# Noah-MP parameter optimization at southern great plains using Bayesian Optimization

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# Land Surface Model (LSM) Biases

LSM biases are mainly contributed from 3 primary components:

- ❑ An imperfect model structure;
- ❑ Inappropriate model parameter values;
- ❑ Incorrect model inputs (including meteorological forcing data and initial surface conditions)

***LSM parameters:*** *the mean physical quantities for a model grid based on observations or estimated using data from other sources, such as satellite imagery or databases*

# Motivation

To optimize surface energy fluxes (e.g., sensible heat flux) and near-surface atmospheric state variables (e.g., 2-m air temperature) in WRF/Noah-MP by optimizing sensitive parameters.

**To be a physically more reasonable value at this specific location and time**

# Observations and Model Configuration


| Physical process | Option used |
| --- | --- |
| **Dynamic Vegetation** | Off – LAI from the Table; Constant vegetated area fraction |
| **Stomatal Resistance** | Ball-Berry (Ball et al., 1987) |
| **Soil moisture factor for stomatal resistance** | Noah type (Chen et al., 1996) |
| **Runoff and groundwater** | Infiltration-excess surface runoff and free drainage (Schaake et al., 1996) |
| **Surface layer drag coefficient** | Monin-Obukhov |
| **Supercooled liquid water** | Standard freezing point depression (Niu & Yang, 2006) |
| **Frozen soil permeability** | Uses total soil moisture to compute hydraulic properties (Niu & Yang, 2006) |
| **Radiation transfer** | Two-stream with canopy gap equal to one |
| **Snow albedo** | CLASS (only considers overall snow age) (Verseghy, 1991) |
| **Frozen/liquid partitioning** | Based on Jordan (1991) |
| **Soil temperature lower boundary condition** | Zero heat flux |

*Noah-MP options chosen*

**Model:** A single-column WRF with Noah-MP LSM

**Meteorological forcing data**: ERA5 reanalysis data (6 hourly)

**Forcing layers**: 25 (ground up to 50 hPa)

**Soil moisture and temperature**: AmeriFlux observations

**WRF parameterization schemes:**

Longwave radiation: RRTM

Shortwave radiation: Dudhia

Surface layer physics: Revised MM5 Monin-Obukhov scheme

PBL: YSU

# Parameters to test

*A sensitivity analysis (finite difference method)* is performed on 39 parameters in Noah-MP.

***6 most sensitive soil parameters*** are selected for optimization

| *Parameter* | *Description* | *Default Value* | *Units* | *Involved physical process* |
|---|---|---|---|---|
| **BEXP** | Pore size distribution index | | – | Soil hydraulic conductivity, Plant photosynthesis, Soil water evaporation |
| **DKSAT** | Saturated soil hydraulic conductivity | | $m\ s^{-1}$ | Soil hydraulic conductivity |
| **DWSAT** | Saturated soil hydraulic diffusivity | | $m^2\ s^{-1}$ | soil water diffusivity |
| **SMCMAX** | Porosity | | $m^3\ m^{-3}$ | Soil water evaporation, Soil thermal diffusivity and conductivity |
| **SMCREF** | Volumetric soil water content at field capacity | 0.387 | $m^3\ m^{-3}$ | Plant photosynthesis related to soil moisture |
| **SMCWLT** | Wilting point soil moisture | | $m^3\ m^{-3}$ | Plant photosynthesis, Soil water evaporation |

# Bayesian Optimization

Bayesian optimization is a powerful framework for globally optimizing expensive-to-evaluate functions

$$x_{opt} = \underset{x \in X}{\text{argmin}}\, f(x)$$

Objectives can be:

- < 20 dimensions;
- Continuous;
- Observed without gradients;
- "Black Boxes"

Typical application:

- hyperparameter optimization

***f(x) in this problem:***

$$f(x) = \sum_{i=1}^{5} \frac{1}{2\sigma_i^2} \sum_t |obs(x,t) - sim(x,t)|^2$$

**Optimize 10 continuous sunny days**
**$obs(x,t) - sim(x,t)$: mismatches of H, LE, T2, Q2, and WS**
**–> Find the parameters making the mismatch smallest.**

# Optimization results

***Optimized parameters***: global optimization of the six parameters with the smallest cost function value

60 random points to evaluate before actual Bayesian exploration starts
300 iterations after initial exploration.

| *Parameter* | *Description* | *Default Value* | *Optimized Value* | *Units* |
|---|---|---|---|---|
| **BEXP** | Pore size distribution index | | 2.87 | – |
| **DKSAT** | Saturated soil hydraulic conductivity | | | m $s^{-1}$ |
| **DWSAT** | Saturated soil hydraulic diffusivity | | | $m^2$ $s^{-1}$ |
| **SMCMAX** | Porosity | | 0.42 | $m^3$ $m^{-3}$ |
| **SMCREF** | Volumetric soil water content at field capacity | 0.387 | 0.272 | $m^3$ $m^{-3}$ |
| **SMCWLT** | Wilting point soil moisture | | 0.187 | $m^3$ $m^{-3}$ |

*LAI in MPTABLE.TBL is adjusted to MODIS LAI*

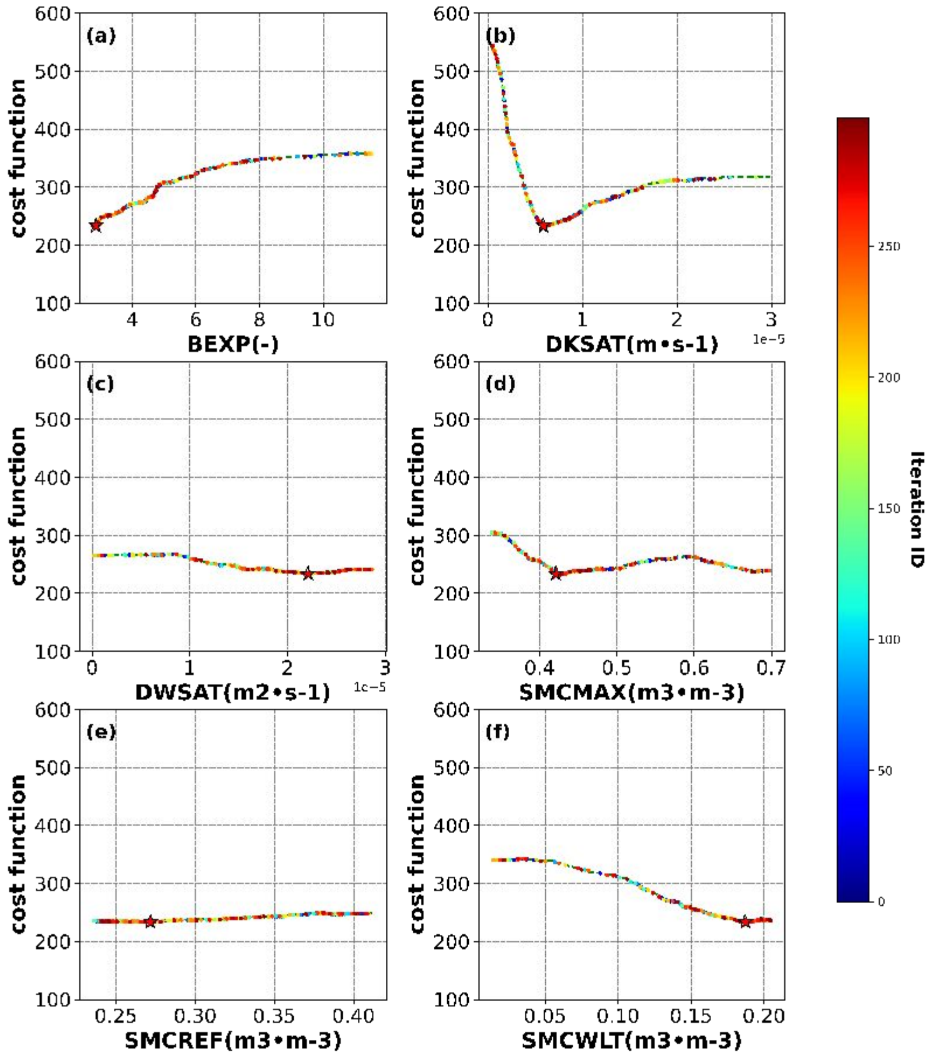
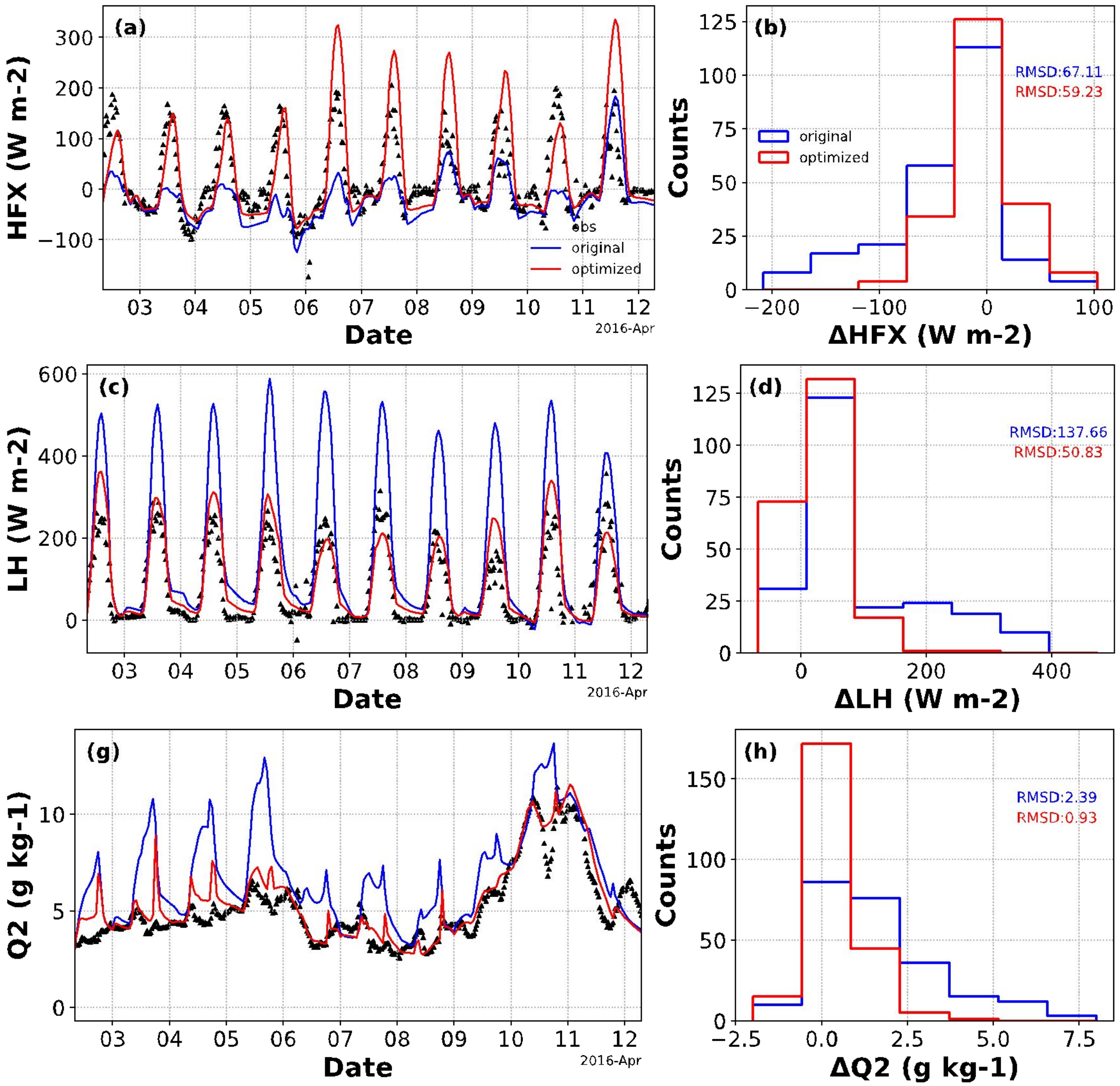


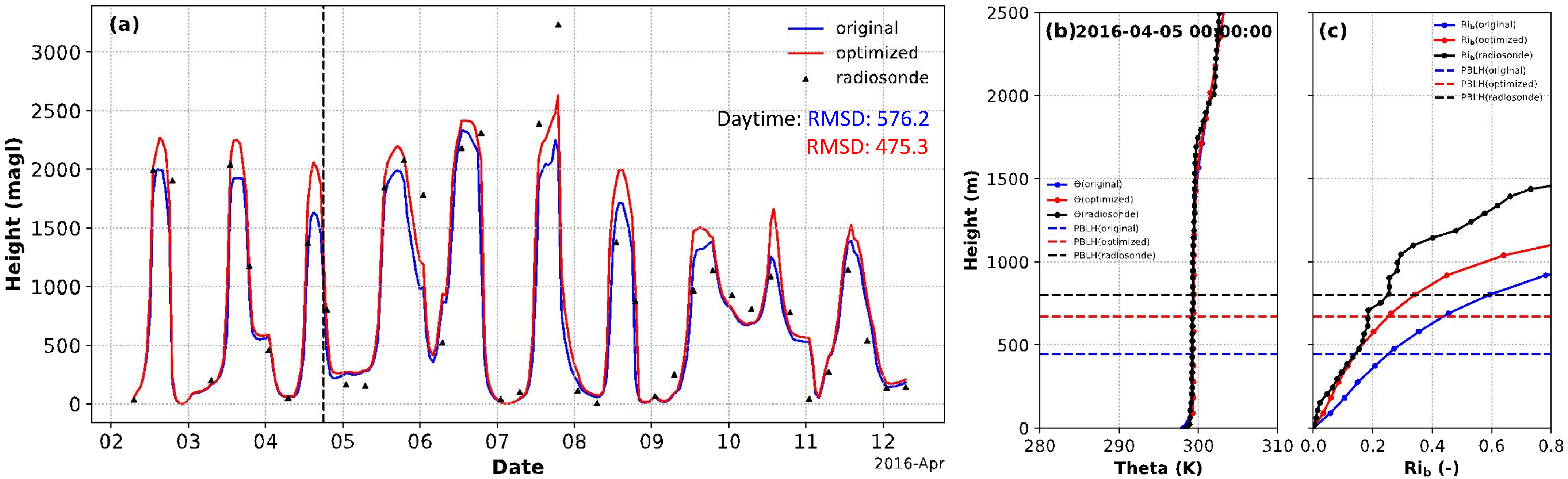

Figure: parameter values and their corresponding cost function values. The color stands for the iteration ID (300 iterations in total after burning period)

# Optimization results



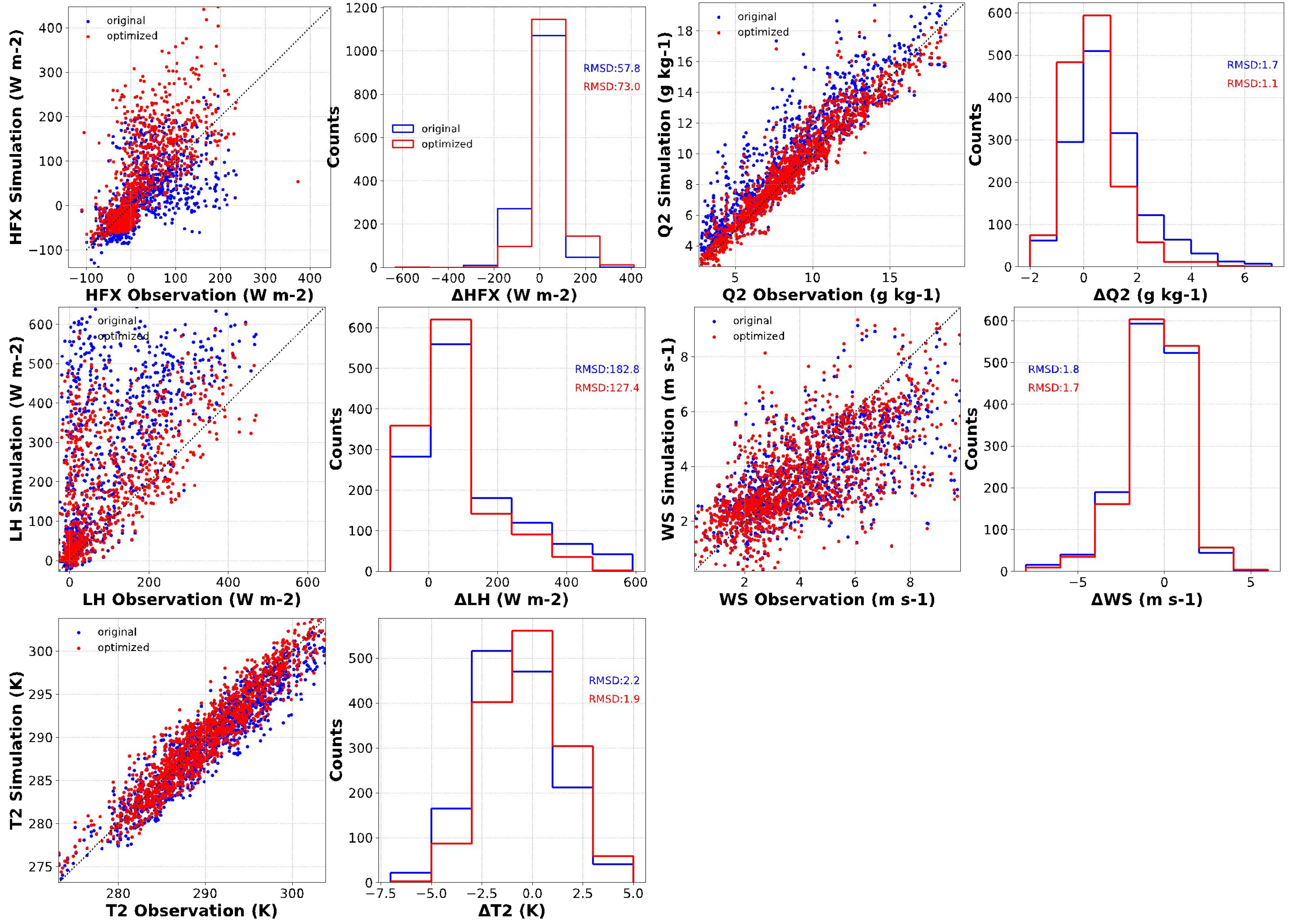

- In general, the global optimization of the six parameters leads to a stronger soil water infiltration
- A better simulation in HFX, LH, T2, Q2, WS

# Optimization results – PBLH




- With Bulk-Richardson Number method (threshold 0.25), the global optimization of the six parameters leads to a better estimation of ***PBLH in the daytime***

# Optimization Results – spring growing season




- Optimized parameters also improve the estimations in the alfalfa growing season (April & May in 2016 at ARM), especially LH, Q2

# Summary

- ❑ Six soil parameters are optimized using Bayesian Optimization in a single-column WRF-Noah-MP. The optimized parameters help improve the 10-day simulation of H, LE, T2, Q2, and WS

- ❑ The optimization also helps improve the simulations of LH, T2, Q2, and daytime PBLH in the whole alfalfa growing season from April to May in 2016 at ARM

# Q&A