R: Parametric Uncertainty Quantification and Dimensionality Reduction for ALM at FLUXNET Sites

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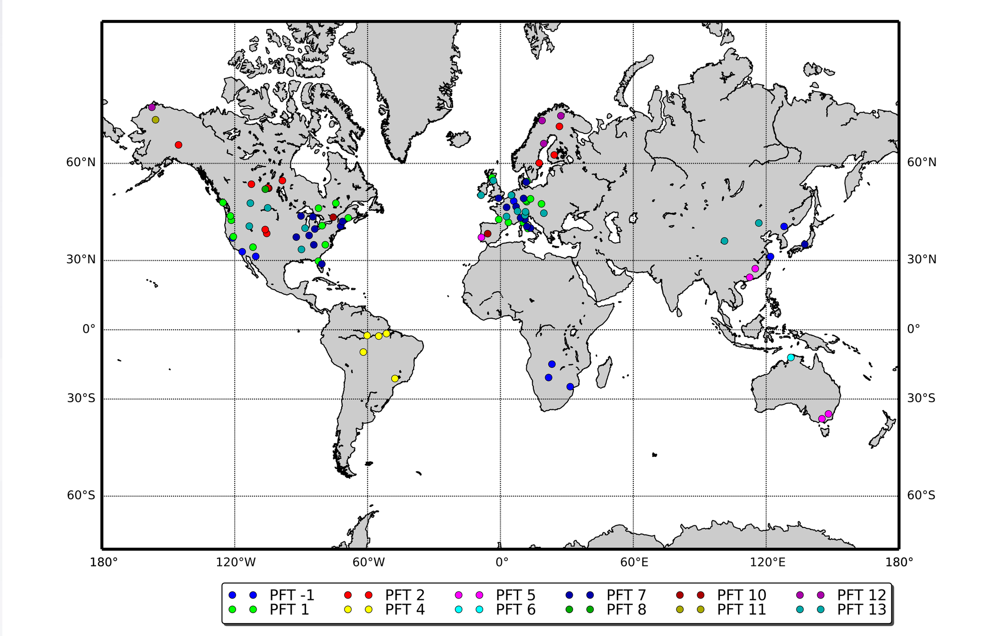
Objective

Parametric uncertainty analysis at FLUXNET sites:

- Selected 96 FLUXNET sites across several PFTs
- Vary 68 input parameters over selected ranges
- Analyze 5 steady state outputs

[GPP, TLAI, TOTVEGC, TOTSOMC, EFLX_LH_TOT]



PFT Id	PFT Name	# of Sites
-1	mixed	9
1	Boreal evergreen needleleaf tree	22
2	Temperate evergreen needleleaf tree	11
3	Boreal deciduous needleleaf tree	0
4	Tropical evergreen broadleaf tree	5
5	Temperate evergreen broadleaf tree	5
6	Tropical deciduous broadleaf tree	1
7	Temperate decidous broadleaf tree	20
8	Boreal deciduous broadleaf tree	1
9	Boreal evergreen shrub	0
10	Temperate decidous broadleaf shrub	2
11	Boreal deciduous broadleaf shrub	1
12	C3 Arctic grass	4
13	C3 non-Arctic grass	15
14	C4 grass	0

Major goals:

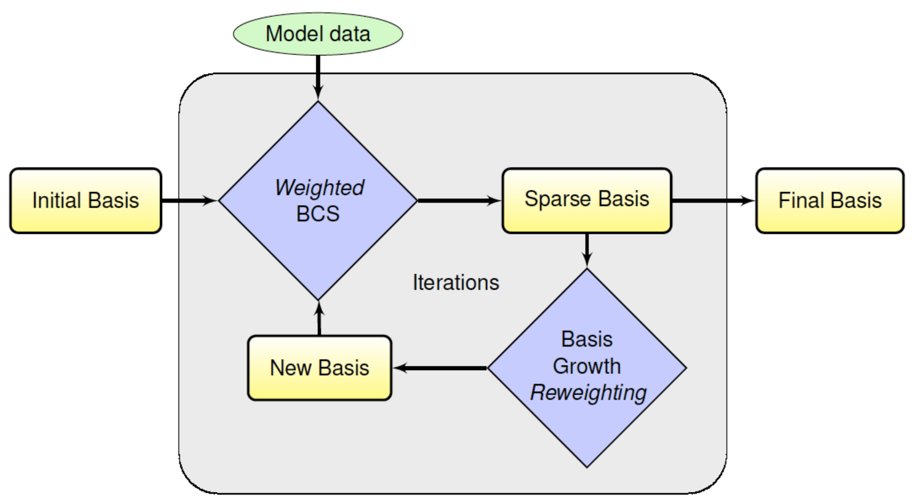
- Variance-based decomposition (Sobol sensitivities) of uncertainties into fractional input contributions
- Dimensionality reduction and subsequent focus on fewer sites/parameters
- Accurate surrogate construction for input-output maps to enable optimization and efficient calibration

Approach

$$y = u(\boldsymbol{x}) \approx \sum_{k=0}^{K-1} c_k \Psi_k(\boldsymbol{x})$$

$$\Psi_k(x_1, x_2, \ldots, x_d) = \psi_{k_1}(x_1)\psi_{k_2}(x_2)\cdots\psi_{k_d}(x_d)$$

$$\underbrace{P(c_k|u(\boldsymbol{x}_j))}_{\text{Posterior}} \propto \underbrace{P(u(\boldsymbol{x}_j)|c_k)}_{\text{Likelihood}}\underbrace{P(c_k)}_{\text{Prior}}$$



Polynomial Chaos surrogate:

- Cast input/outputs as random variables
- Flexible representation for both forward and inverse UQ
- Free access to variance based decomposition

Bayesian approach:

- Uses any number of model simulations
- Provides an uncertain surrogate with quantified error

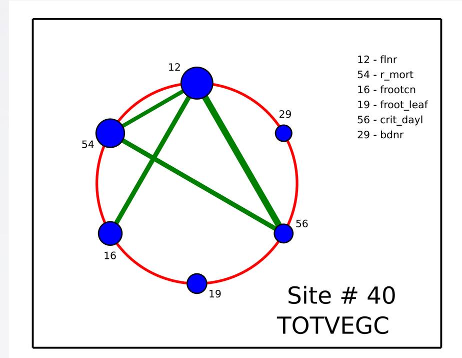
Weighted Iterative Bayesian Compressive Sensing:

- Iterative search for most relevant polynomial bases

Results

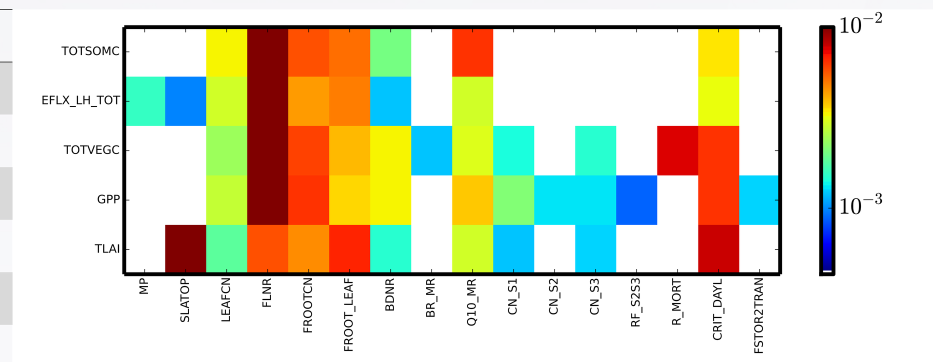
Study 1: High dimensional surrogate construction and dimensionality reduction

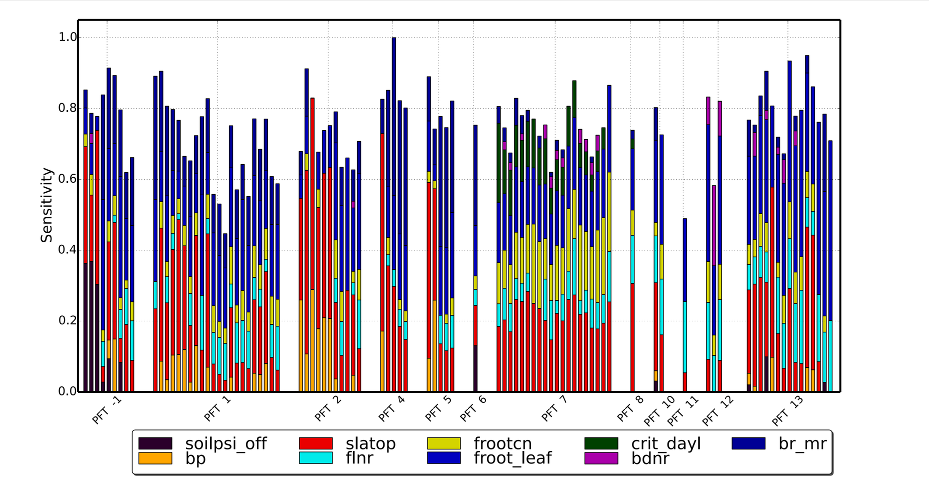
- Built surrogate model approximations (per site, per output) with respect to 68 inputs using 3000 ensemble simulations
- Performed variance-based decomposition
- Sensitivities grouped according to PFTs
- Only ~15 (out of 68) parameters have significant impact to overall uncertainty
- Parameter ranking
- Dimensionality reduction



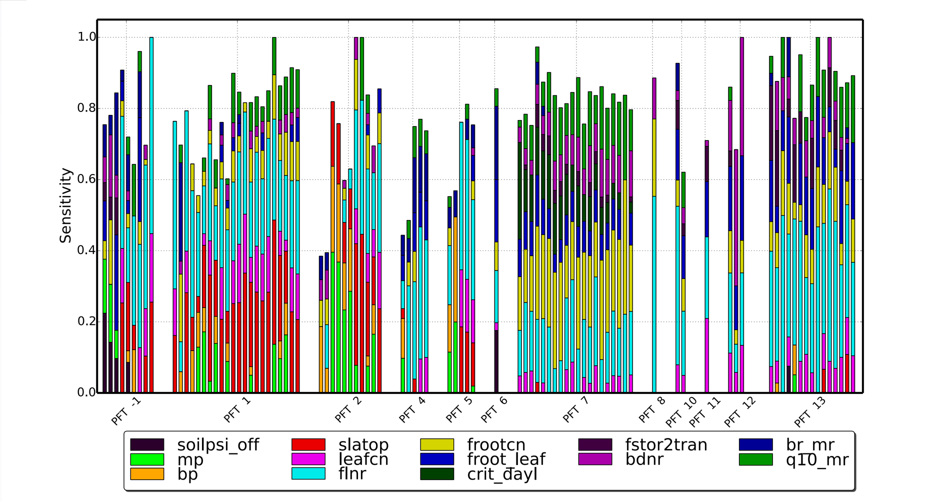
Site #40: Harvard Forest

Parameter	Description
flnr	Fraction of leaf N in RuBisco
froot_leaf	Fine root to leaf allocation ratio
br_mr	Base rate for maintenance respiration (MR)
q10_mr	Temperature sensitivity for MR
frootcn	Fine root carbon/nitrogen (C:N) ratio
leafcn	Leaf C:N ratio
slatop	Specific leaf area at canopy top





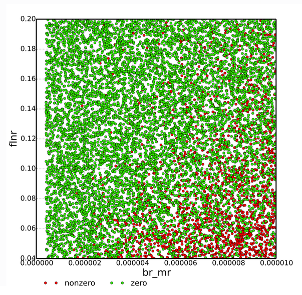
Total Leaf Area Index (TLAI)

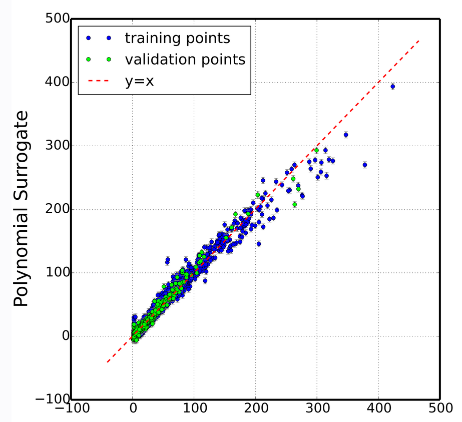


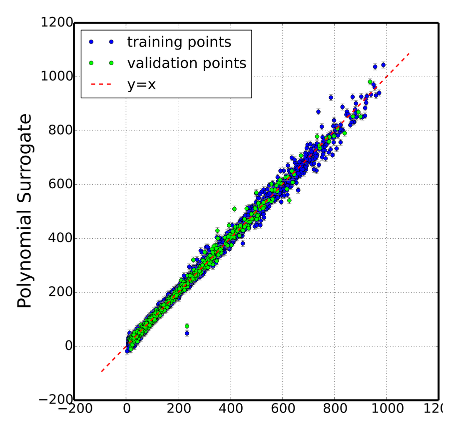
Gross Primary Productivity (GPP)

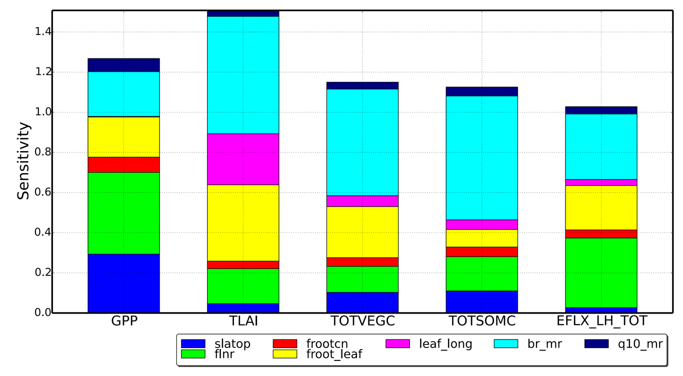
Study 2: Lower-dimensional accurate surrogate for selected sites

- Selected 16 representative sites and top 5-15 parameters for each site
- Repeat the workflow with 10000 simulations per site
- Much more accurate surrogates while sensitivities remain consistent
- Accurate assessment of parameter regions with no vegetation growth

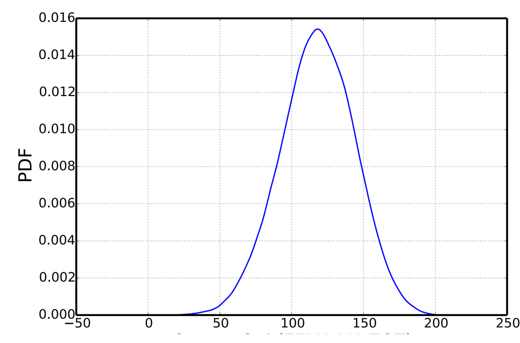








Site #9: Santarem, Brazil



Parametric UQ Workflow for ALM

- *git clone git@github.com:ACME-Climate/Uncertainty-Quantification.git*
- Python interface to UQTk v3.0 (www.sandia.gov/uqtoolkit)
- Full workflow is non-intrusive, i.e. model runs as a black-box

ACME Accelerated Climate Modeling for Energy

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