PECAn:
workflow management for data assimilation and forecasting

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ILLINOIS

Overview

Goals

Improve ecological forecasts

Investigate and reduce uncertainty

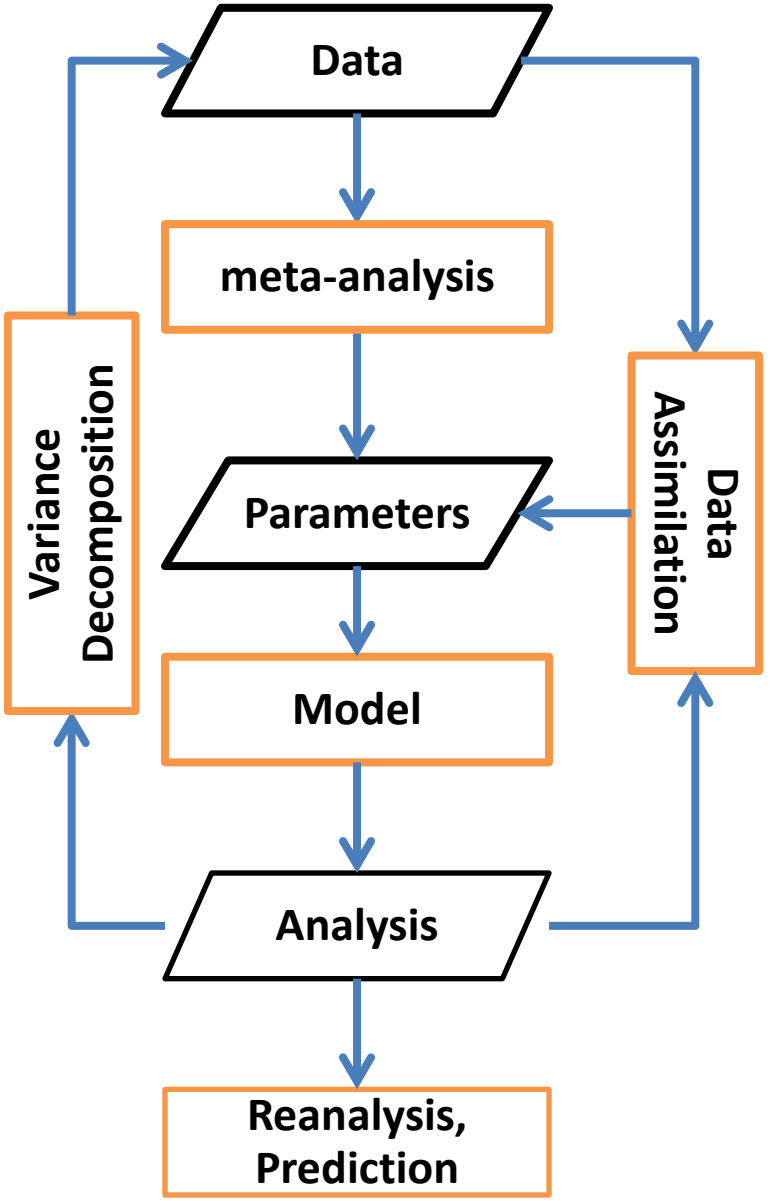
Reproducible computation

Ecosystems

Biofuel Agriculture

- Perennial grass
- Woody crops
- LIHD prairie

Temperate forests



Overview

Approach

Bayesian meta-analysis

Data Summary

ED2 Ecosystem Model

Vegetation Model

Data Assimilation

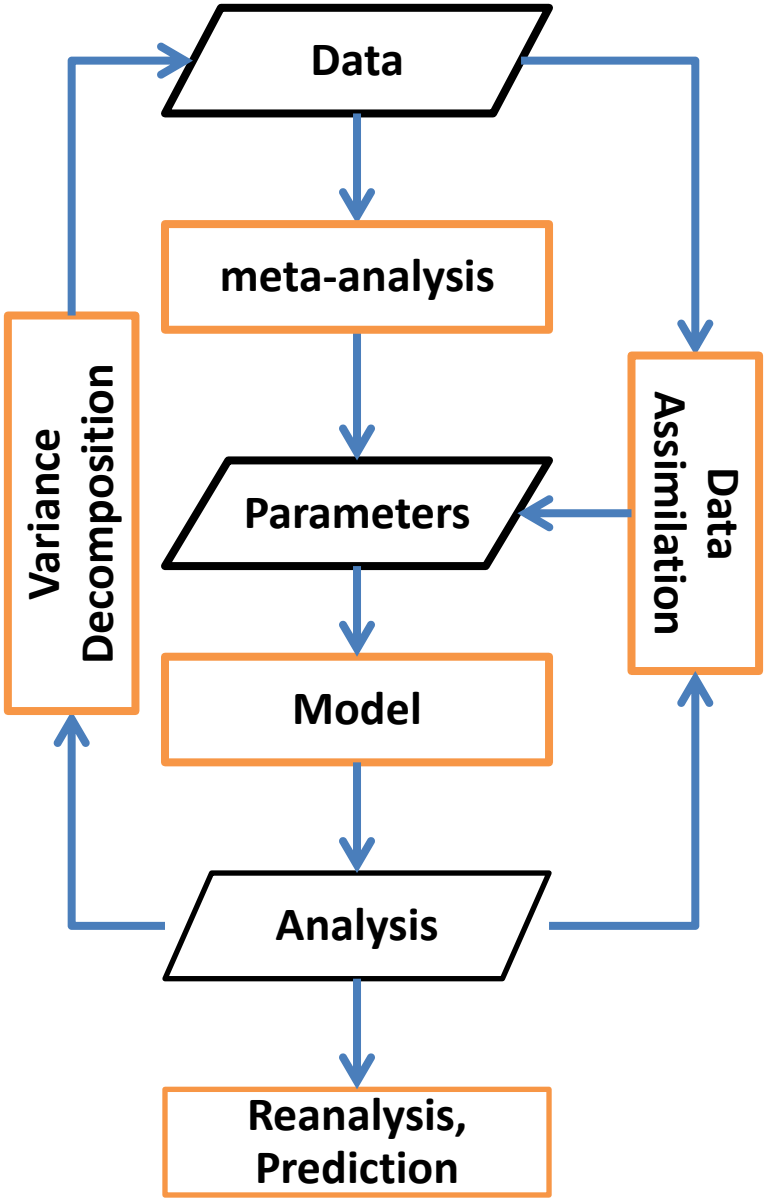
Parameter Constraint

Variance Decomposition

Understand Uncertainty

Workflow management (PECAn)

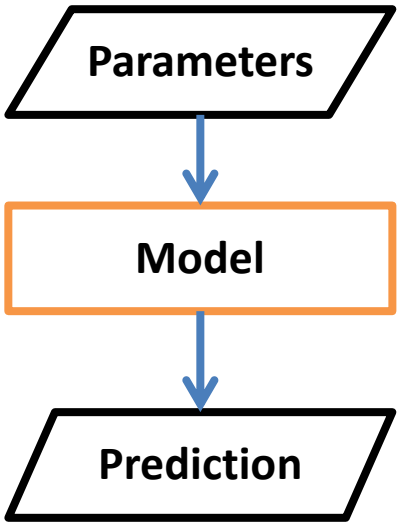
Efficient Computation



Overview: Modeling approaches

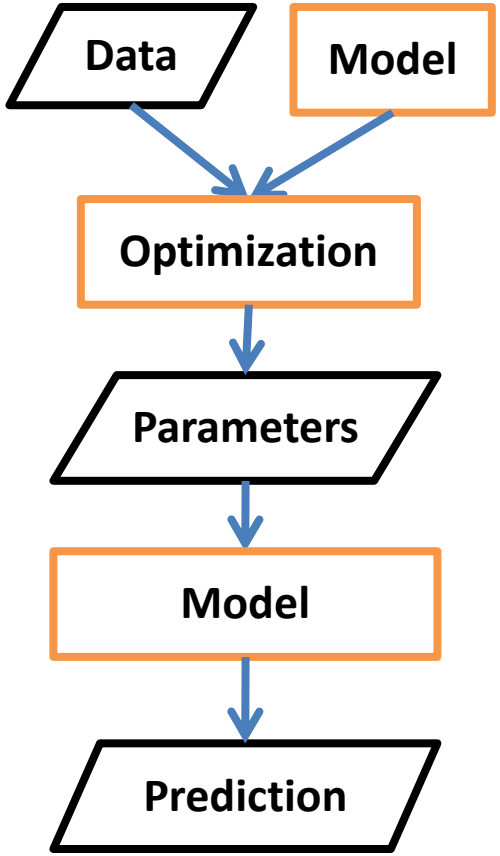
Conventional

No formal data integration



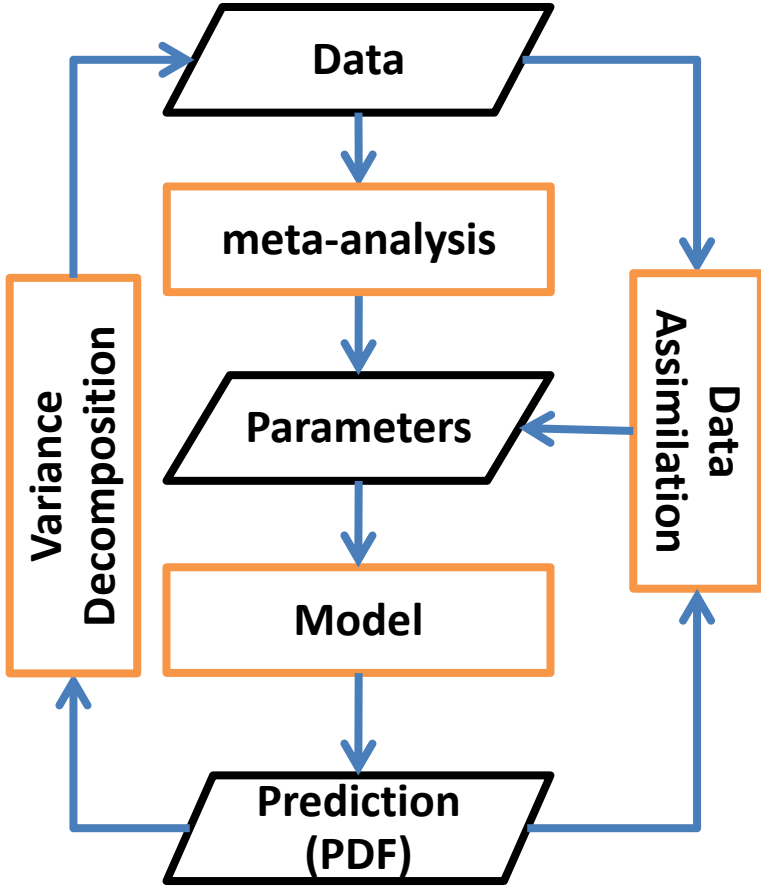
Inversion

Computationally expensive
No PDF of prediction

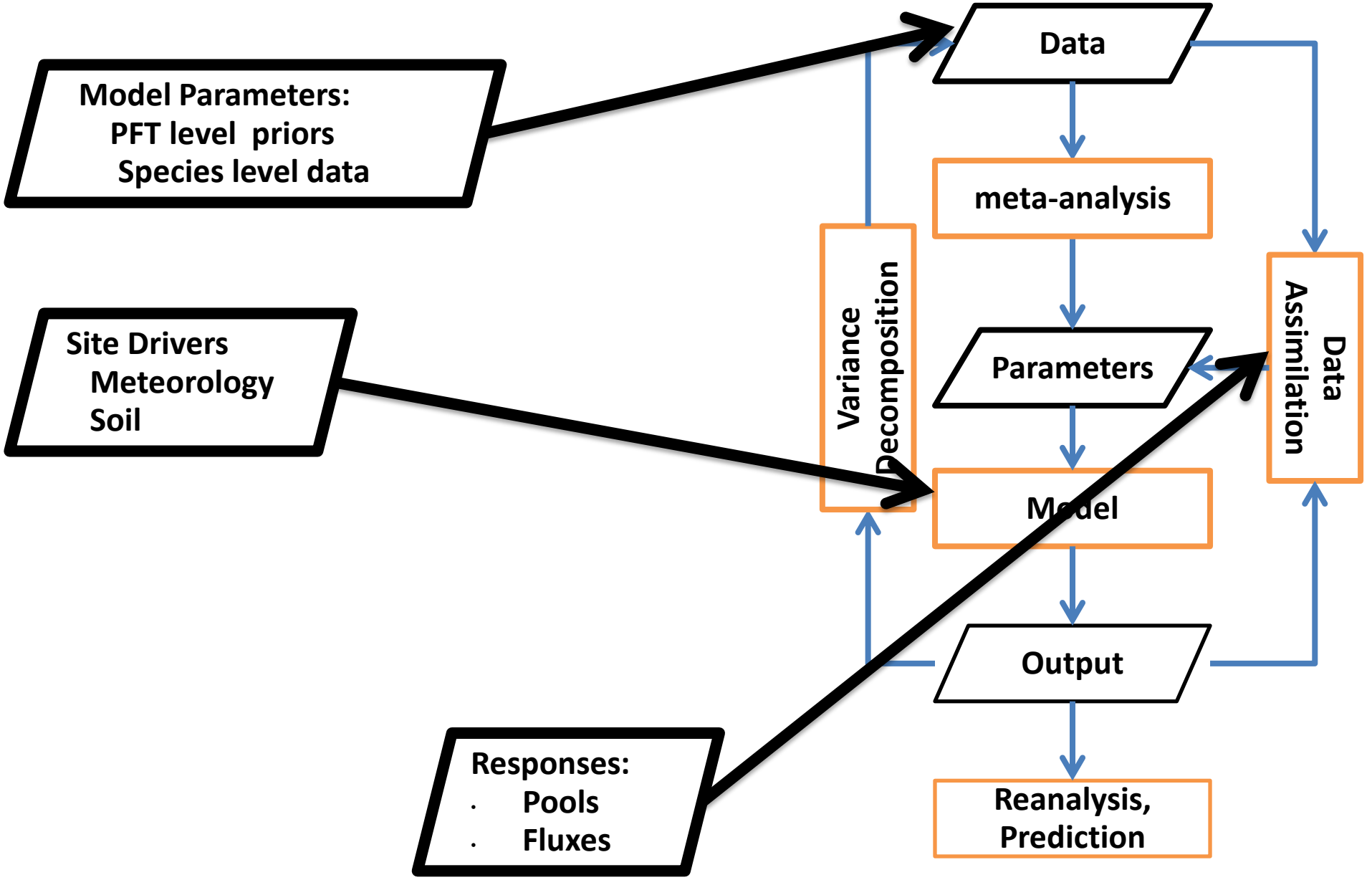


This Study

Probabilistic output
Computationally efficient
Multiple feedbacks to constrain uncertainty

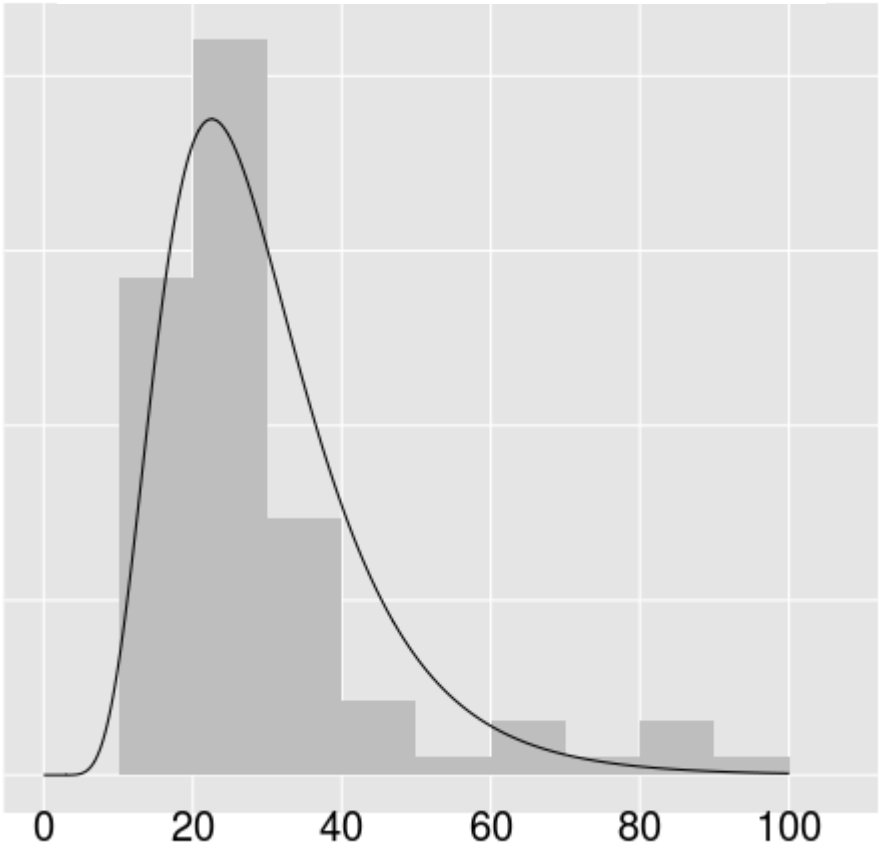


Data


Model Parameters:
PFT level priors
Species level data
Site Drivers
Meteorology
Soil
Responses:
Pools
Fluxes
Data
meta-analysis
Parameters
Model
Output
Reanalysis,
Prediction
Variance
Decomposition
Data
Assimilation

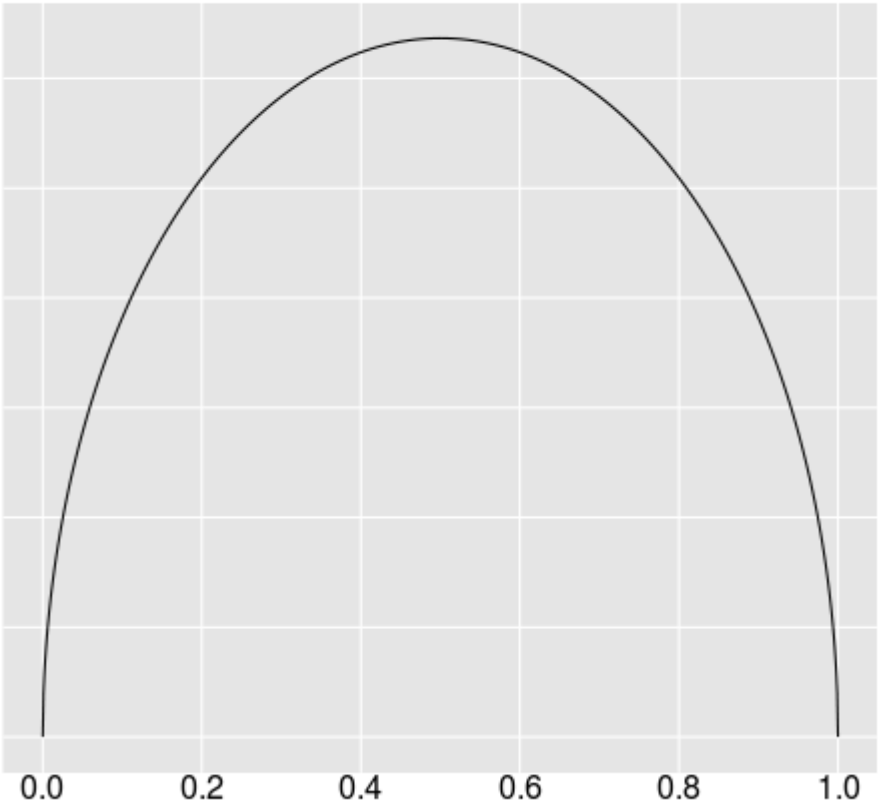
Meta-analysis: Priors for 17 Traits

Leaf C:N (grass)



good constraint:
data from GLOPNET
N=95
c2n~logN(3.3,0.4)

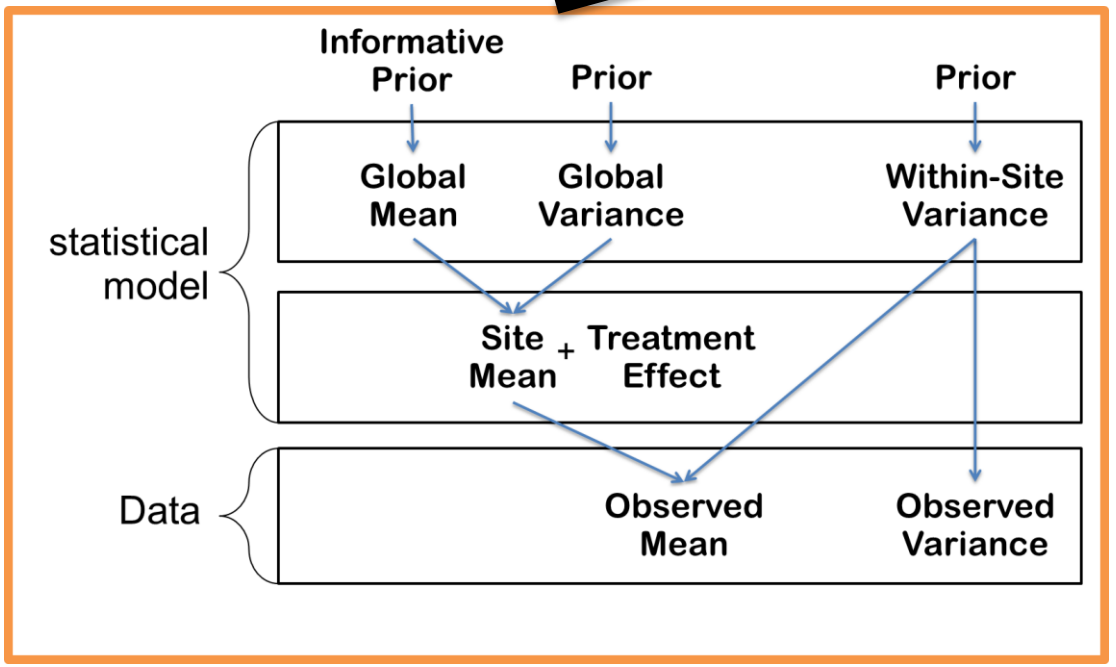
litter labile fraction

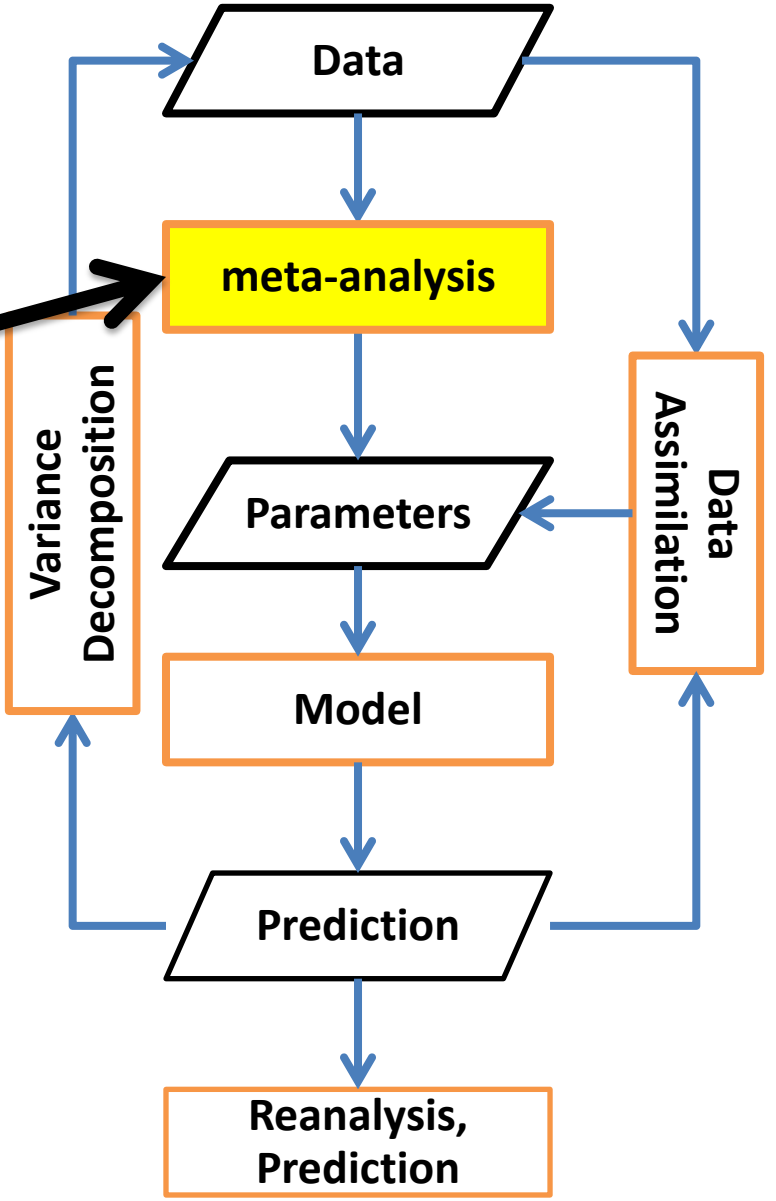


poor constraint:
f_{labile}~beta(1.5,1.5)

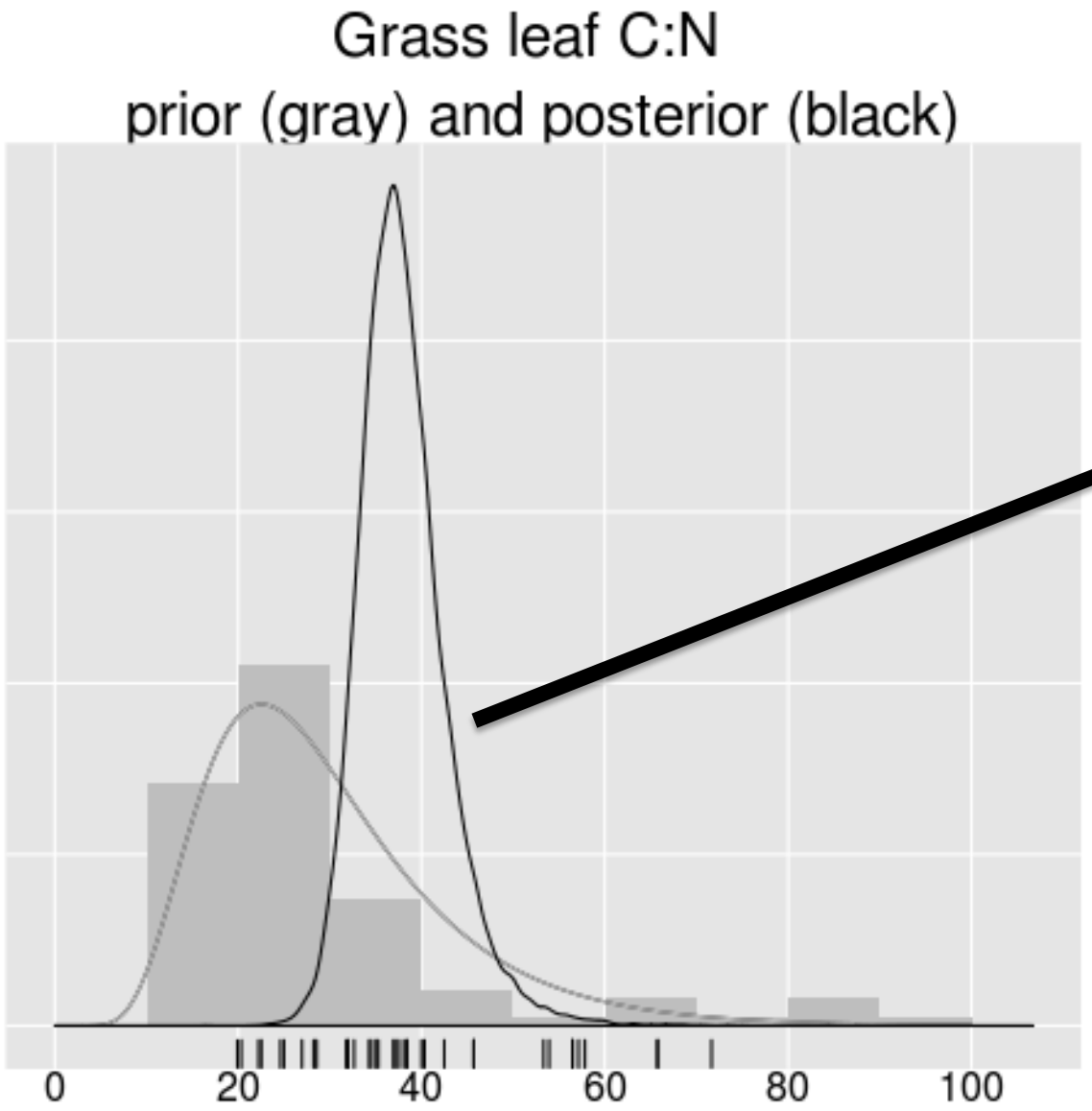
Meta-analysis Posteriors = Model Parameters

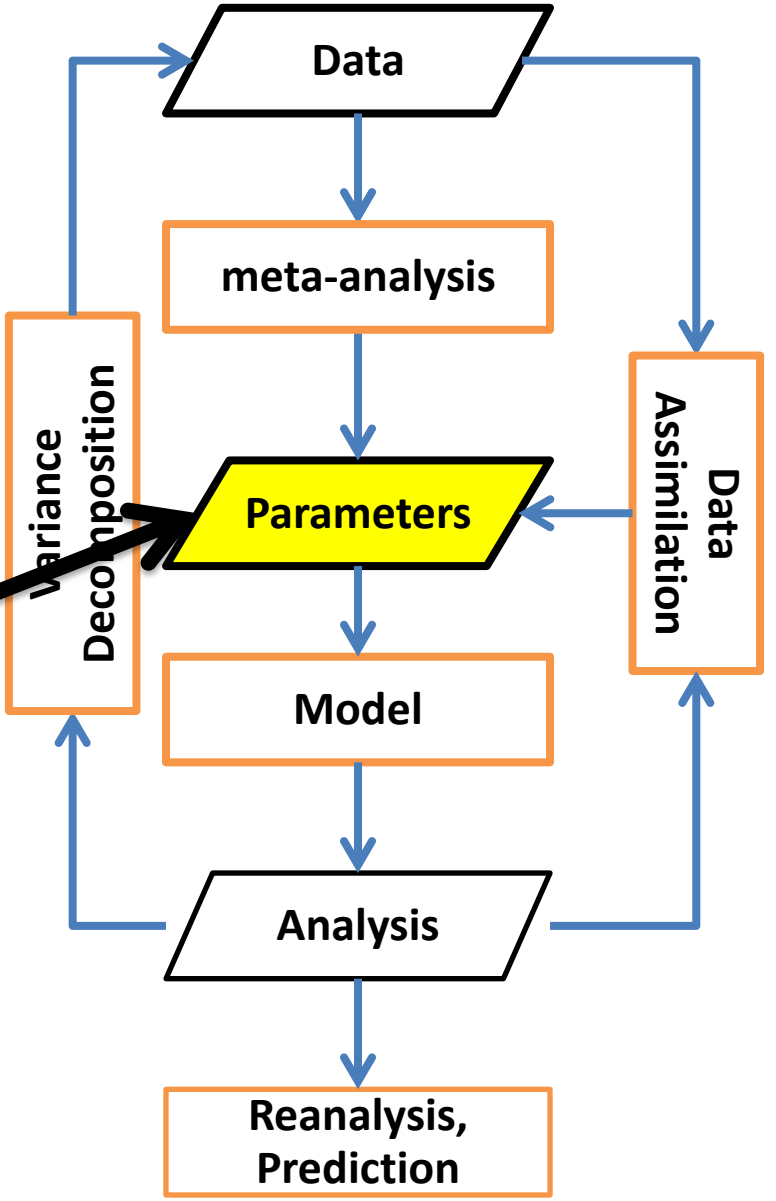
PDF of model parameter combines data with prior





Meta-analysis Posteriors & Model Parameters

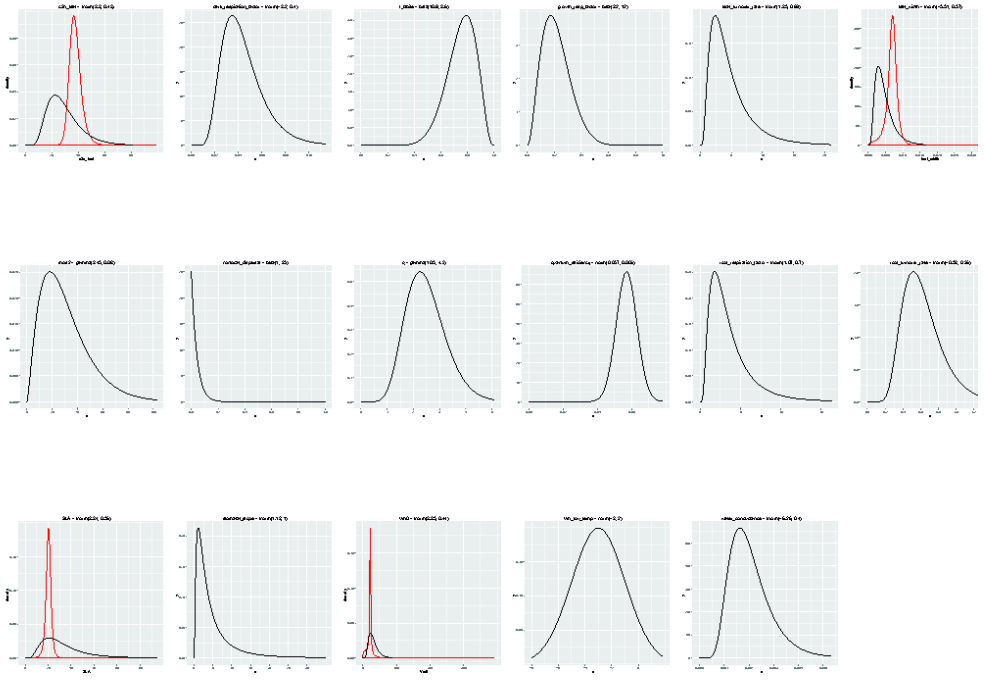




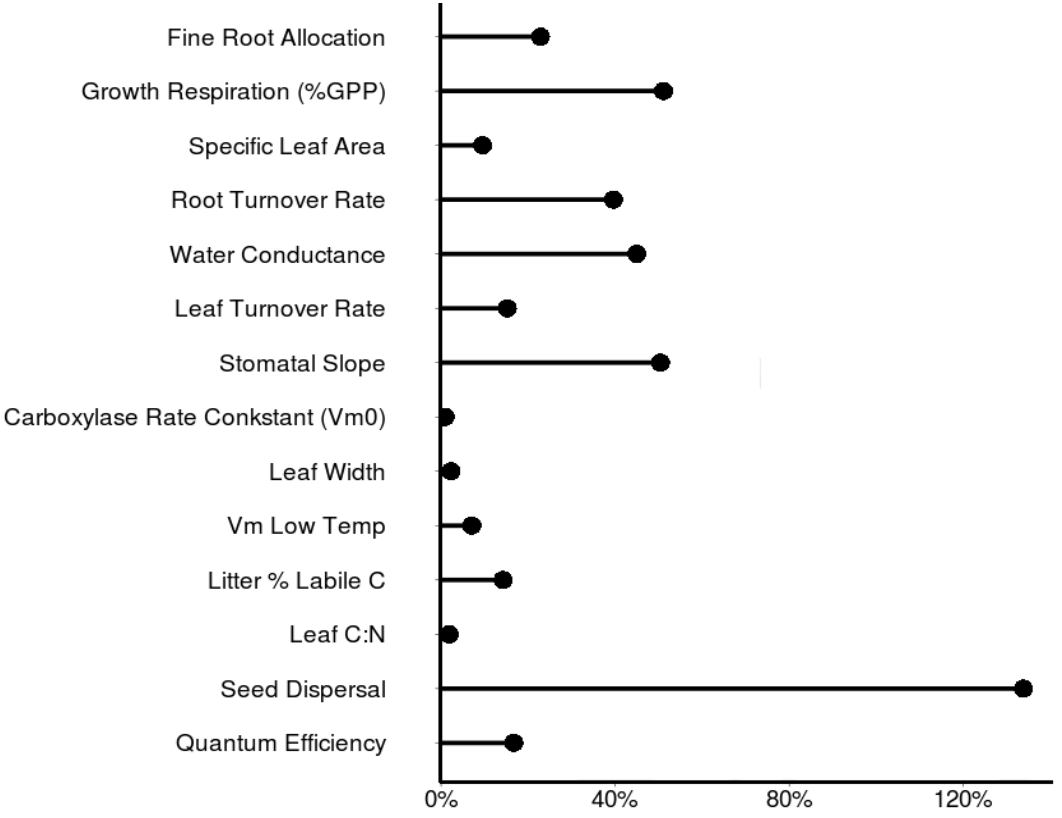
Meta-analysis Posteriors & Model Parameters

500-1000 parameter combinations
pseudo-random samples from PDFs used in model

Parameter PDFS



Parameter CVs

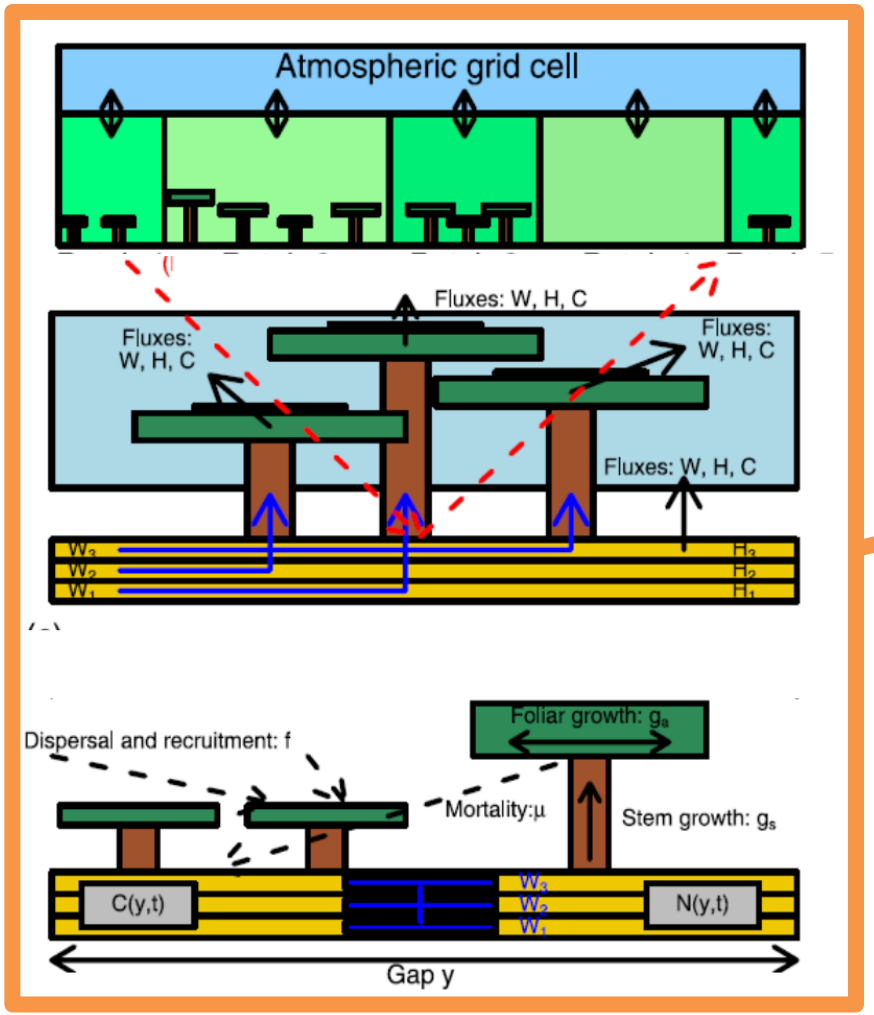


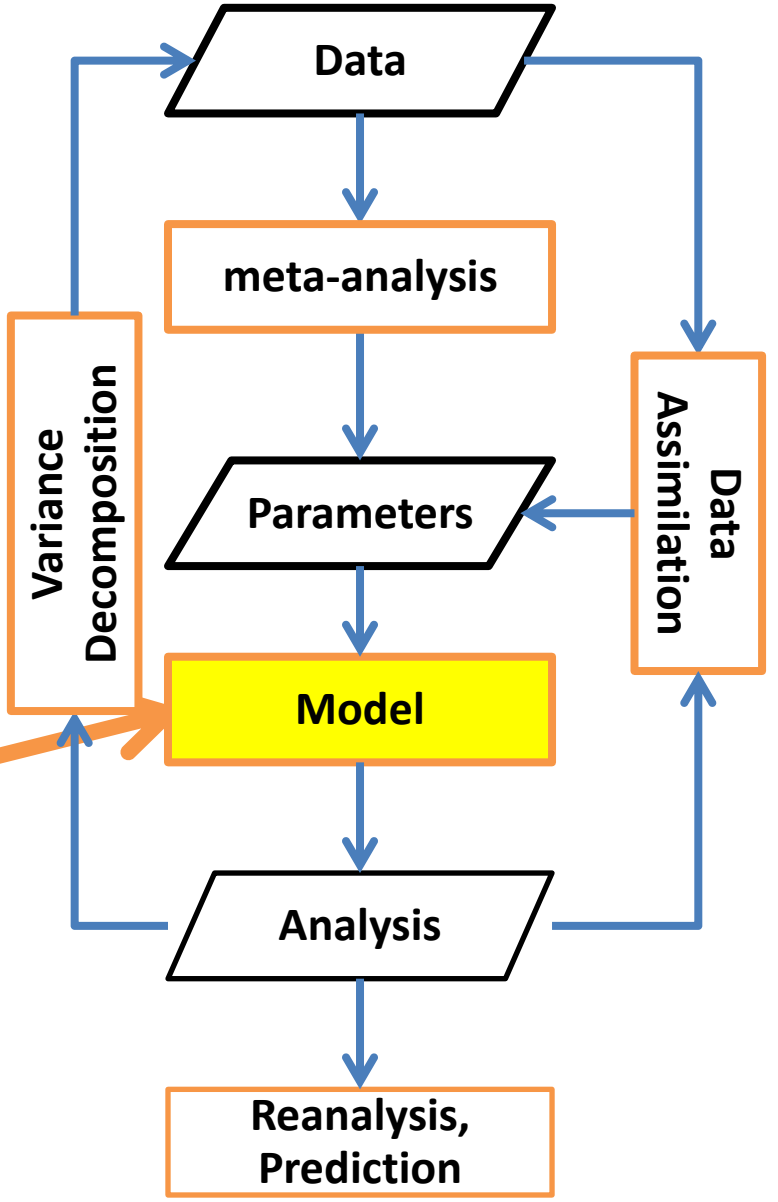
Ecosystem Demography Model (ED)

biophysical ecosystem model

ED2.2 = ED2.1 + Agriculture

- -planting and harvest
- -dynamic allocation and phenology
- -fertilization

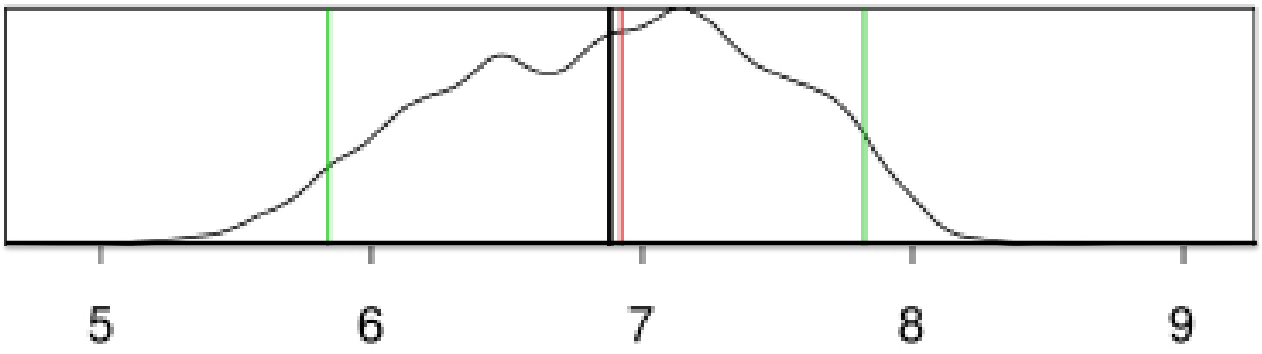


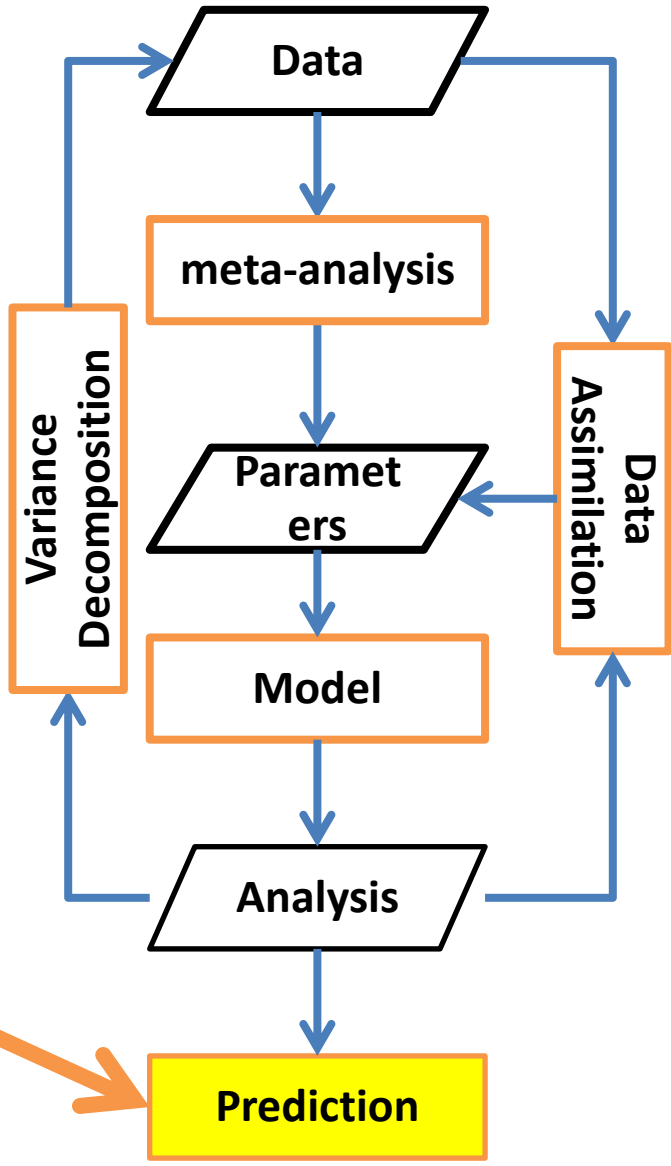


Moorcroft et al. 2001

Medvigy et al. 2009

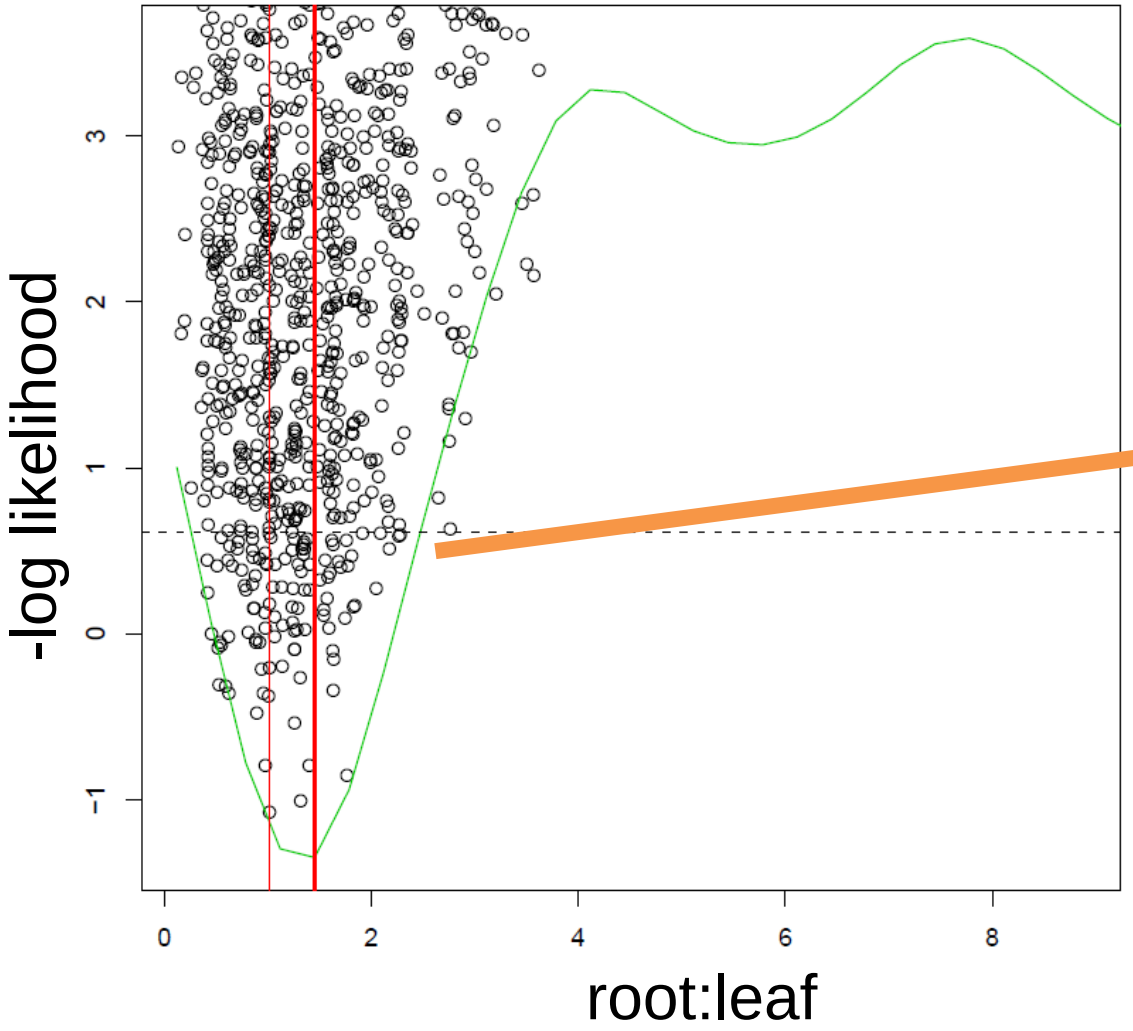
Model Ensemble Posterior

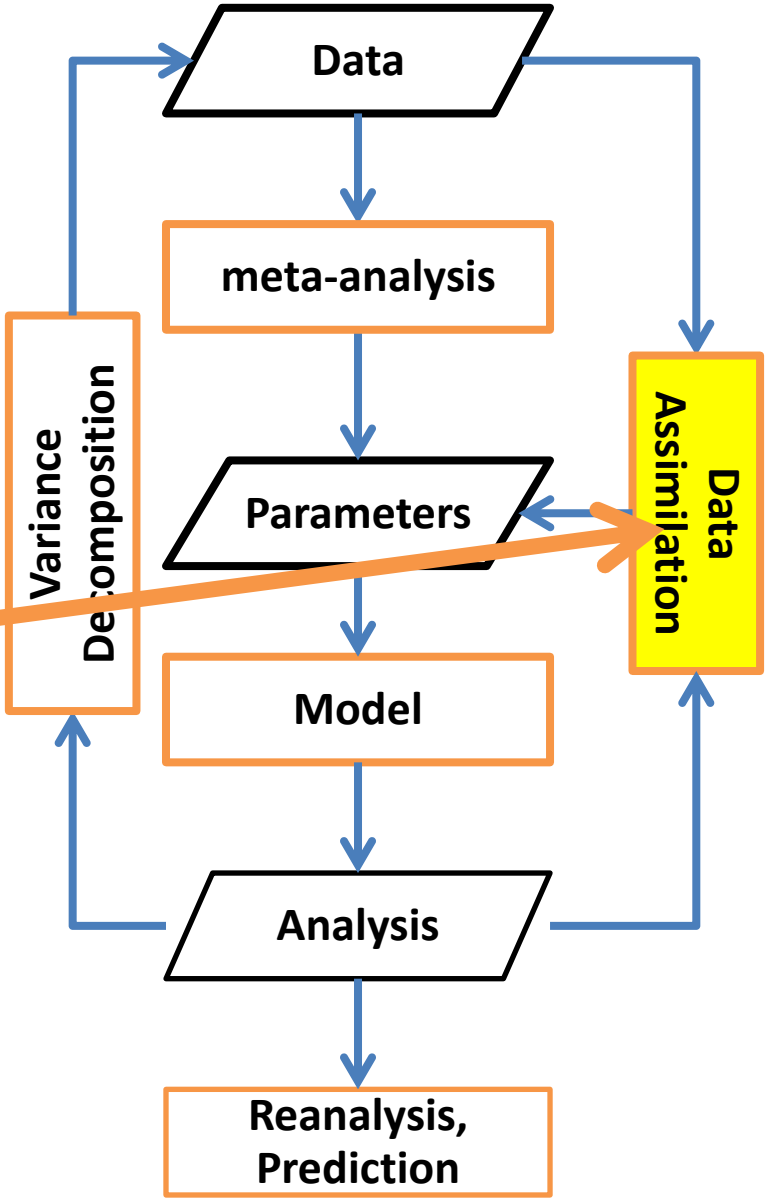




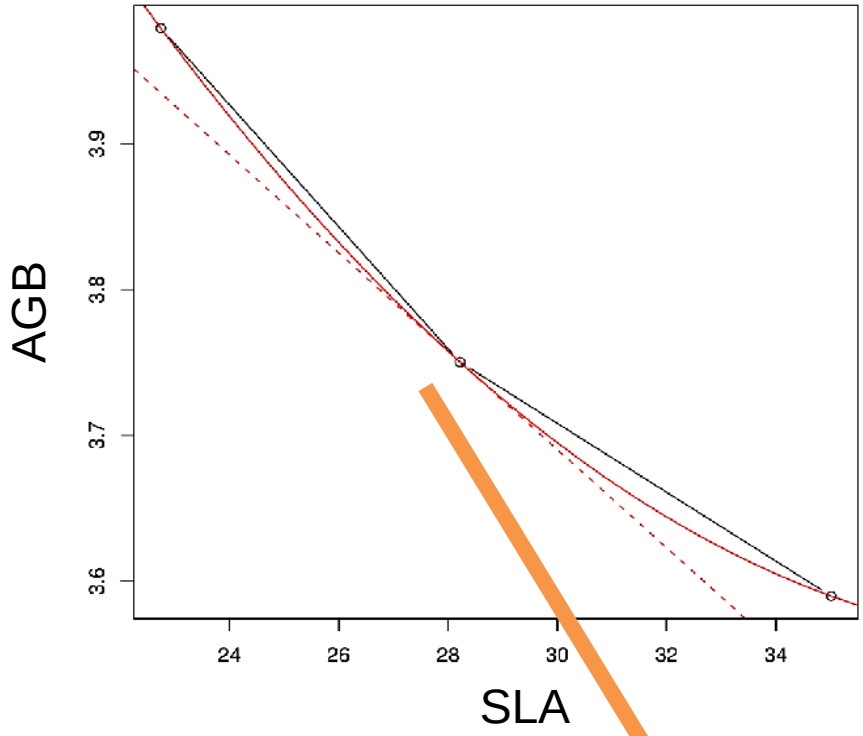
Data Assimilation

L=f(Model output – Observation)





Variance Decomposition

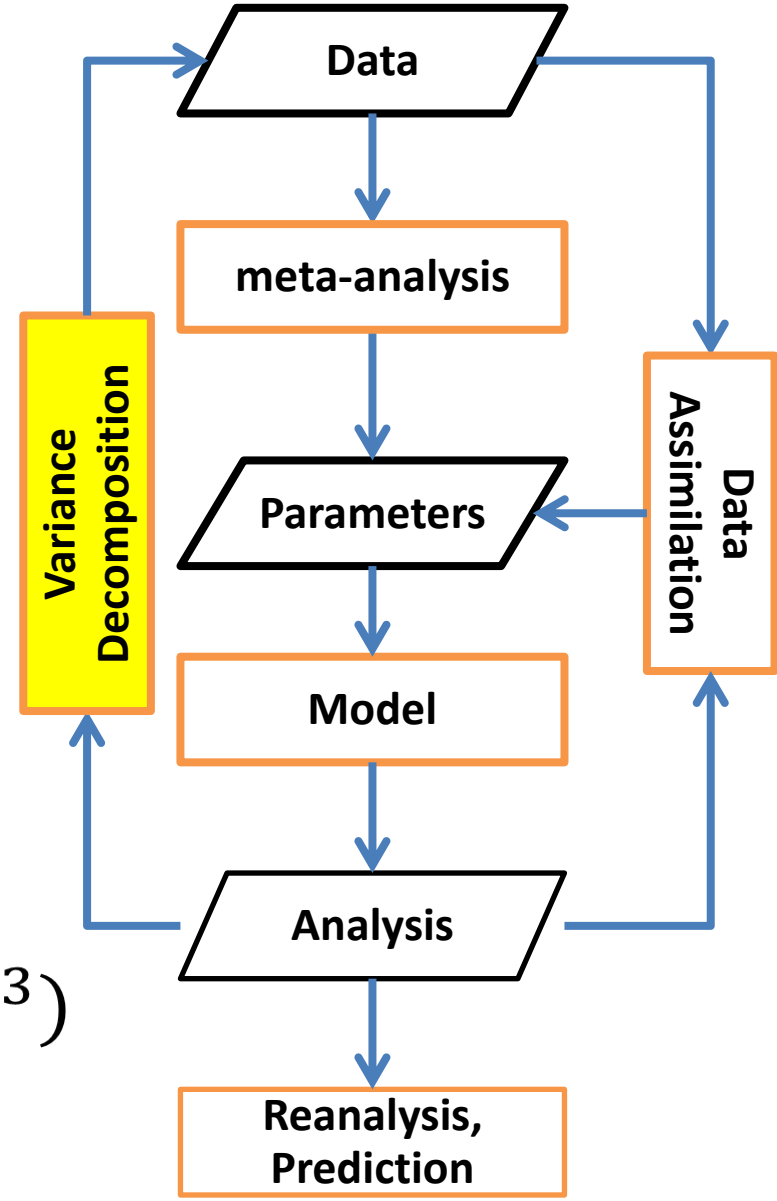


Sensitivity Analysis

Ensemble Variance

$$Var(Y) = \sum Var[\Theta_i] \left(\frac{dY}{d\Theta_i}\right)^2 + O(\Theta^3)$$

Posterior Parameter Variance



Variance Decomposition

$$Var(Y) = \sum Var[\Theta_i]\left(\frac{dY}{d\Theta_i}\right)^2 + O(\Theta^3)$$

CV

$\sqrt{Var(\Theta_i)}/\bar{\Theta}_i$

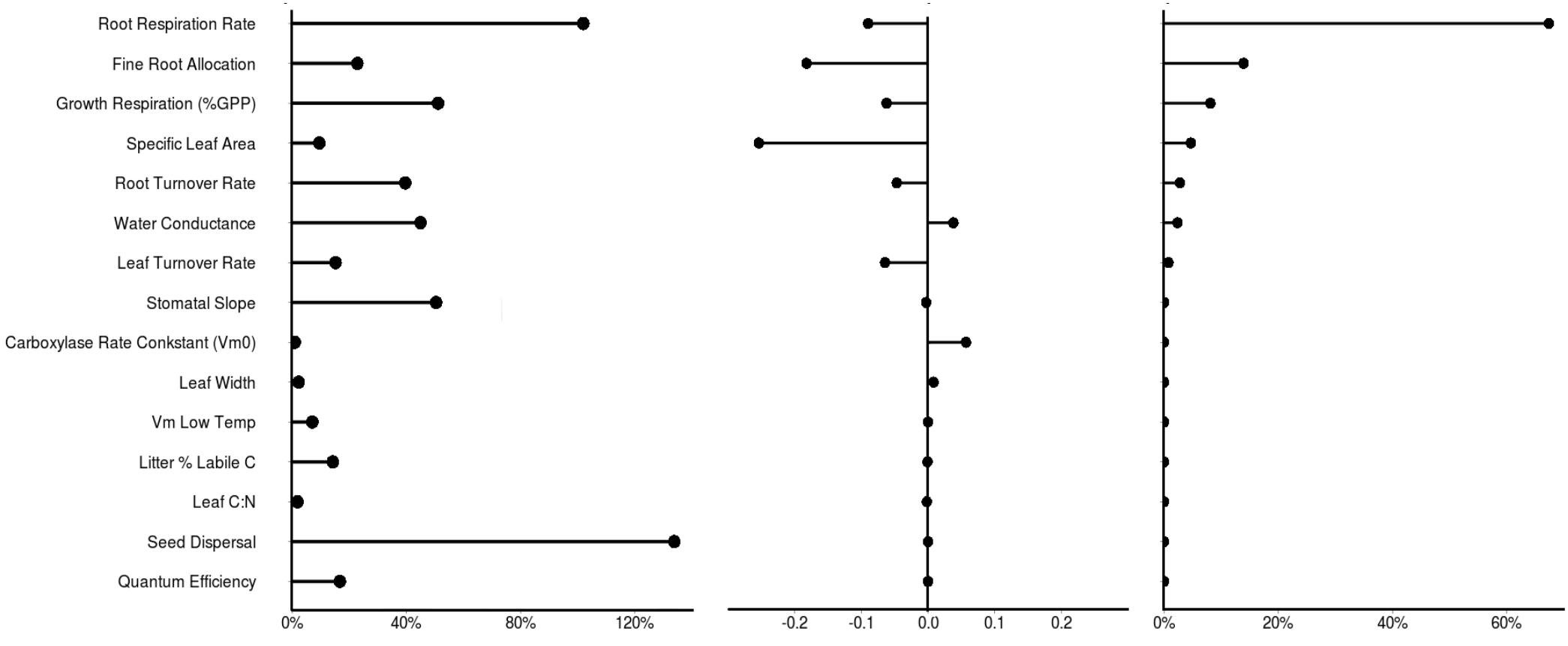
Elasticity

(Normalized Sensitivity)

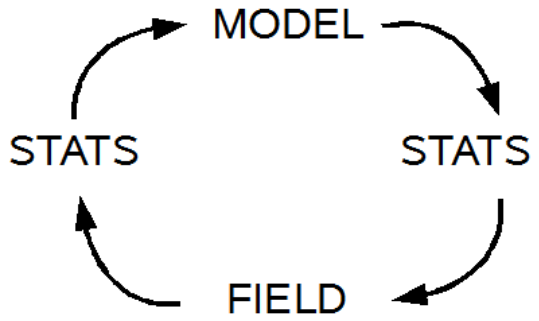
$\frac{dY}{d\Theta_i}\Big/\frac{\bar{Y}}{\bar{\Theta}}$

% Variance

$Var(\Theta_i)\Big/\sum Var(\Theta)$



Model-data feedback

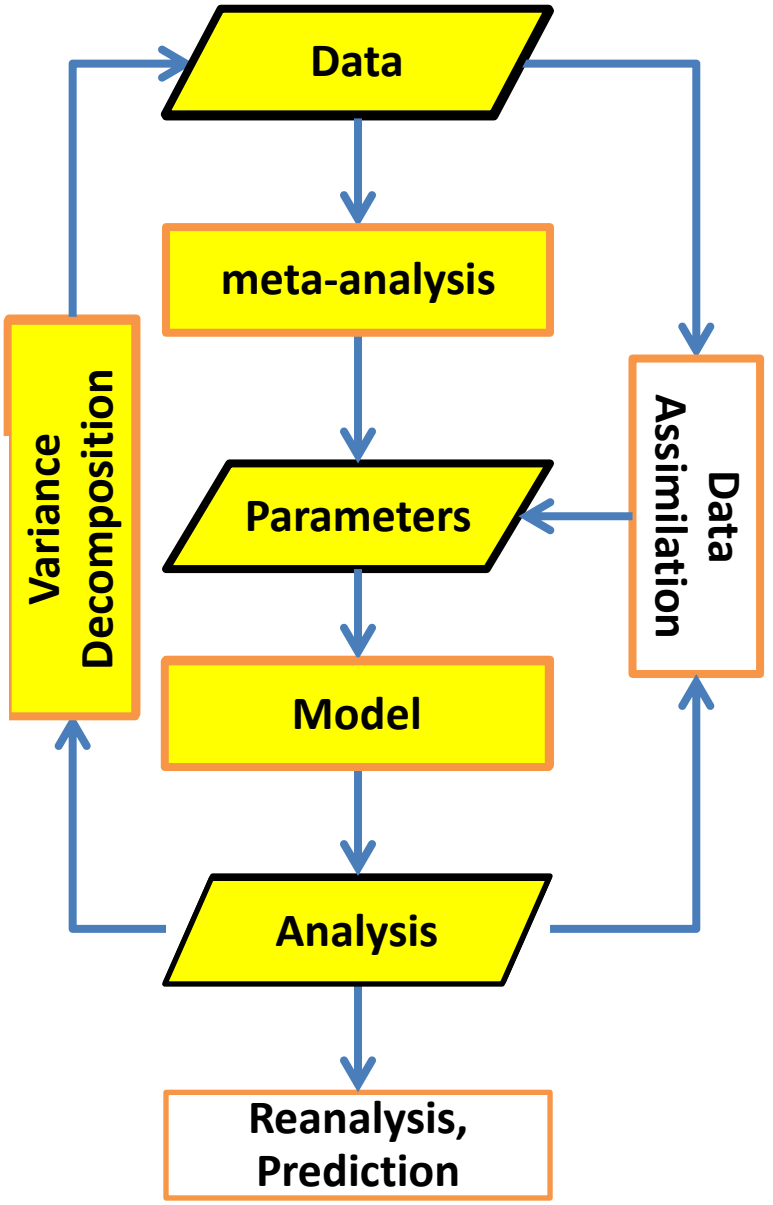


Reducing Uncertainty:

- given dY/dΘ, n, cost/sample
- identify target data

E.G. for switchgrass

- root respiration data top priority
- would need n=800 to reduce var(SLA) by ½
- for new species, SLA is 1st priority



Next steps

- Real time forecasting and data-assimilation
  - 10 day weather
  - 9 month climate
  - daily flux data
  - Yield, Spectral, other data as available
- Operational estimates of yield, other ecosystem functions
- Requires automation, thus PECAn

PECAn:

the Predictive Ecosystem C-cycle Analyzer

1. Workflow Manager
    - Directs computational steps
    - Automates and documents workflow
2. Applications
    - Biofuel crops
    - Temperate forests
    - Assimilation of data and models across scales - Fluxnet, NEON

Conclusions

- Integrate diverse available data into forecasts and reanalysis that reflect state of scientific understanding
- Uncertainty propagation and investigation
- Kriged Likelihood surface improves efficiency
- PECAn automates and documents computation
- PECAn makes modeling accessible and reproducible

Acknowledgements

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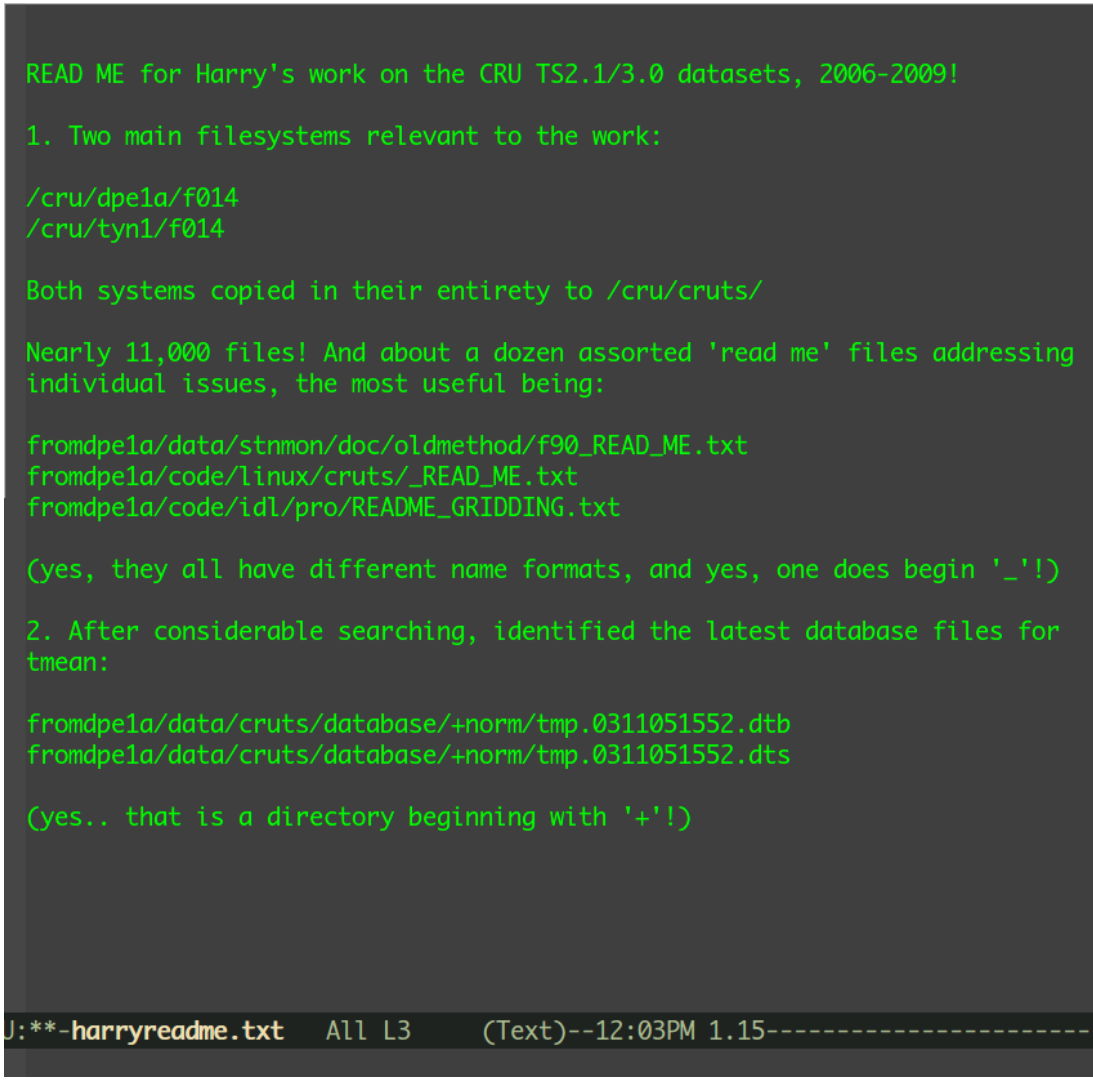
Biosciences
Institute

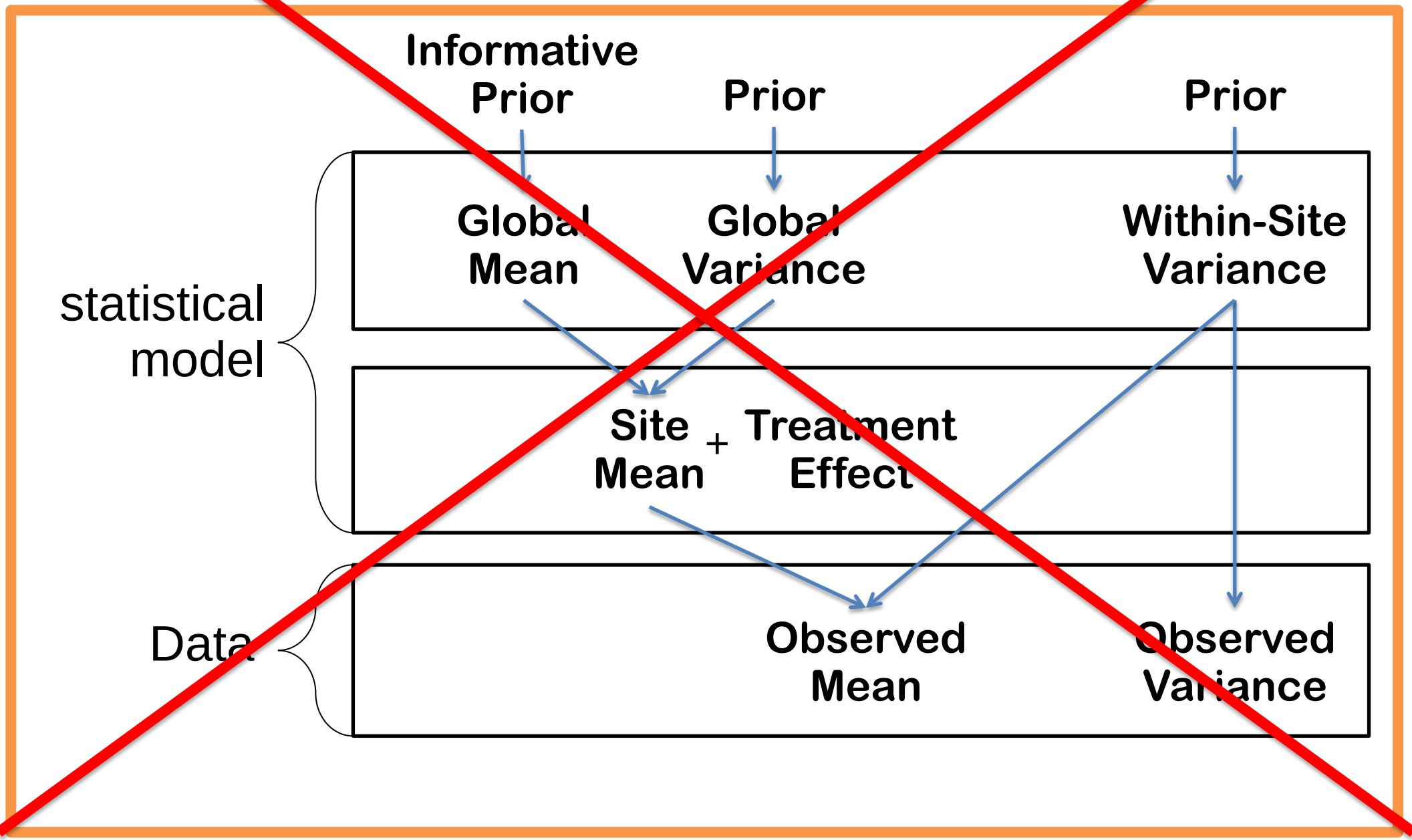
Workflow management

What is it?

Why is it important?



# Meta-Analysis:
Parameter = f(Priors, Data)



A more user friendly approach

Sensitivity Analysis

Inputs: $\boldsymbol{\Theta_i}$

Outputs: $\boldsymbol{Y}$

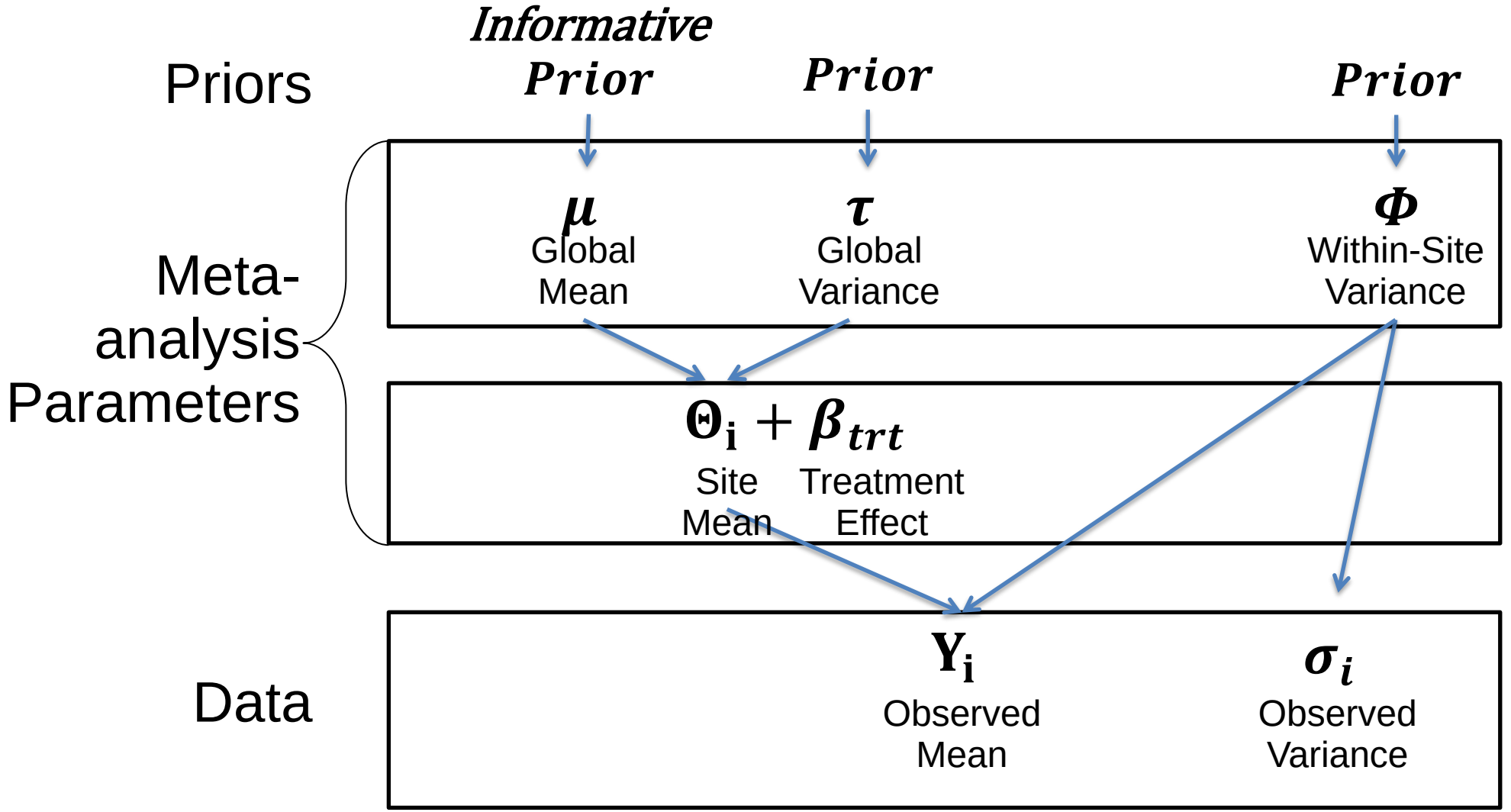
Sensitivity: $\boldsymbol{\frac{dY}{d\Theta_i}}$

Elasticity: $\boldsymbol{\frac{\frac{dY}{d\Theta}}{\frac{\bar{f}}{\bar{\Theta}}}}$

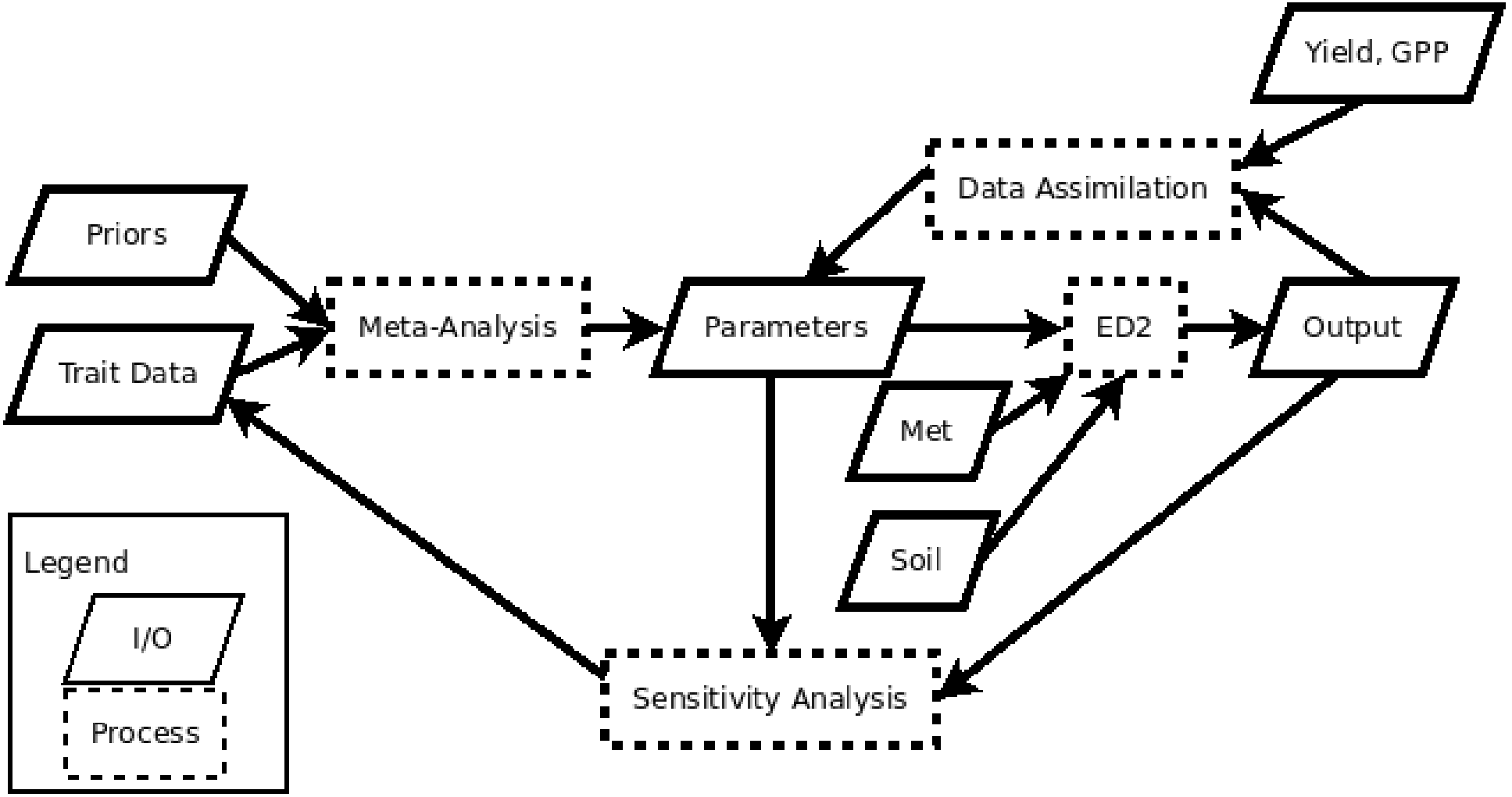
Ensemble Variance

$$Var(Y) = \sum \underbrace{Var[\Theta_i]}_{\text{Posterior Parameter Variance}} \overbrace{\left(\frac{dY}{d\Theta_i}\right)^2}^{\text{Sensitivity}} + Var[\Theta_i - \bar{\Theta}]\left(\frac{d^2Y}{d{\Theta_i}^2}\right) + O(\Theta^4)$$

Meta-Analysis of Plant Traits



Introduction

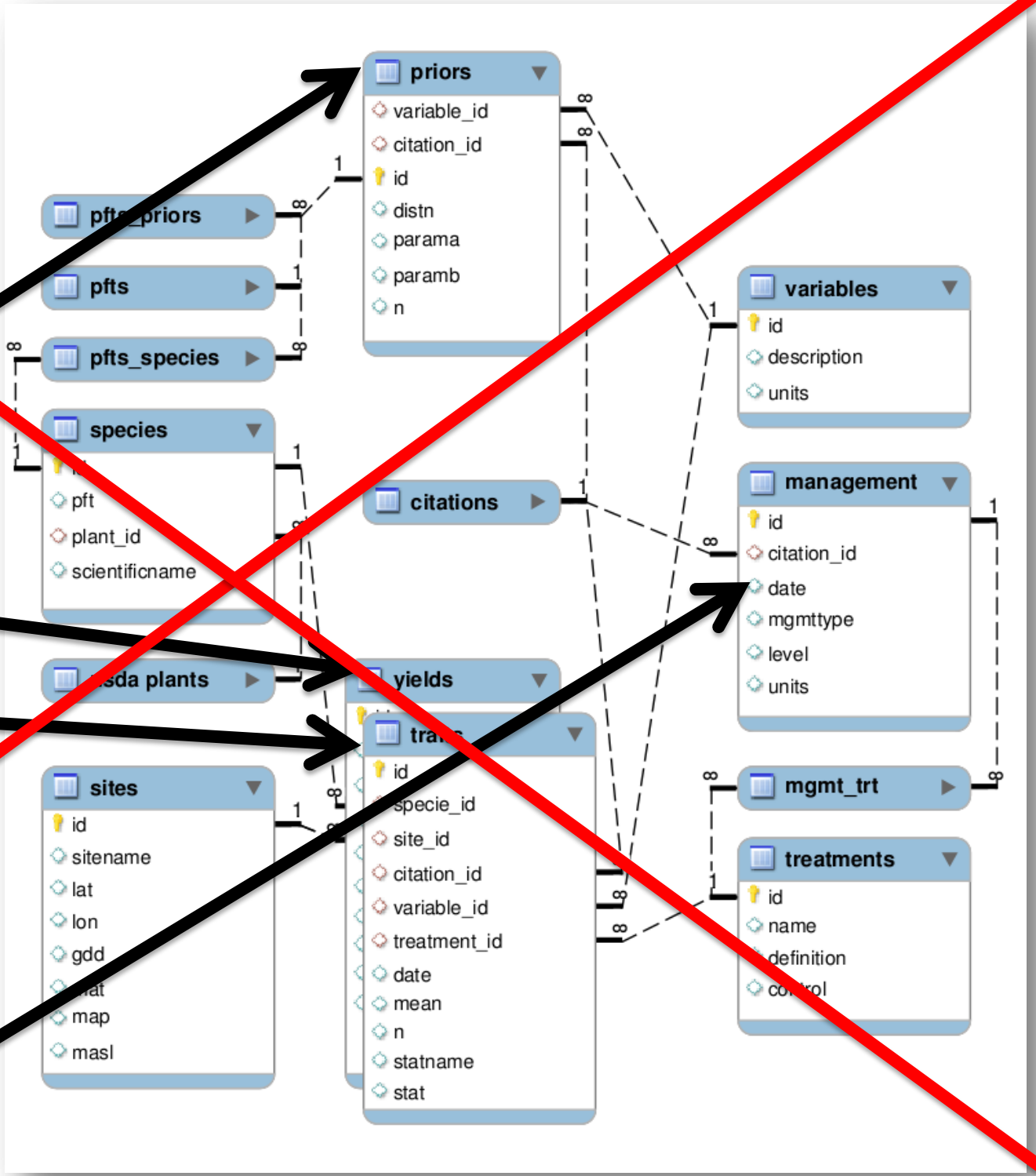


BETYdb Database

Data

- Priors
- Yields
- Traits
- Management

Consistent record of covariates



Variance Decomposition

Ensemble Variance

Sensitivity Analysis

$$Var(Y) = \sum Var[\Theta_i] \left(\frac{dY}{d\Theta_i} \right)^2 + O(\Theta^3)$$

Posterior Parameter Variance

Variance Decomposition: Sensitivity Analysis

- Evaluate model at posterior
- Estimate
- quadratic