Using Remotely-Sensed Estimates of Soil Moisture to Infer Soil Texture and Hydraulic Properties Across a Semi-Arid Watershed

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Collaborators

Army Remote Moisture System (ARMS)

Principle Investigators

- Christa Peters-Lidard – NASA-GSFC
- Susan Moran – USDA-SWRC
- David Goodrich – USDA-SWRC
- Scott Miller – Univ. of Wyoming

US Army Corps of Engineers
Topographic Engineering Center

University of Wyoming

NASA

ars

NASA's LAND INFORMATION SYSTEM (LIS)

- Matthew Garcia – GEST-UMBC/NASA-GSFC
- David Mocko – SAIC/NASA-GSFC
- Michael Tischler - US Army Corps of Engineers, TEC
- Dave Thoma – USDA-SWRC

LIS

What is ARMS?

Goal: To provide better input data for estimates of:

Soil Moisture & Hydraulic Properties

- Speed Calculations
- Troop and vehicle mobility
- Landing Strip Site Suitability
- Countermine Detection
- Any decision dependant on soil conditions

Components:

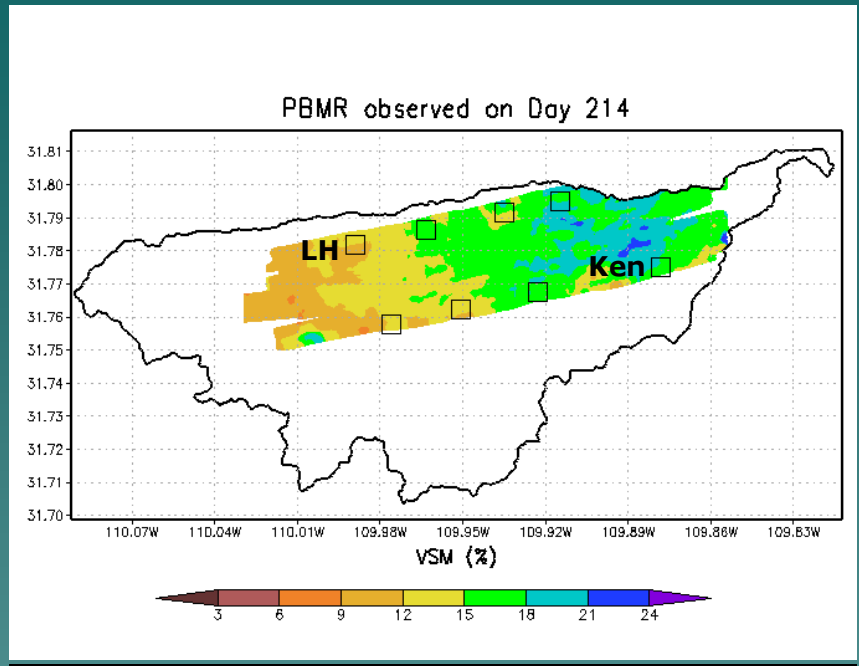
- Remote Sensing
- Land Surface Modeling (LIS)
- Parameter Estimation

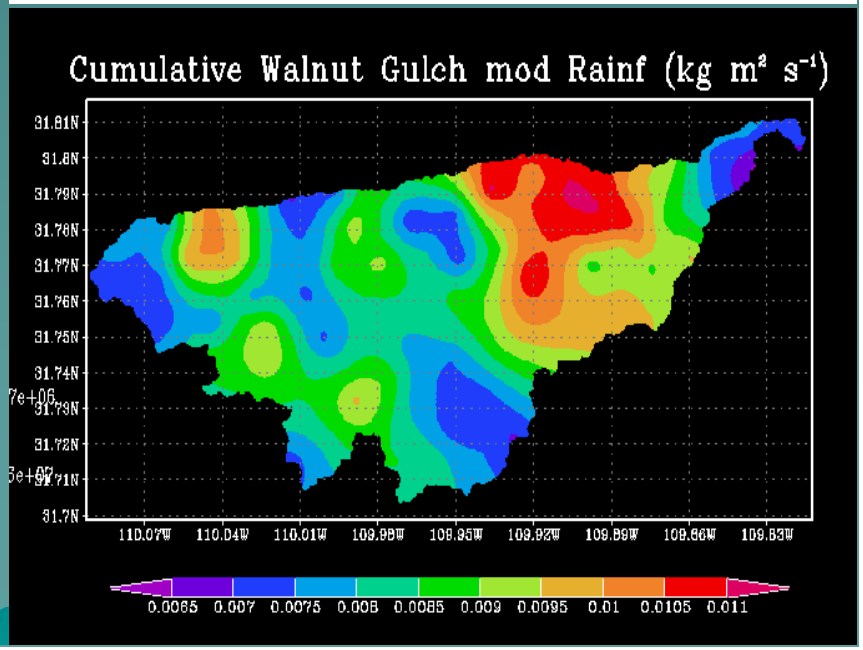
Monsoon '90 Field Experiment

- **Walnut Gulch Experimental Watershed**
  - Summer 1990; SE Arizona
  - 8 Metflux Sites
  - 2 Supersites
    - Kendall
    - Lucky Hills

- **Remote Sensing of Soil Moisture**
  - **Push Broom Microwave Radiometer (PBMR; L-band; 21cm)**
  - 6 Acquisition Dates; 31 July – 9 August
  - 40m resolution; 0-5 cm depth

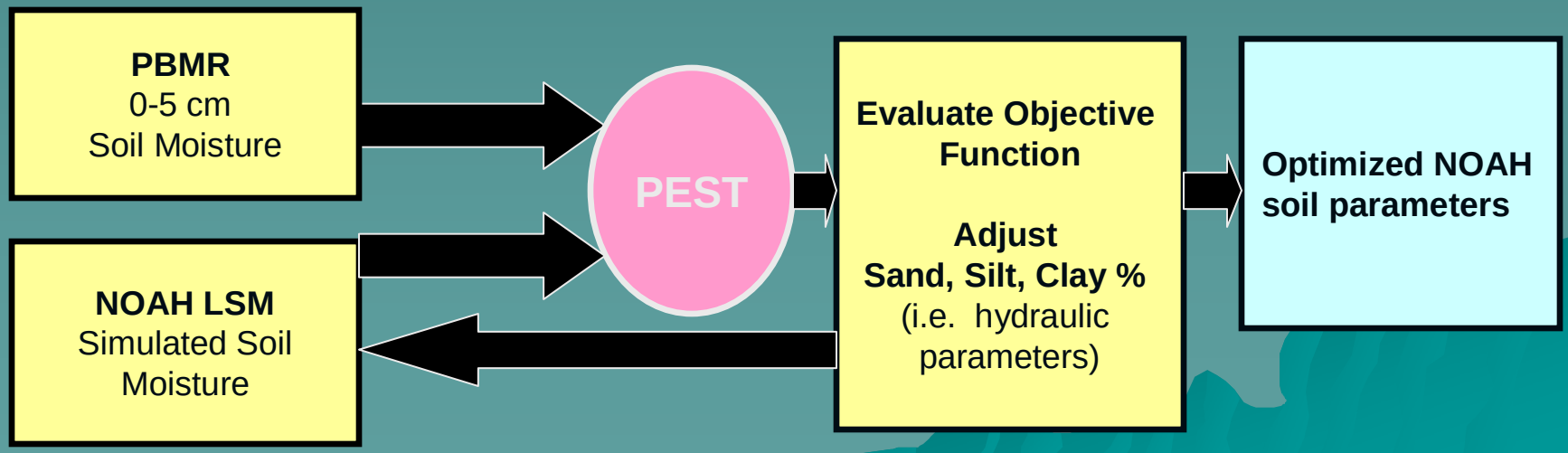
- **Noah Land Surface Model (LIS)**
  - → NASA's Land Information System
  - 22 July – 9 August 1990
  - Watershed-scale (40m resolution)
  - Meteorological Forcing: Kendall
  - Interpolated 84-gauge precipitation





Parameter Estimation - PEST

- PEST (Doherty et al. 2004) is a model-independent tool used to calibrate input parameters by minimizing an objective error function
- Error = **PBMR** (Observed) – **Noah LSM** (Modeled)
- Parameters: ~~Ksat / Porosity~~ ?
  Pedotransfer functions (PTFs)
  - Relate Sand, Silt, Clay % to hydraulic properties
  - Community Land Model (CLM2) & Cosby et al. (1984)



Research Objectives

1) Determine the ability of parameter estimation to calibrate a LSM using limited remote sensing estimates of soil moisture and PTFs to infer hydraulic properties.

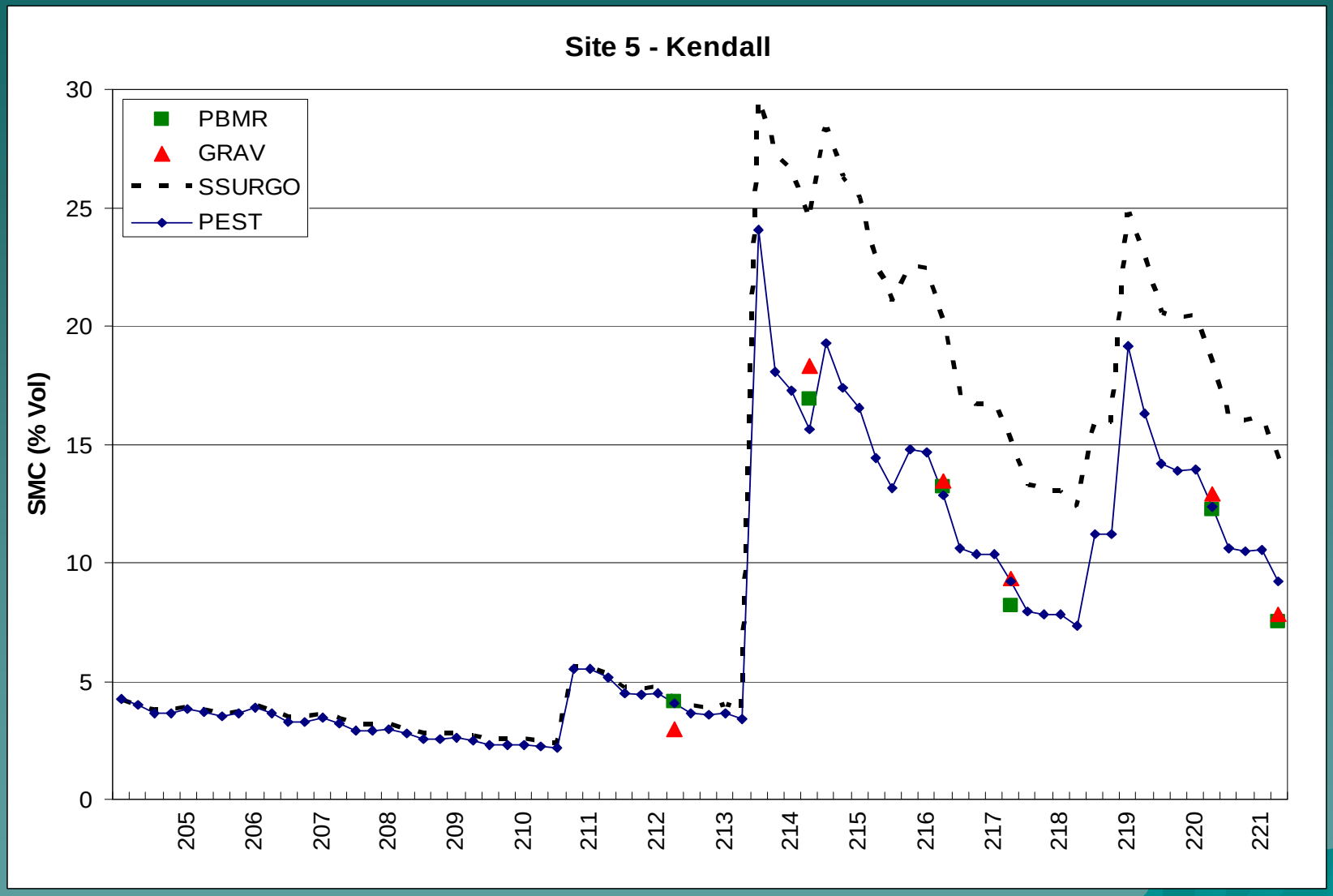
2) Determine the sensitivity of the calibration process to precipitation and soil drydown patterns using temporal and spatial sampling of input data.

   - ***How many*** and ***which*** PBMR images are required?
   - What ***quality*** of precipitation data is required?

3) Apply and compare methodology and optimized parameters to an independent dataset and active remote sensing data.

   - Are retrieved ***soil texture*** and ***hydraulic properties*** physically meaningful or applicable outside of this study?

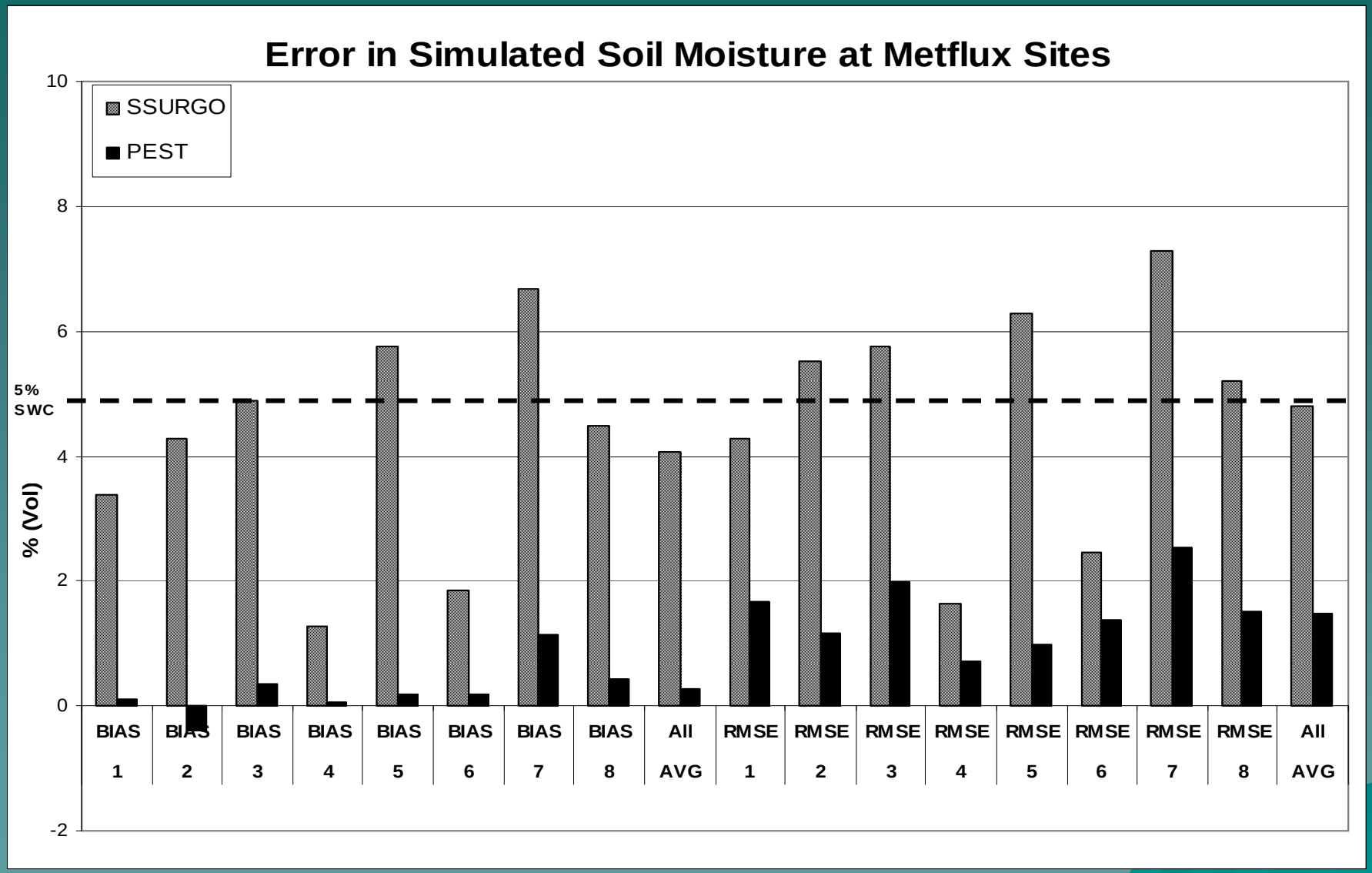
Calibration Results



PEST = Noah calibrated using PEST and PTFs

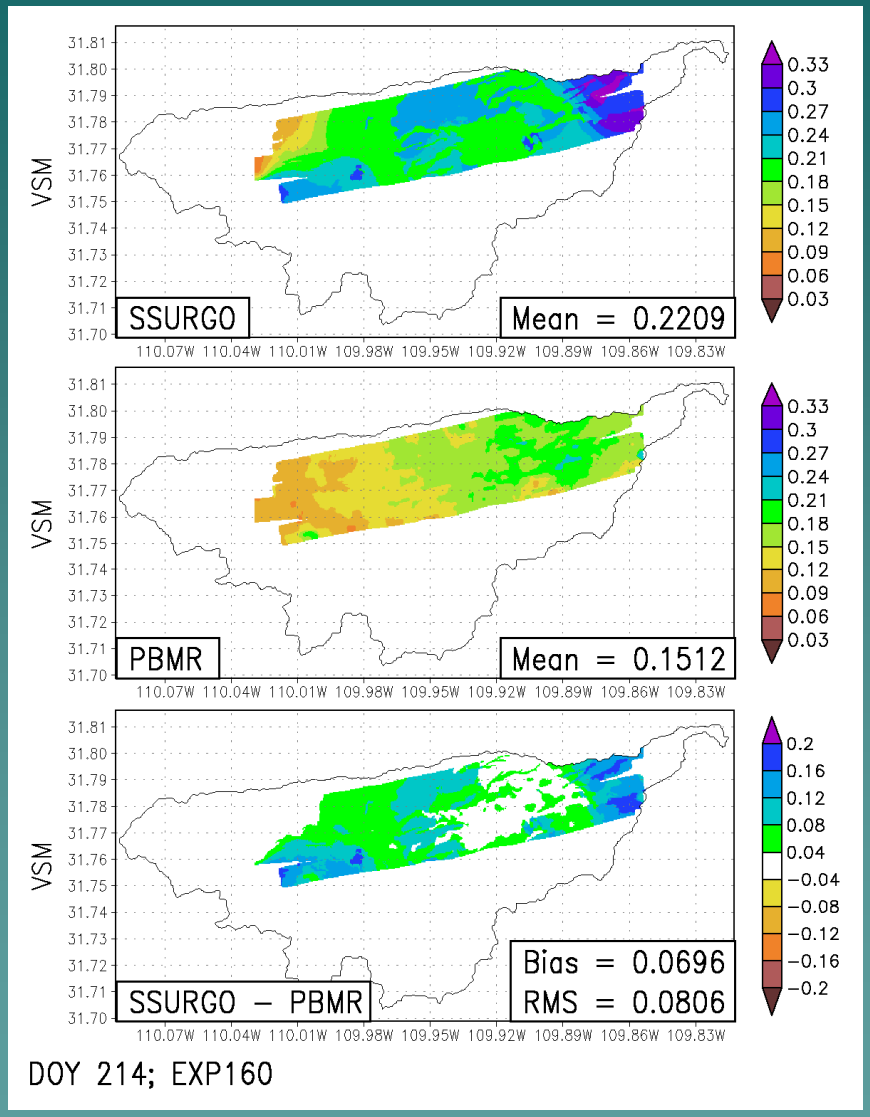
SSURGO = Noah w/default (lookup table) soil types and properties

Evaluation of Soil Moisture



- **ARMS goal: Soil Moisture estimates within ± 5%**

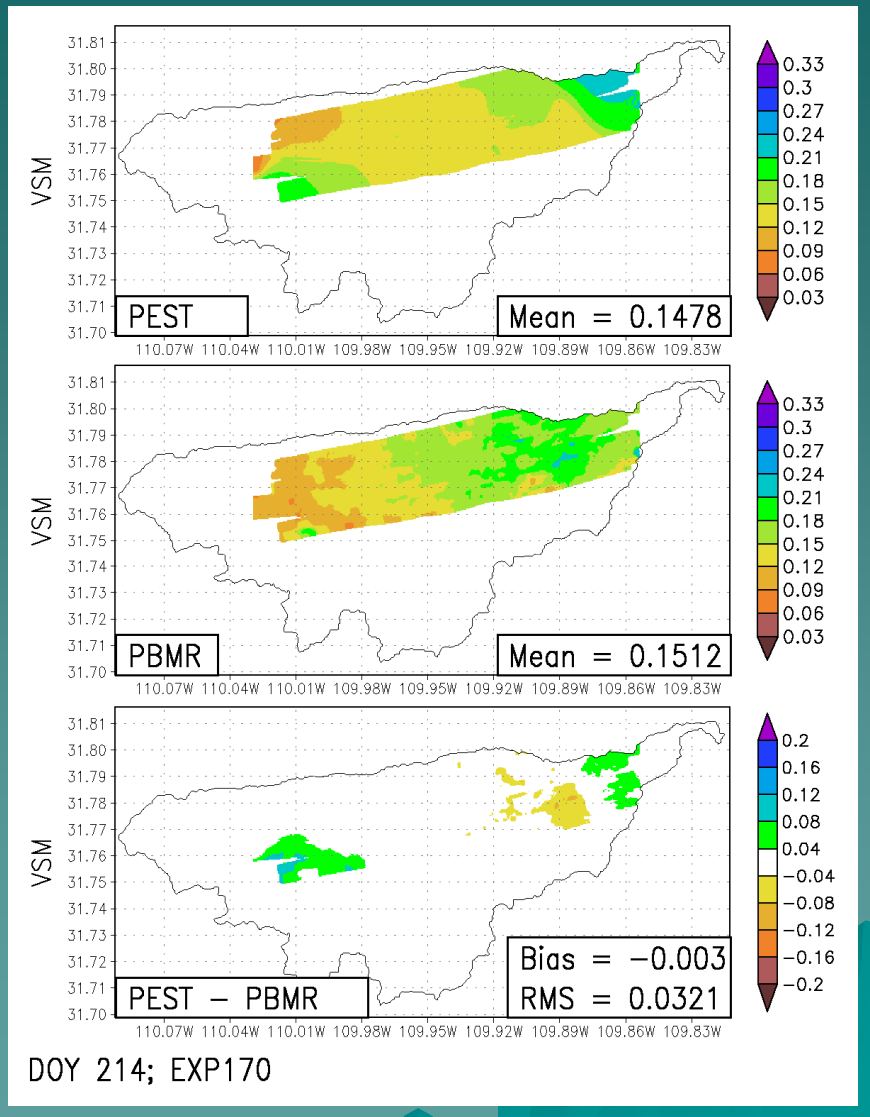
Evaluation of Soil Moisture



NOAH

PBMR

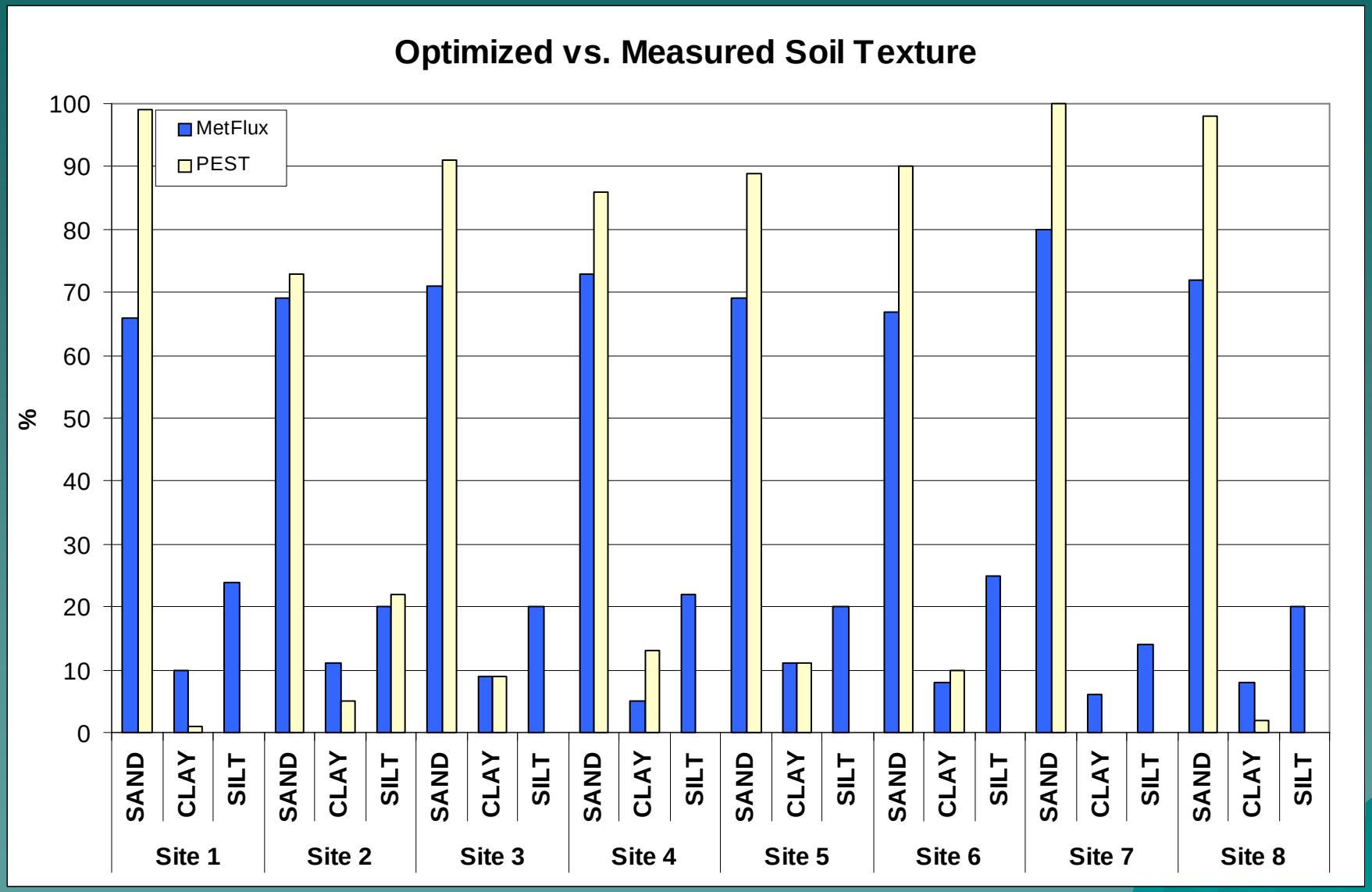
RMSE



Uncalibrated

Calibrated

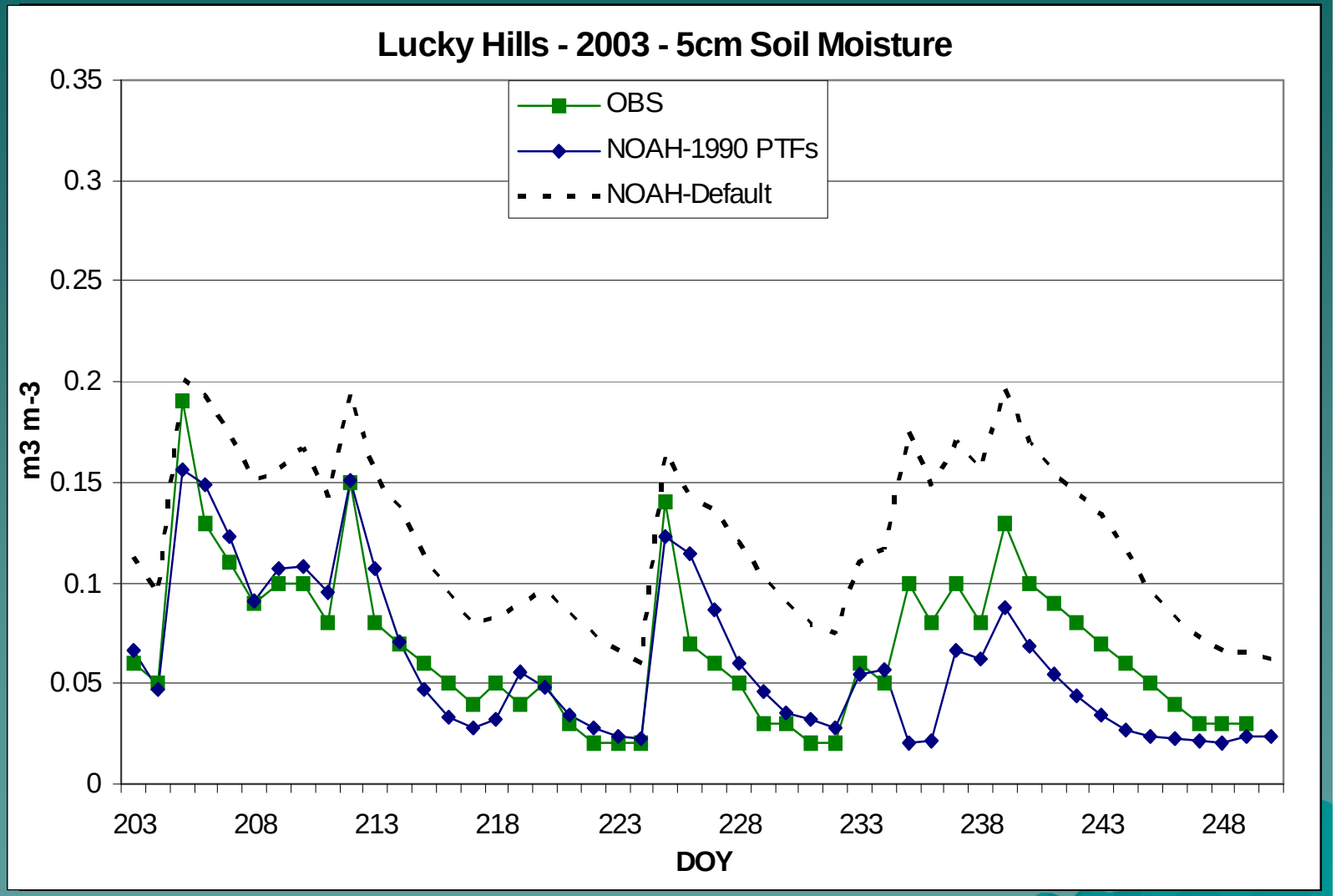
Soil Texture Evaluation



- Calibrated values of sand, silt, and clay % at each site compare well with in-situ observations and suggest a high sand content

Independent Test of Optimized Soil Properties

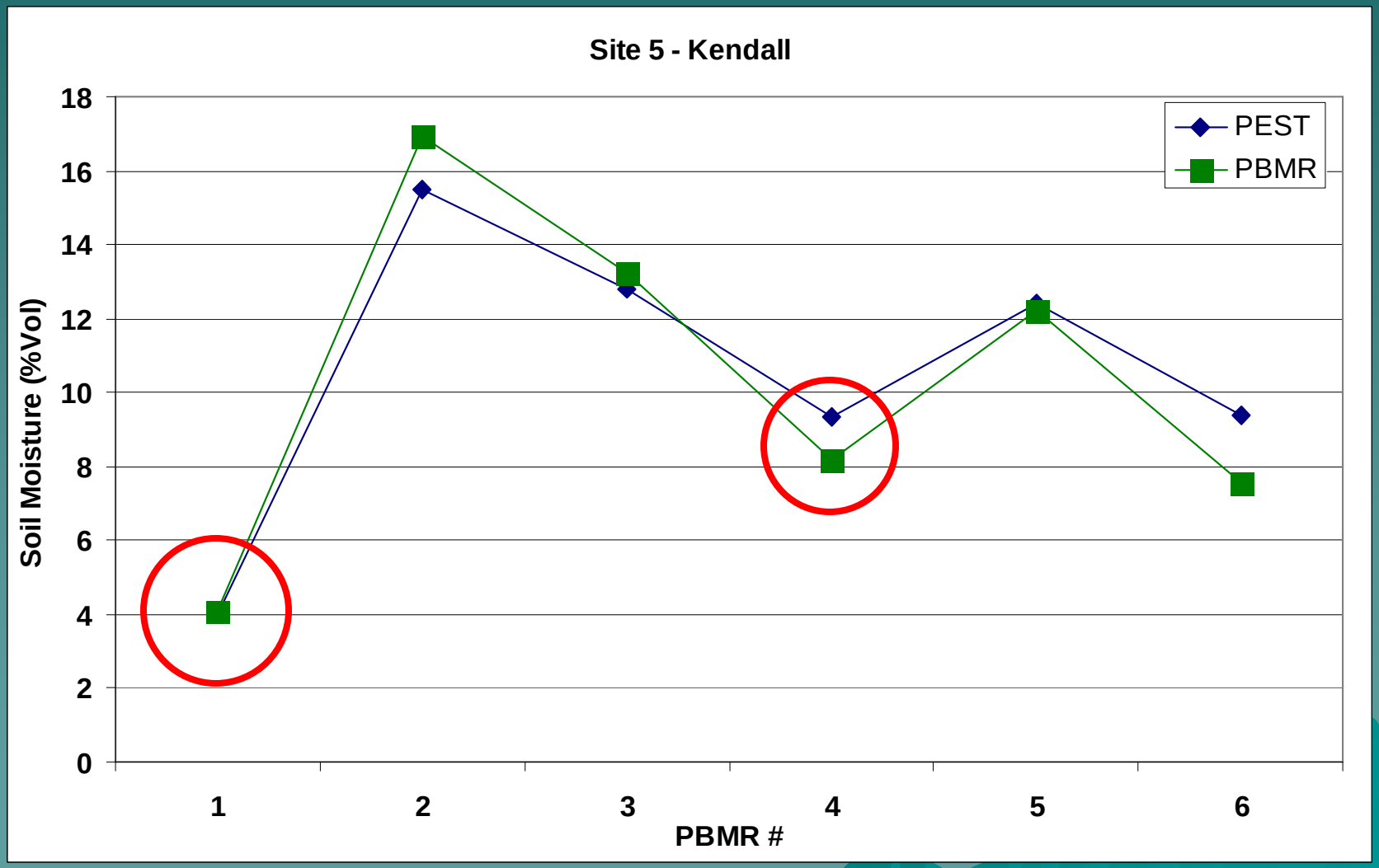
*Observed = **Vitel Probes** (USDA-ARS)



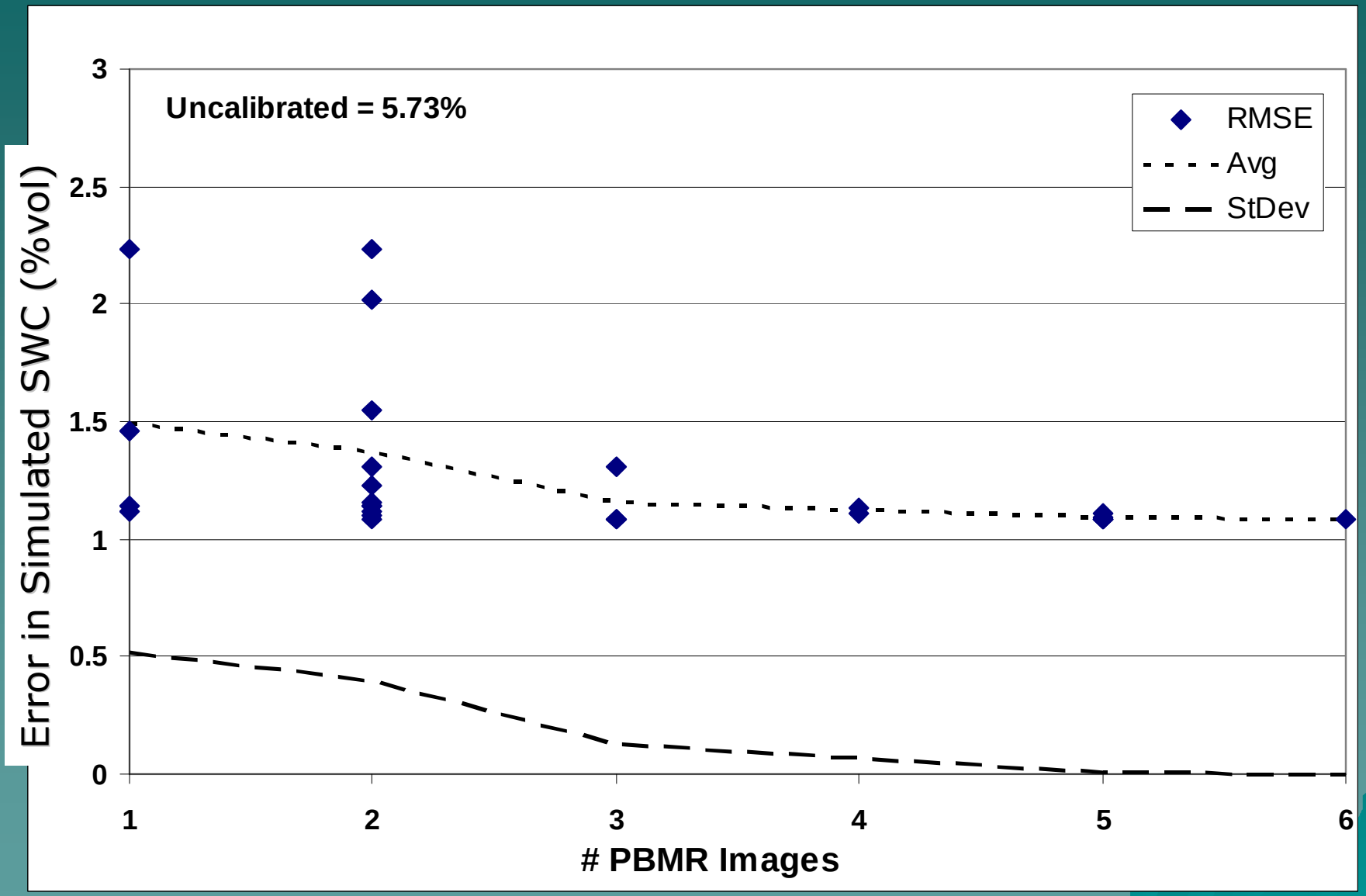
- Sand, Silt, Clay % estimated from 1990 (PBMR) used in Noah to simulate 2002-4 period at Metflux Sites

Temporal Sampling

- How many PBMR images are required for successful PEST calibration?
- Does it matter which portion of the drying curve is captured?

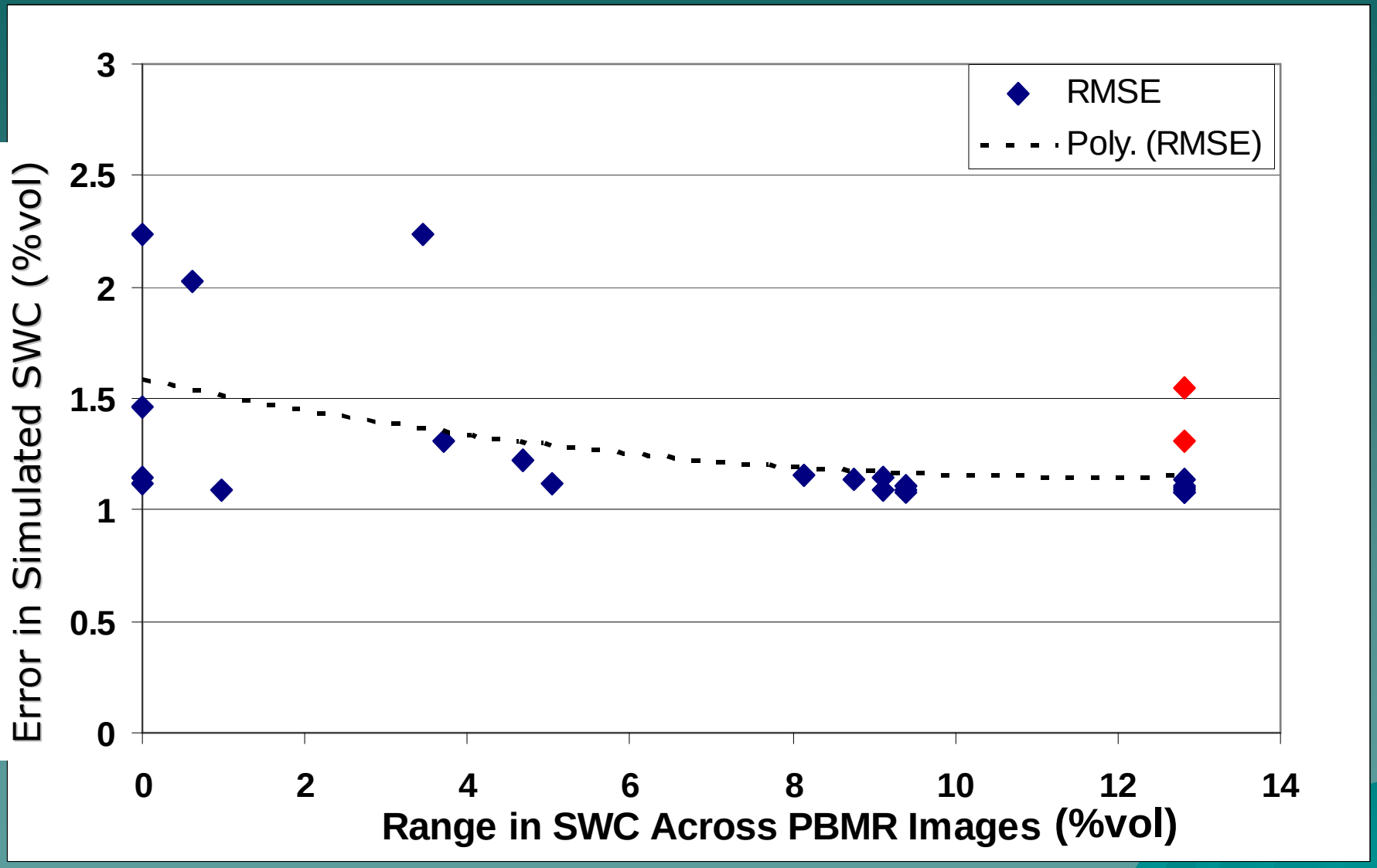


Sensitivity of PEST to the # PBMR Images - Kendall



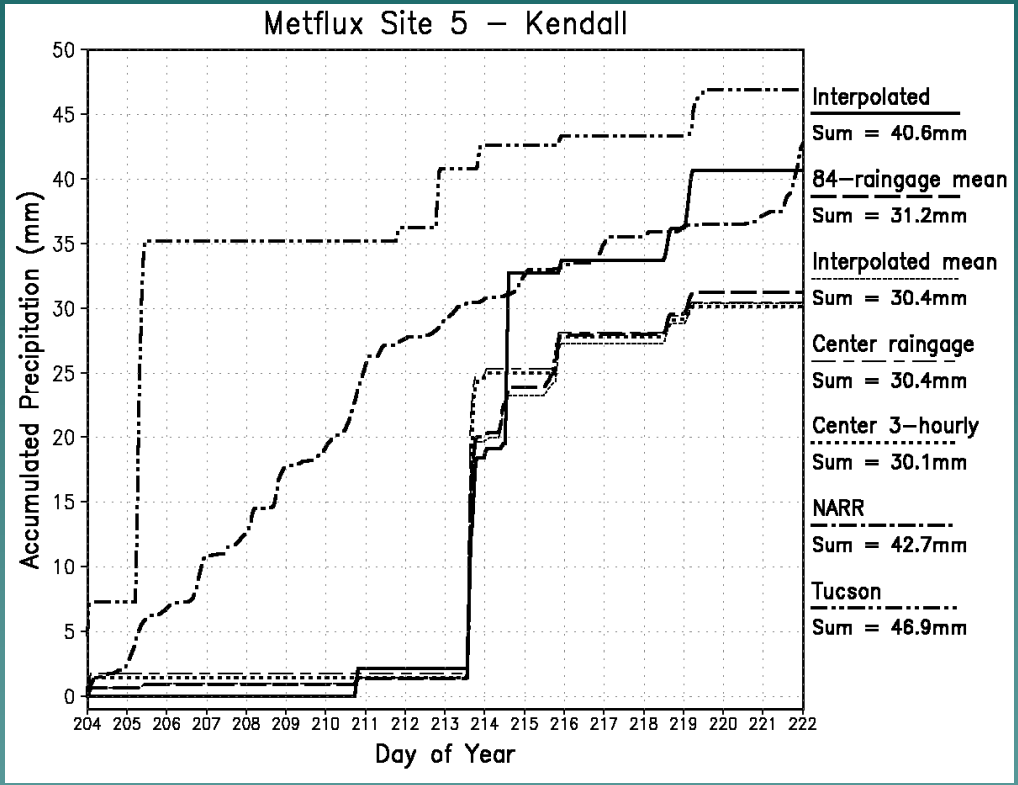
Independent Test: Calibrated using PBMR #1,2,(3)
Evaluated using PBMR # (3),4,5,6

Sensitivity of PEST to the Range of Soil Moisture

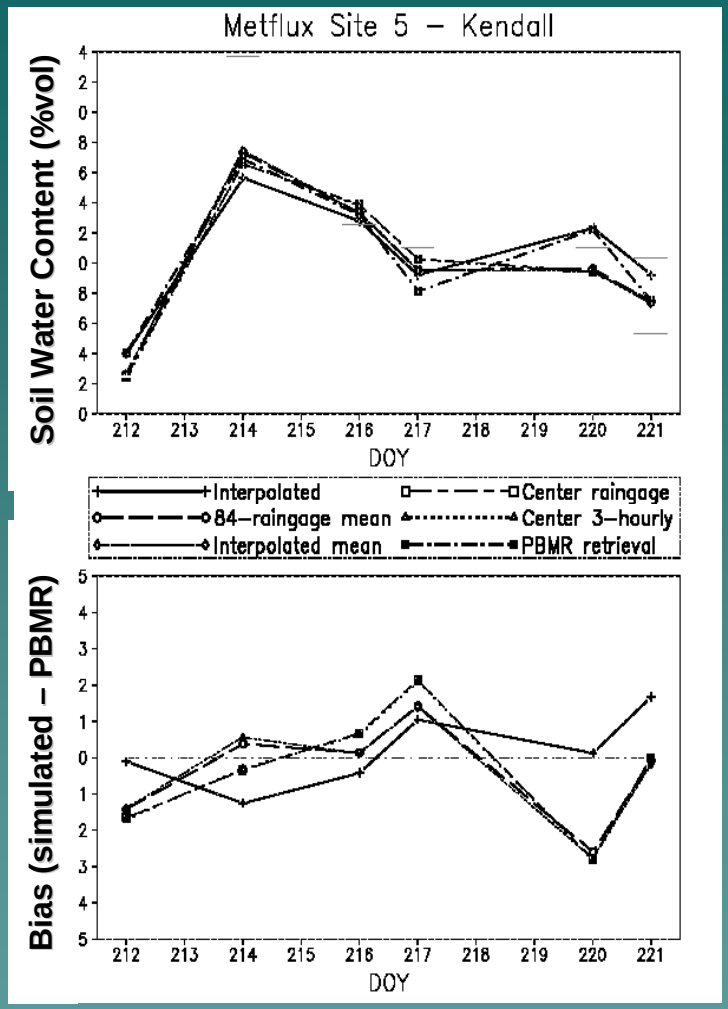


Greater range captures more of the soil drying curve and enables PEST to better estimate the *magnitude* of soil moisture

Precipitation Uncertainty



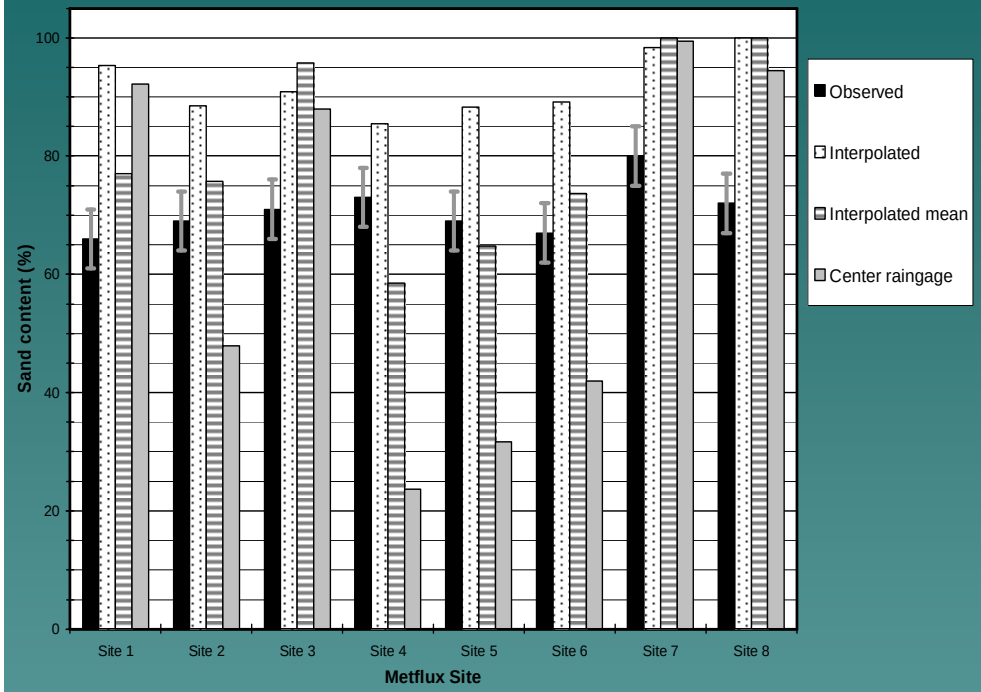
- **Accumulated precipitation from the various datasets used to force PEST-Noah simulations**



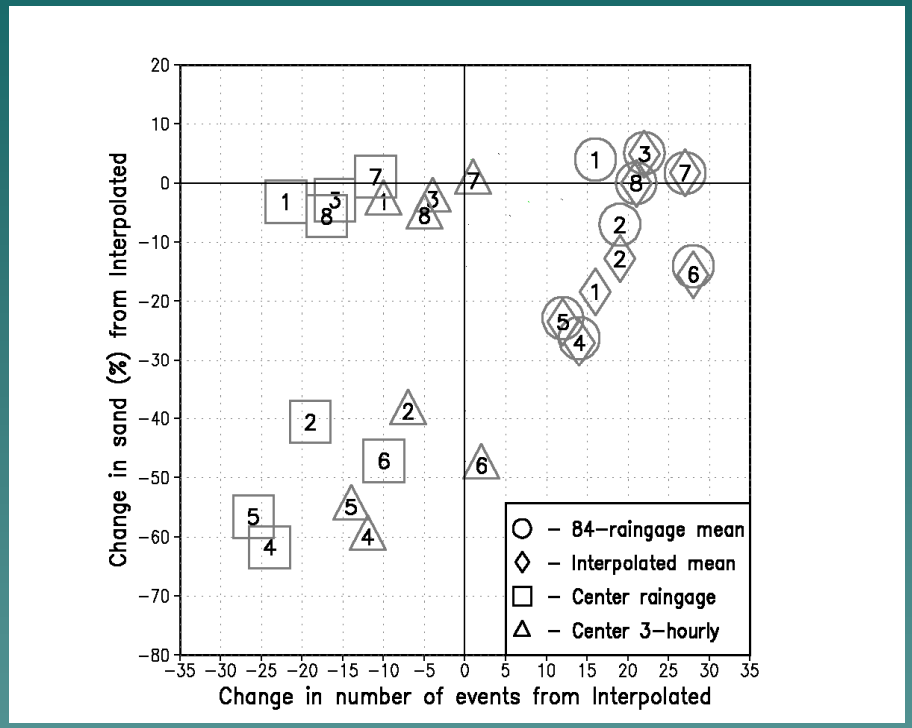
- **Impact of precipitation forcing on simulated soil moisture**

Garcia, M. et al. (2007): Spatial interpolation of precipitation in a dense gauge network for monsoon storm events in the southwestern U. S. *Water Resour. Res., accepted.*

Precipitation Uncertainty



- **Observed and LIS-PEST-Noah estimated sand contents using three different precipitation forcing inputs**



- **Scatter plot of the change in the number of precipitation events versus the change in the PEST-estimated sand percentage.**

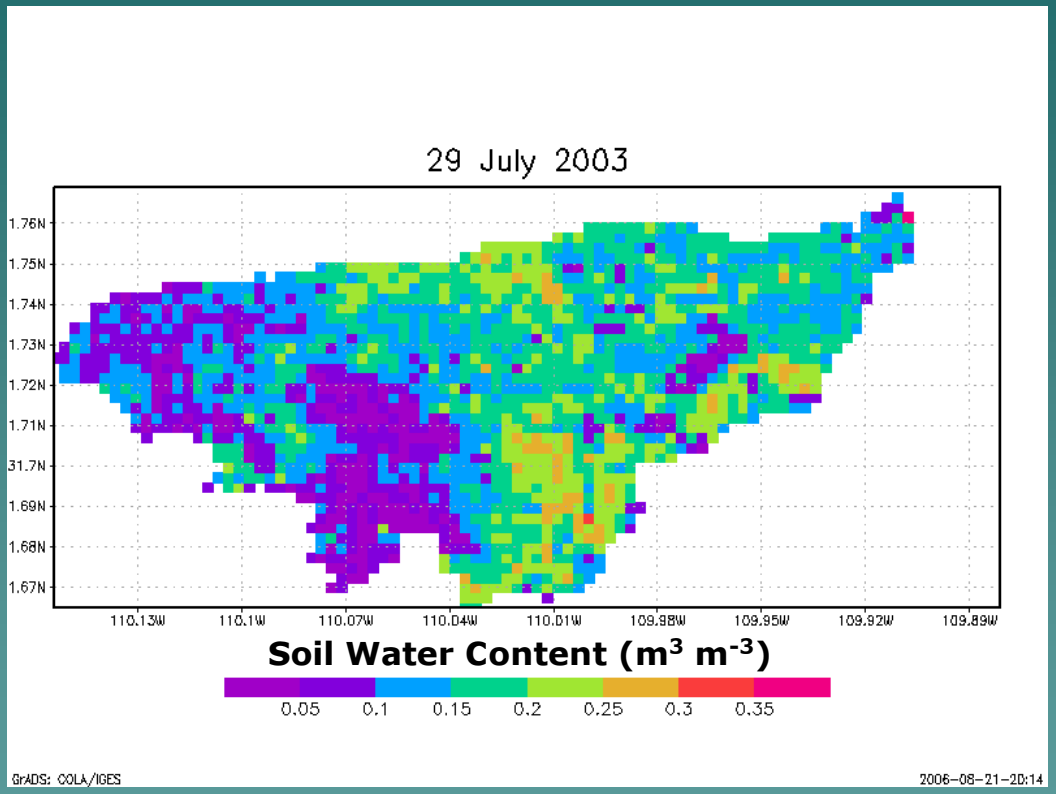
Peters-Lidard, C. D. et al. (2007): The Relative Roles of Soil, Land Cover, and Precipitation Uncertainty for Watershed-scale Soil Moisture Prediction in a Semi-arid Environment. *Water Resour. Res.*, *under review.*

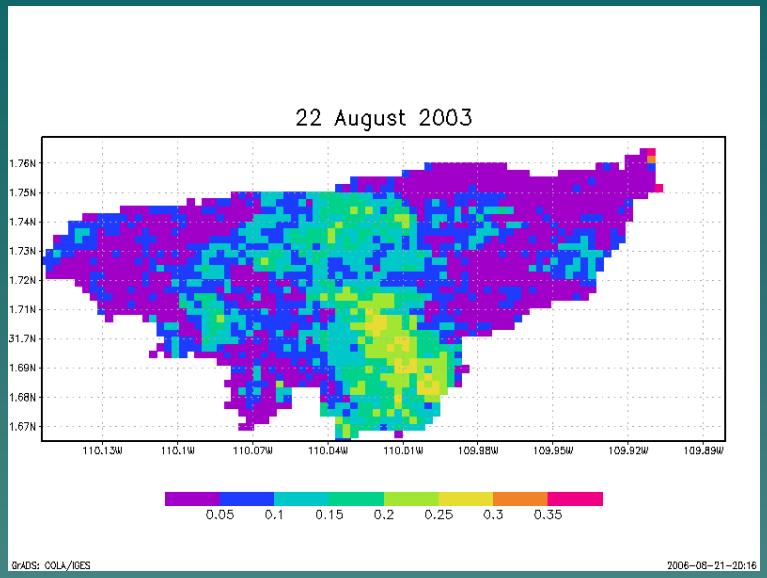
Ongoing Work

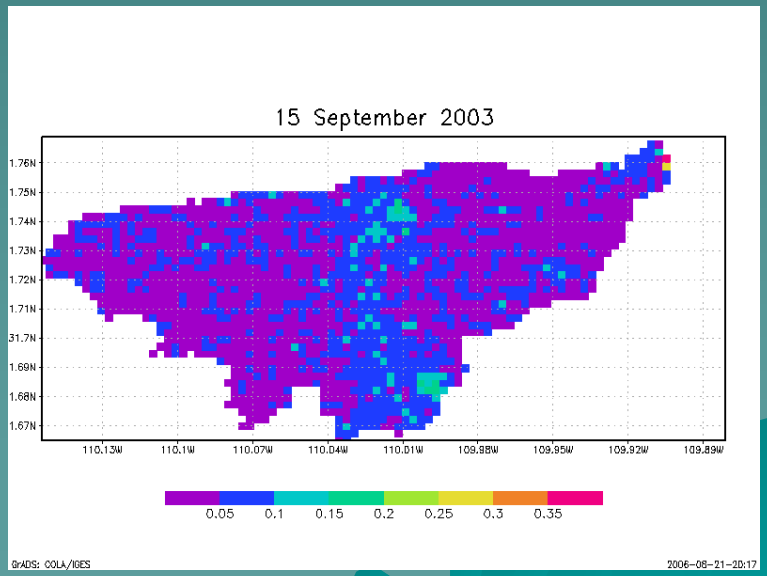
- **Active Microwave (C-band radar; 5.6cm) Calibration Experiments**
  - **Repeat methodology in WGEW using a new estimate of soil moisture from RADARSAT-1**
  - **Delta Index (USDA-ARS)**
    - Based on image differencing (wet vs. dry)
    - Image dates: 29 Jul, 22 Aug, 15 Sep 2003
  - **Compare results to 1990 PBMR-based results**
  - **Impact of limited # images (3) spread over a longer timescale (6 weeks vs. 10 days)**

Soil Moisture from Active Microwave RS

Delta Index = $\left| \frac{\sigma_{wet} - \sigma_{dry}}{\sigma_{dry}} \right|$



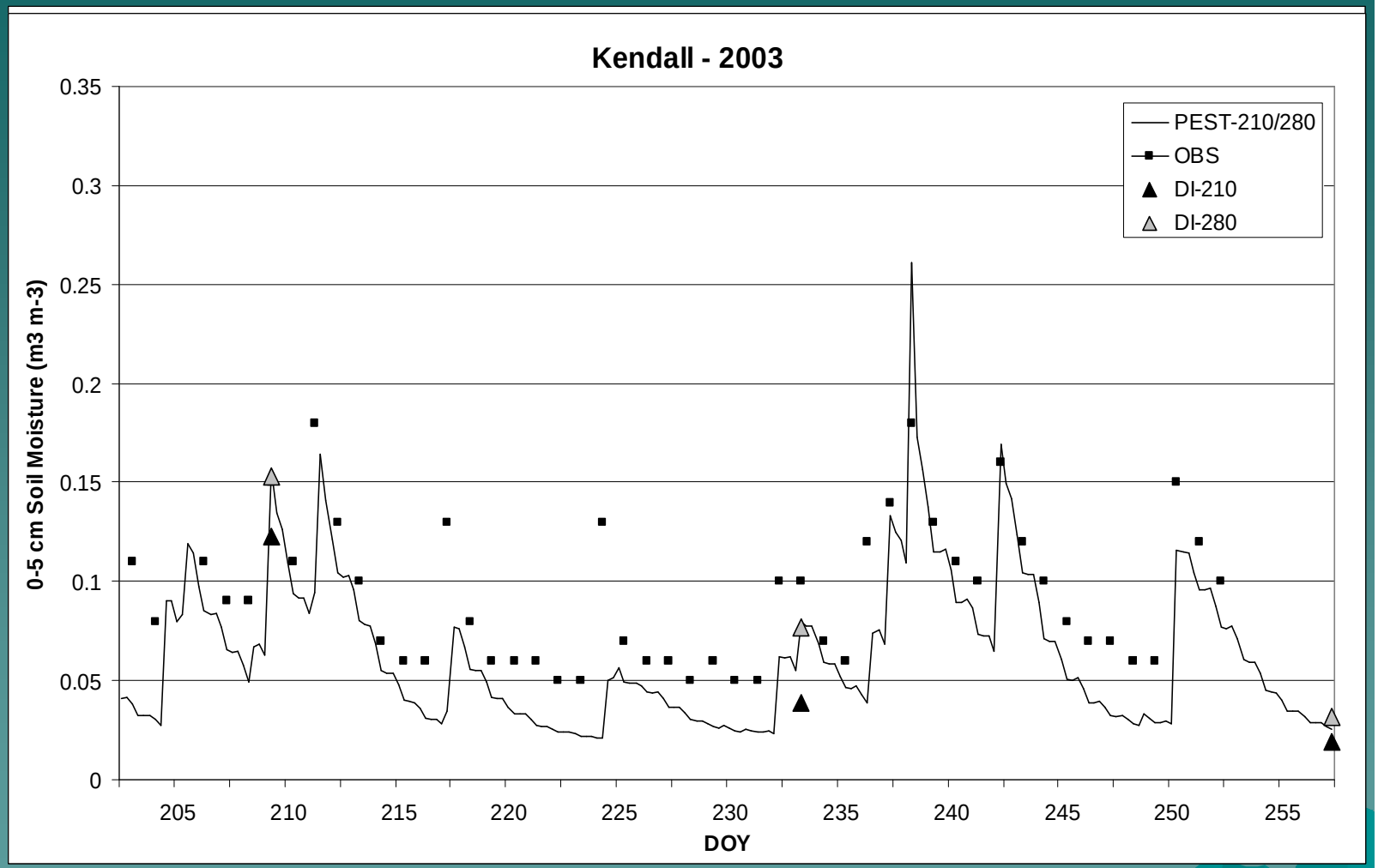




- 7m raw backscatter data aggregated to 280m resolution to reduce speckle effects
- 6-week period captures seasonal drydown but lacks day-day precipitation events that yield soil hydraulic information

Calibration Results – Delta Index

*Observed = Vitel Probes (USDA-ARS)



- PEST-Noah calibrated to 210 and 280m Delta Index
- LH: 20/35/45% sand/clay/silt
- Kendall: 100/0/0% sand/clay/silt

Summary

- Limited microwave retrievals of near-surface soil moisture can be used to calibrate a LSM at high temporal and spatial resolutions.
- Optimizing soil hydraulic properties using PTFs gives better and more physically meaningful results than a one-at-a-time parameter estimation approach.
- Independent tests indicate that this methodology can be successful in calibrating LSMs in semi-arid regions.
- Errors in the calibration process are minimized when there are at least 3 images included that represent the typical range of moisture exhibited by the soil type.
- The quality of precipitation data is critical to the calibration process and applicability of retrieved hydraulic properties.
- Delta Index approach using C-band remote sensing offers potential for semi-operational model calibration and property estimation.

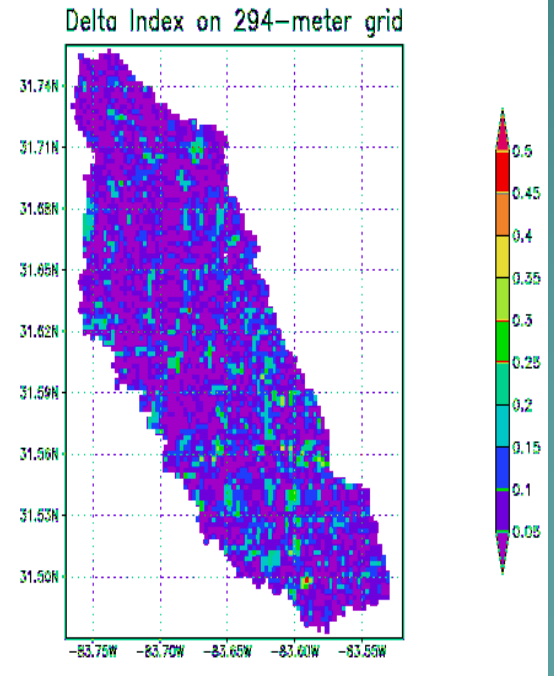
Santanello, J. A. et al. (2007): Using Remotely-Sensed Estimates of Soil Moisture to Infer Soil Texture and Hydraulic Properties Across a Semi-Arid Watershed. *Rem. Sens. Environ.*, **110**, 79-97.

ARMS at Other Watersheds

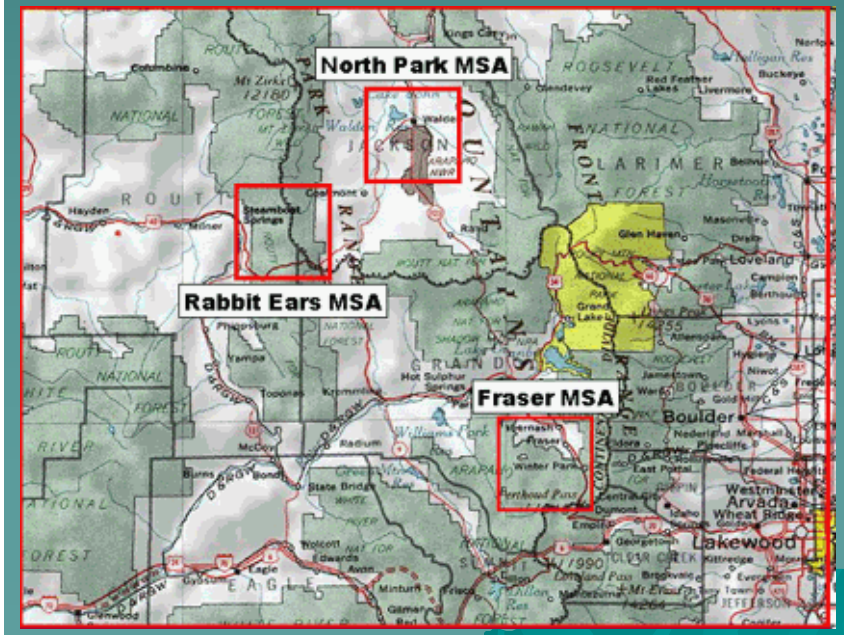
Additional watersheds & time periods are being simulated with PEST-Noah, from semi-arid to wet to frozen.

The Delta Index and other retrievals will be used with in situ data to demonstrate ability of PEST-Noah to establish physically meaningful soil moisture and parameters

Little River GA



NASA CLPX



Little Washita OK