Uncertainty Quantification and Calibration of E3SM Land Model

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Objective

Develop workflows of surrogate construction for outputs of earth system models (ESM) to enable uncertainty quantification (UQ)

Sample-intensive studies, such as UQ and parameter calibration, for earth system models require a construction of a **surrogate model** that approximates the ESM behavior across a range of conditions and input parameters.

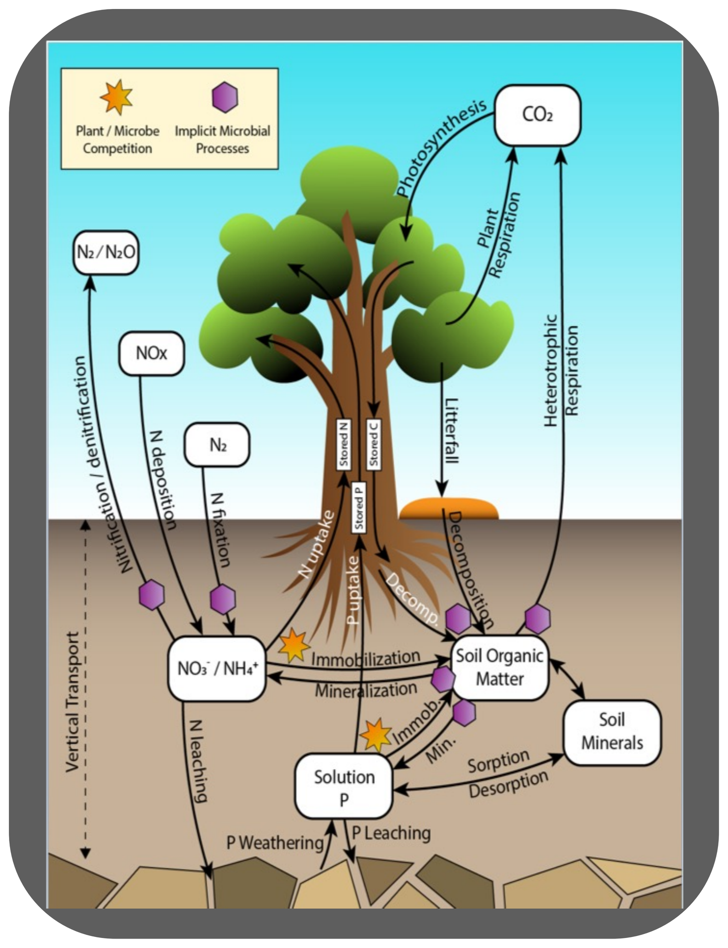
$$\underset{\text{ESM}}{M(\lambda; x)} \approx \underset{\text{Surrogate}}{M_s(\lambda; x)}$$

Model output Quantity of Interest (QoI)

Uncertain input parameters

Conditions, e.g. (Longitude, Latitude Altitude, Pressure, Time)

E3SM Land Model

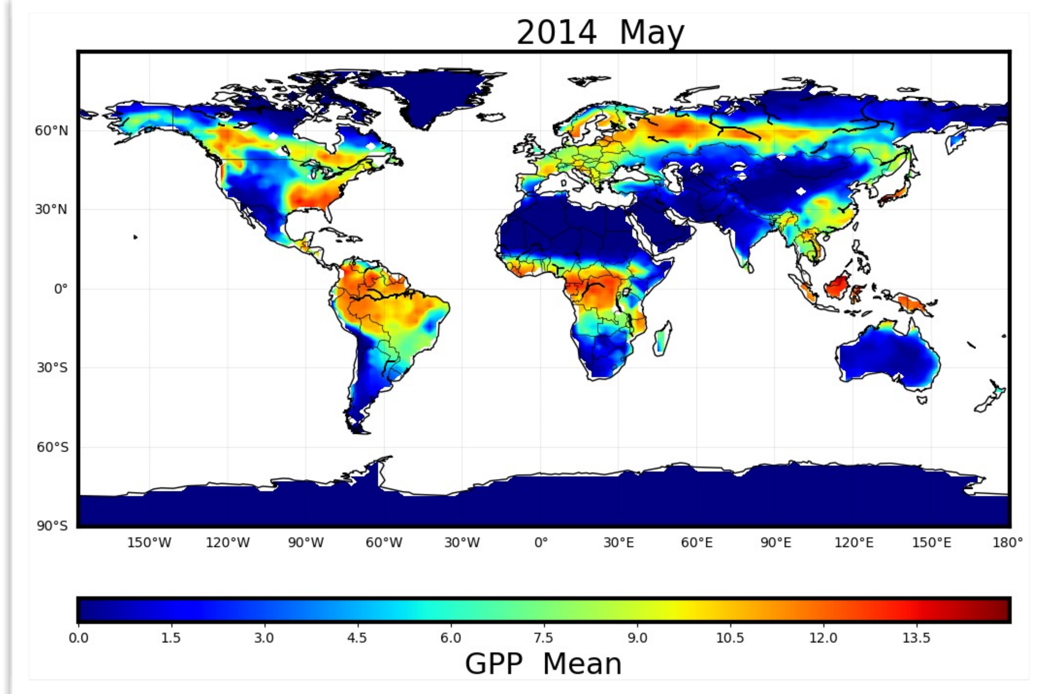


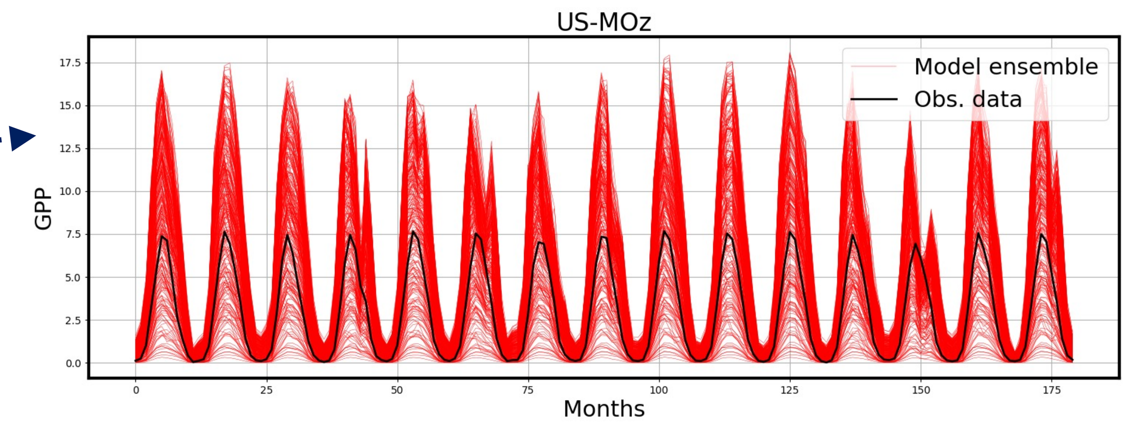
Satellite Phenology version used for this study

Quantity of Interest: Gross primary productivity (GPP)…

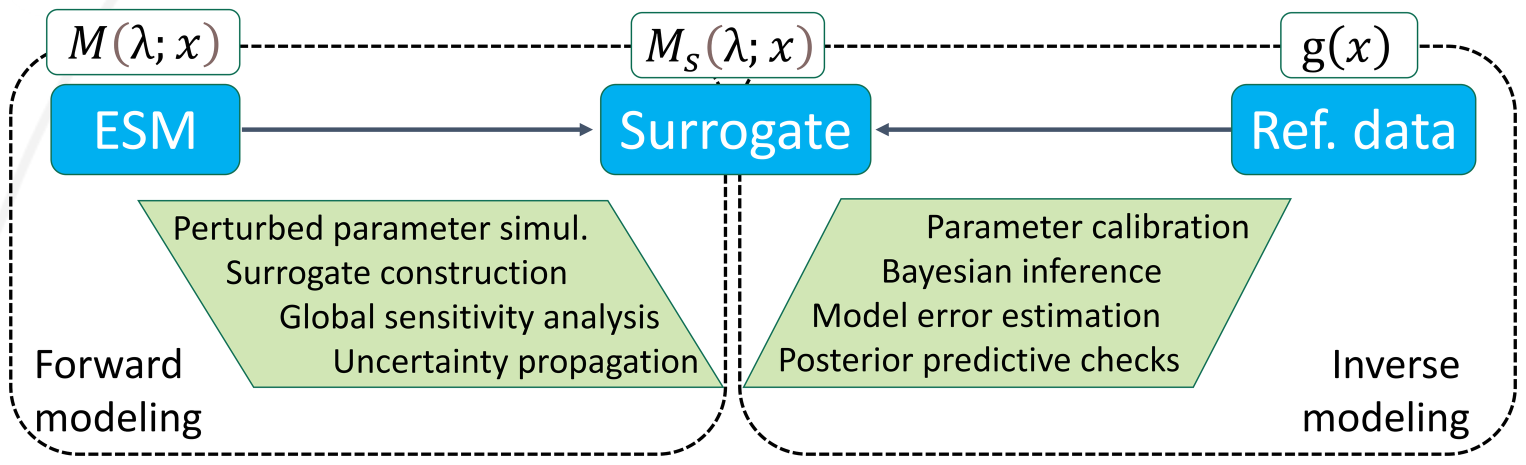
resolved in space …

… and time.





UQ Workflow



Major challenges:

- **Large number of conditions / high-dimensional output fields**
  - ✓ Employ Karhunen-Loève decomposition to reduce dimensionality

$$M(\lambda; x) \approx \bar{M}(\lambda; x) + \sum_{j=1}^{J} \xi_j(\lambda)\sqrt{\mu_j}\,\phi_j(x)$$

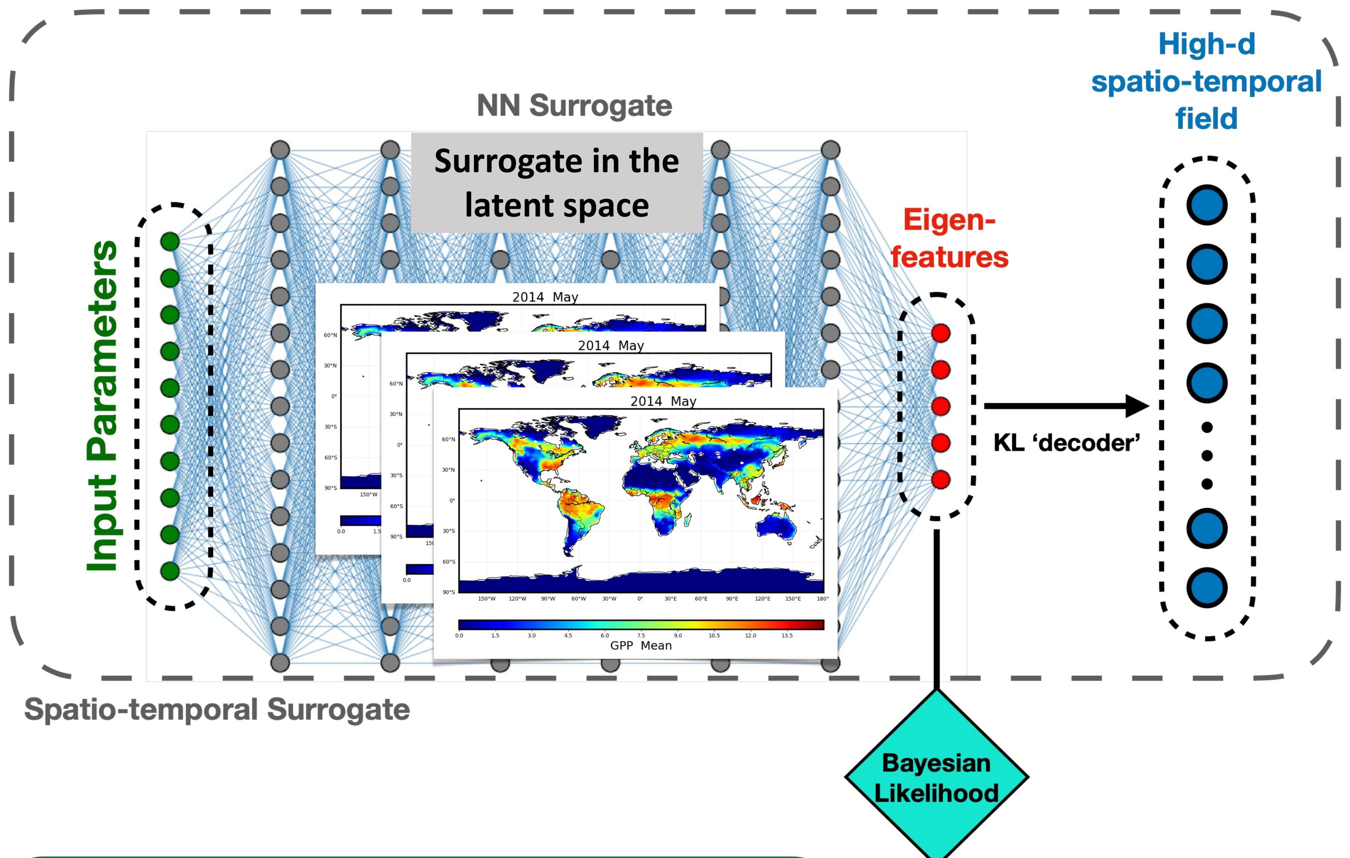
  - ✓ Construct surrogate in the latent eigen-space $\xi(\lambda) \approx \xi_s(\lambda)$

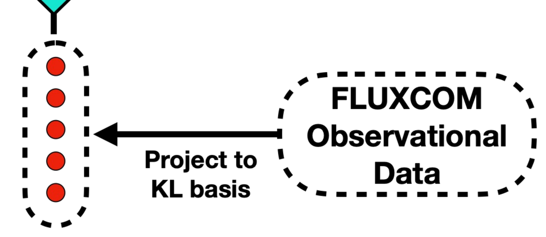
- **Large number of uncertain inputs / high-dimensional stochastic space**
  - ✓ Employ polynomial surrogates with compressed sensing to pick only relevant parameter combinations

$$\xi_s(\lambda) = \sum_{k=1}^{K} c_k \Psi_k(\lambda)$$

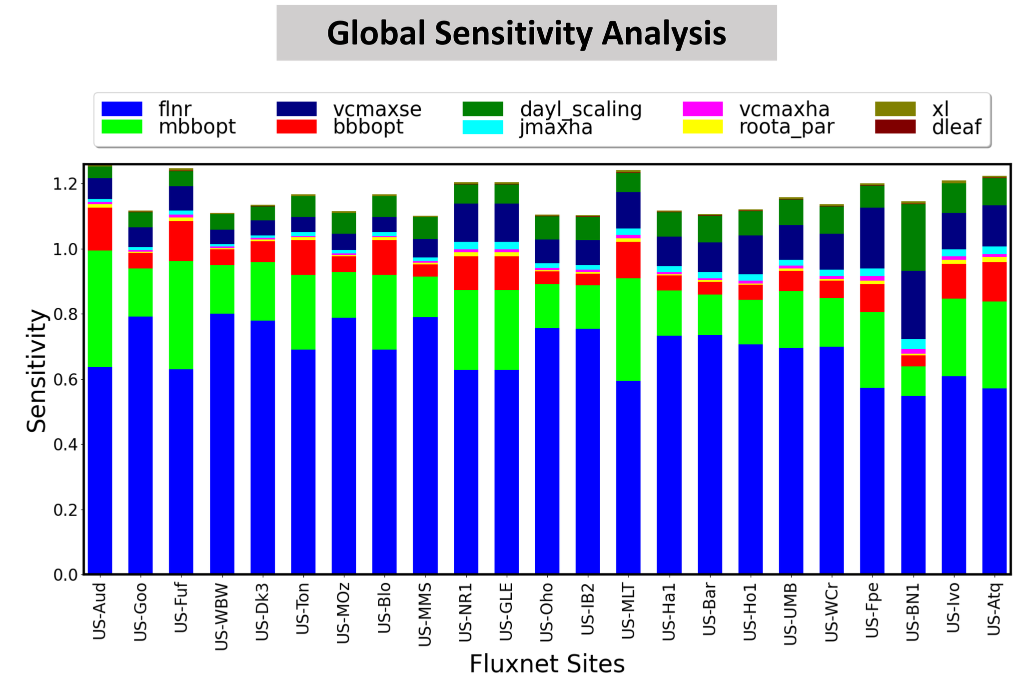
- **Expense of ESM / low number of training simulations**
  - ✓ No real remedy but cross-validation and hyperparameter optimization help.

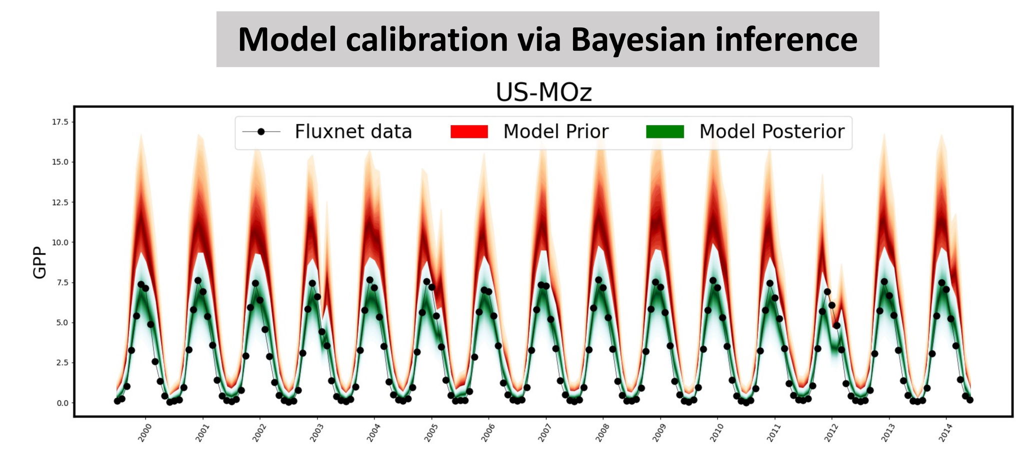
Land Model Calibration enabled by Spatio-Temporal Neural Network Surrogate





- ~5000 spatio-temporal cells down to ~10 eigenfeatures with 1% loss of accuracy
- The overall spatio-temporal surrogate has a fraction of ELM cost





E3SM Energy Exascale Earth System Model

e3sm.org

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