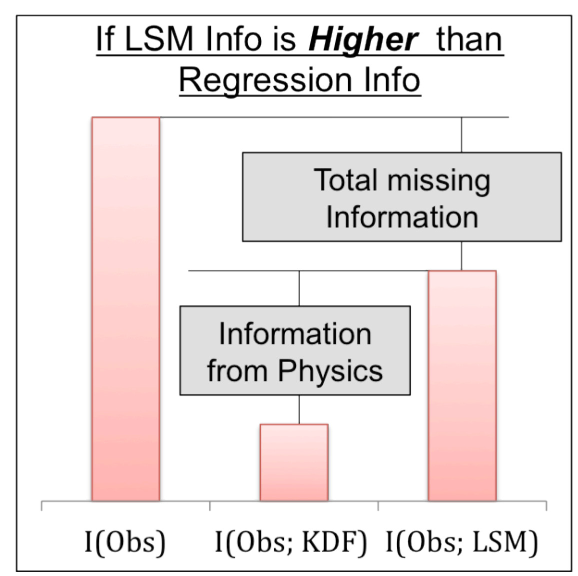
Measure Missing Information

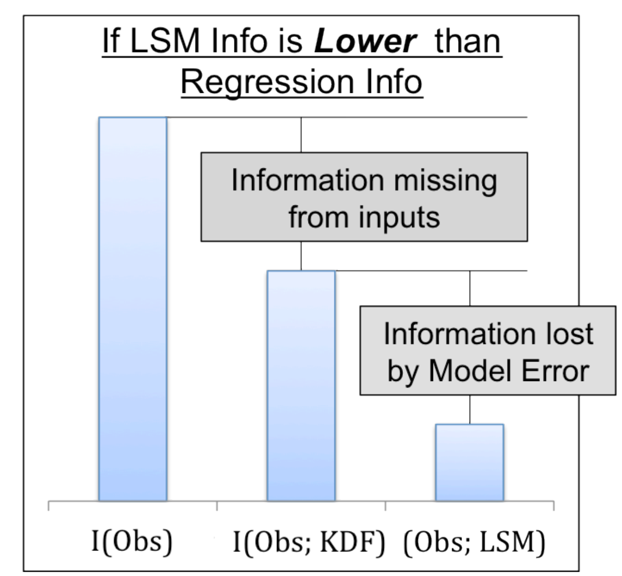
Methods



Can measure information missing from:

- Boundary Conditions
- Parameters
- Model Structure





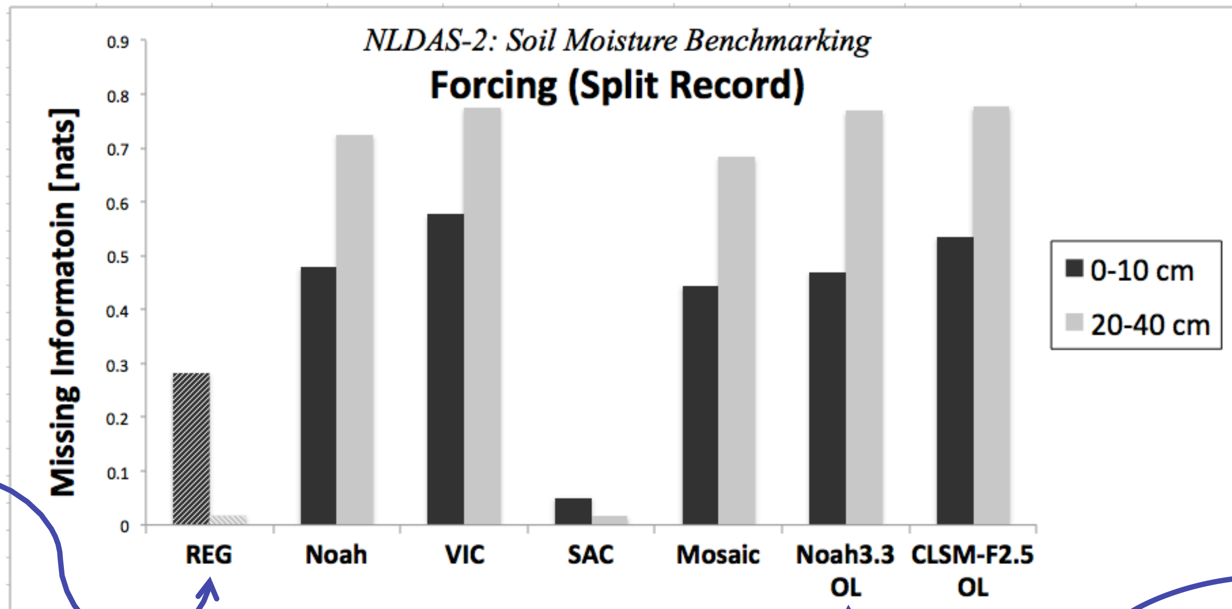
Measure Missing Information

Methods

In the soil moisture case, almost all uncertainty can be attributed to parameters.

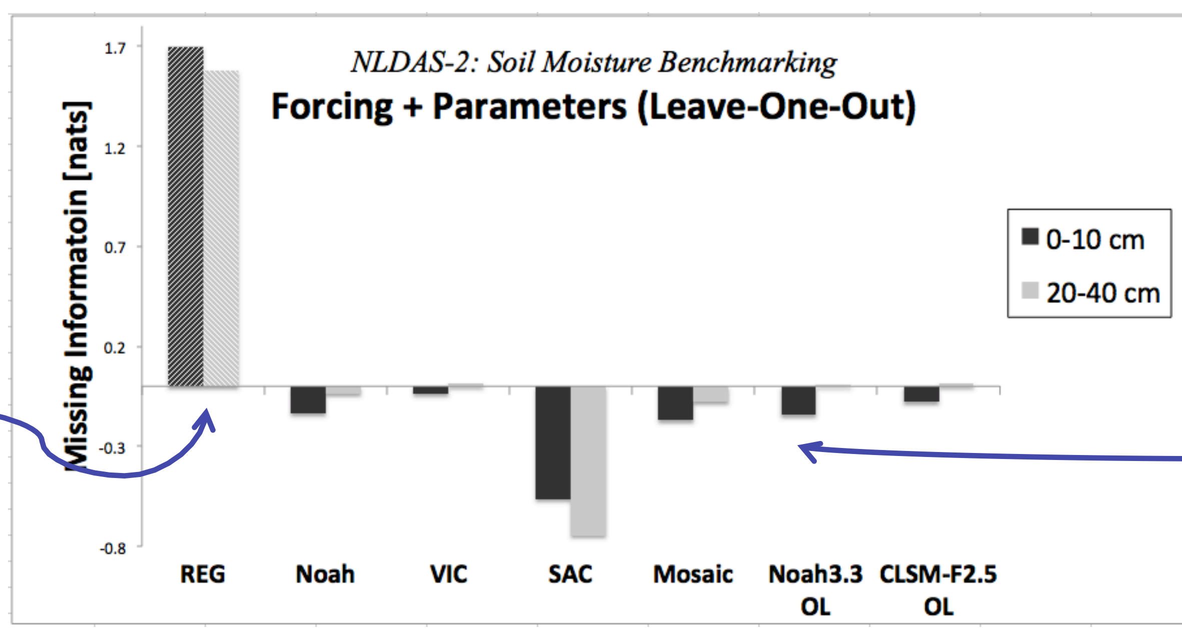
Very little information loss due to model structure.

Information missing from Boundary Conditions



Information from B.C.s lost due to errors in model physics and parameters

Information missing from Parameters + B.C.s



Information <u>gained</u> from Model Physics (structure)

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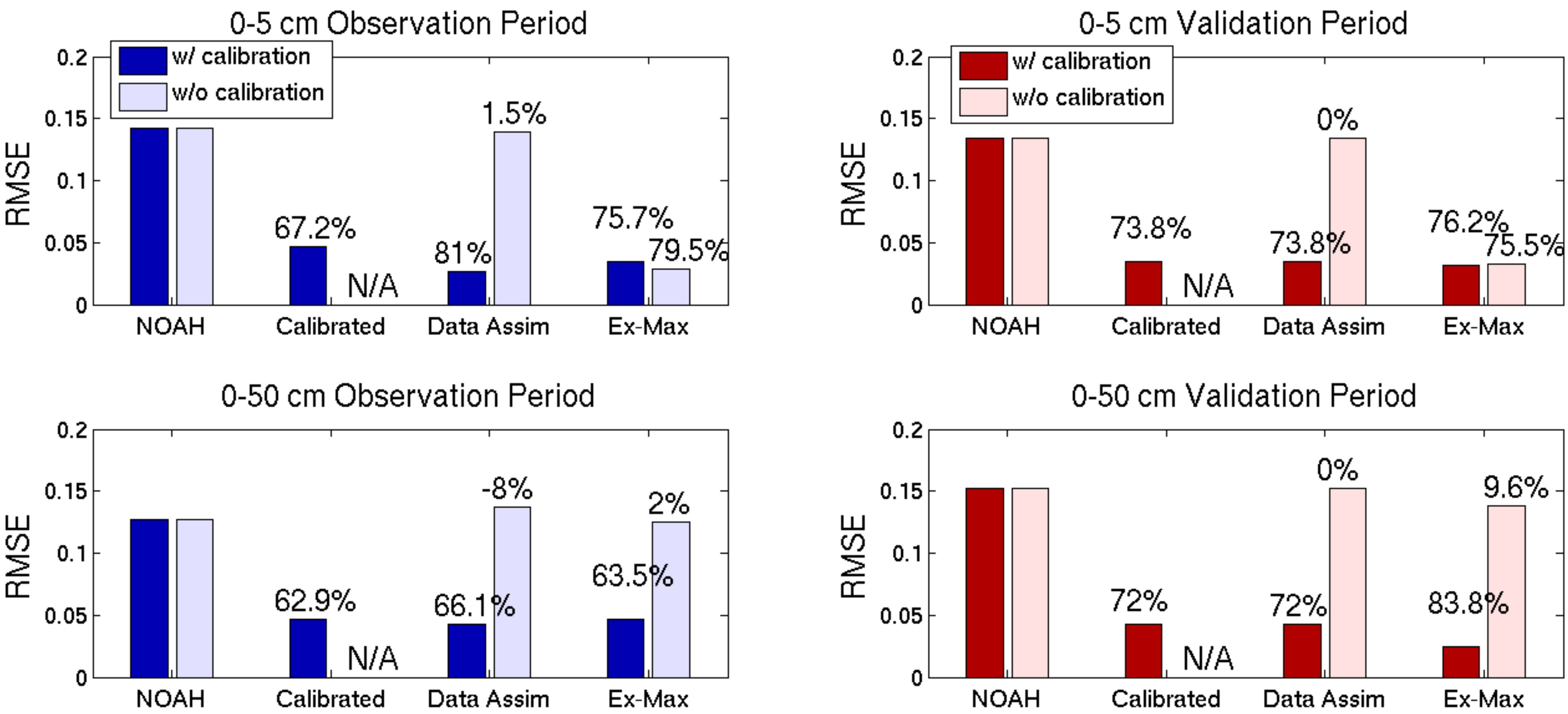
SMAP OSSE - Compare Methods to Extract Info

Results

How does structure estimation perform when used on calibrated vs. uncalibrated models?

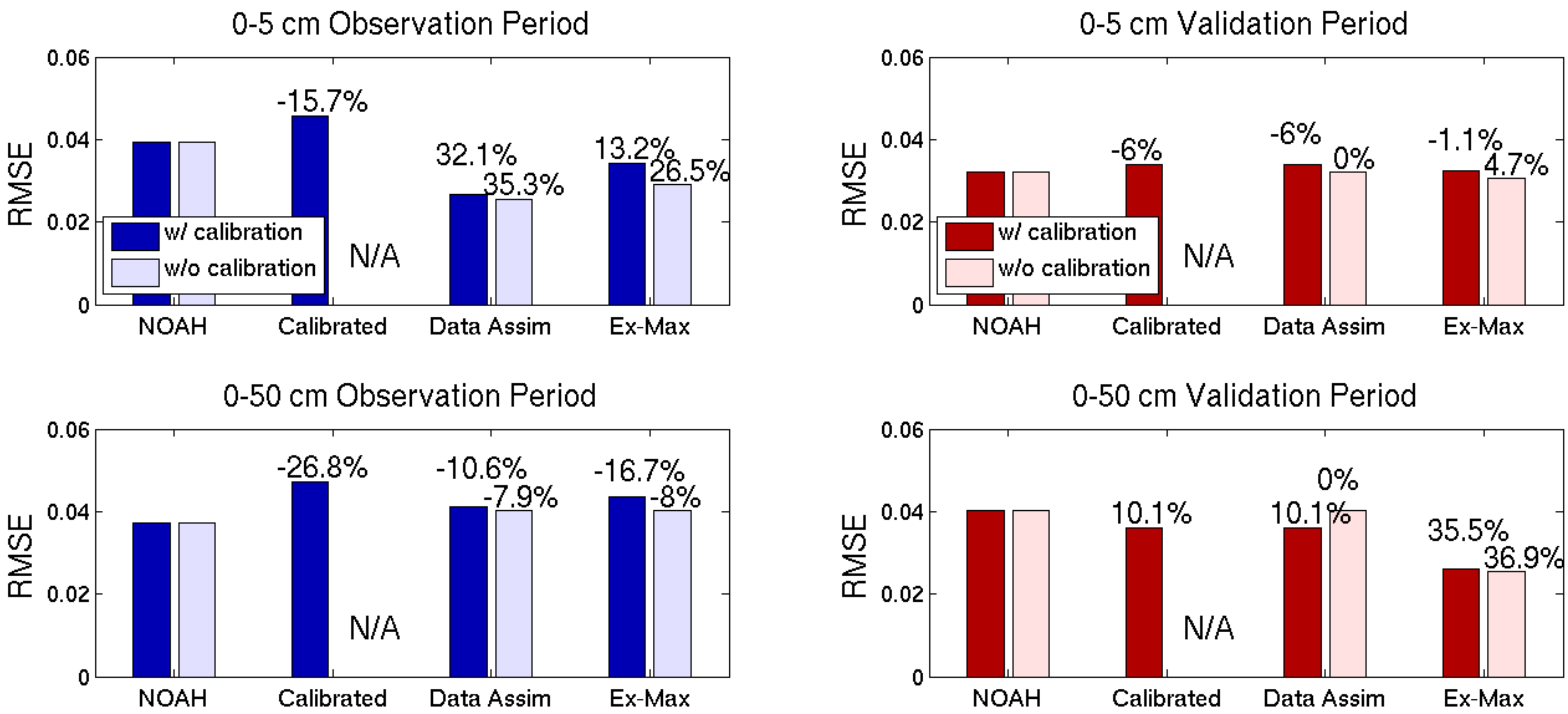


SMAP OSSE - Compare Methods to Extract Info

Results

In case we don't care about the bias …

Anomaly RMSE



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Takeaway Messages

- Data assimilation does not address fundamental sources of uncertainty:
  - Boundary Conditions
  - Parameters
  - Structure
- Can measure information missing from each of the three sources of uncertainty.
- This project tested a new strategy for dealing with Structure uncertainty (for any dynamical systems model):
  - Works well with and without parameter estimation.
  - Next step is to combine with B.C. estimation for full Bayesian solution.