Measurement and Modeling of Soil C and Soil GHGs

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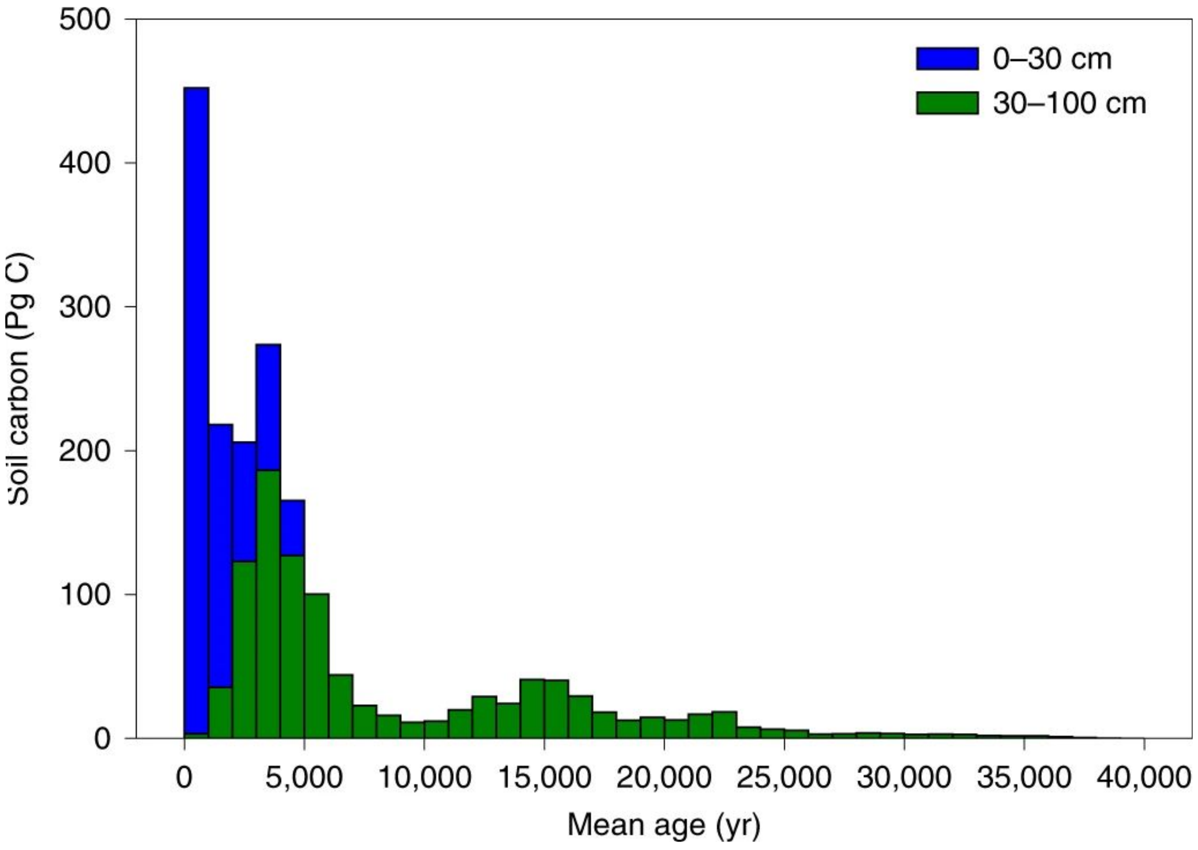
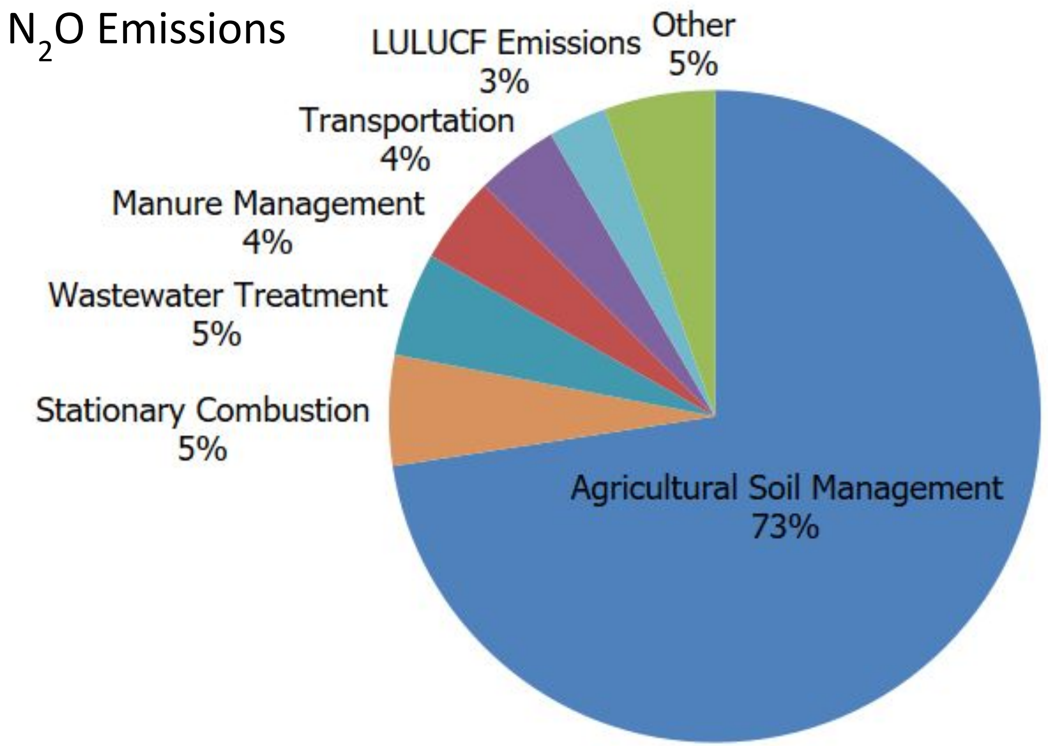
Colorado State University

Why Enhance Agricultural Soil C Stocks?



Shi et al., Nature Geosciences, 2020

Why reduce other GHG emissions from Agriculture?



U.S. Environmental Protection Agency (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

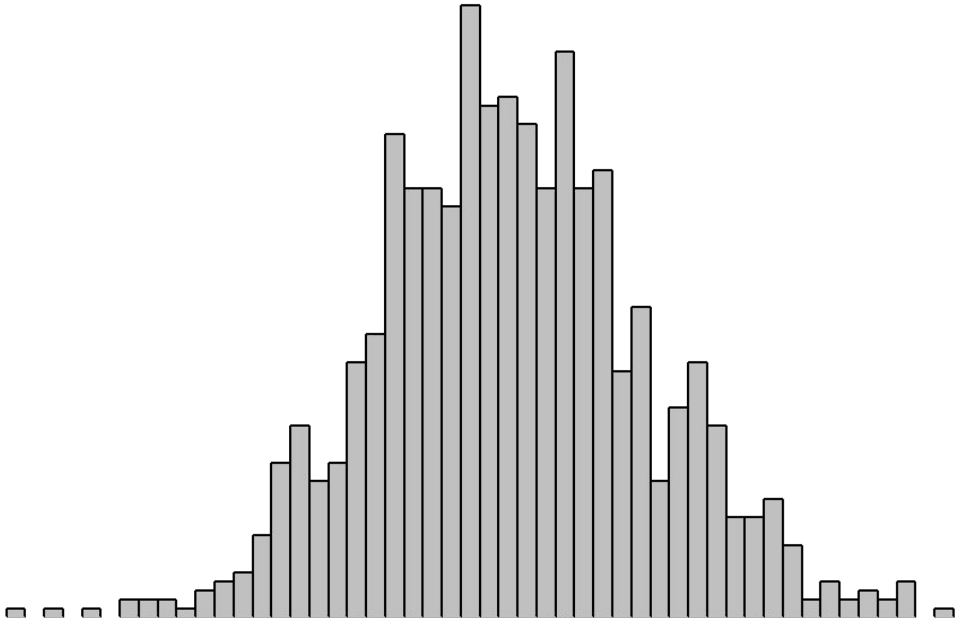
Key Challenge: Quantifying the Benefit

… ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that they are precise so far as practicable …

2019 IPCC Refinement to the 2006 National GHG Inventory Guidelines

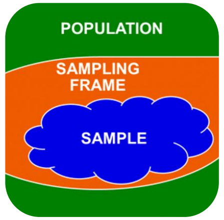
US-EPA National GHG Inventory Report

Uncertainty and Risk

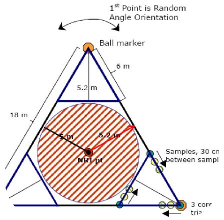


Estimating Soil Organic C Stock Change and GHG Emissions

Measurement-Based Approach



Sampling Design

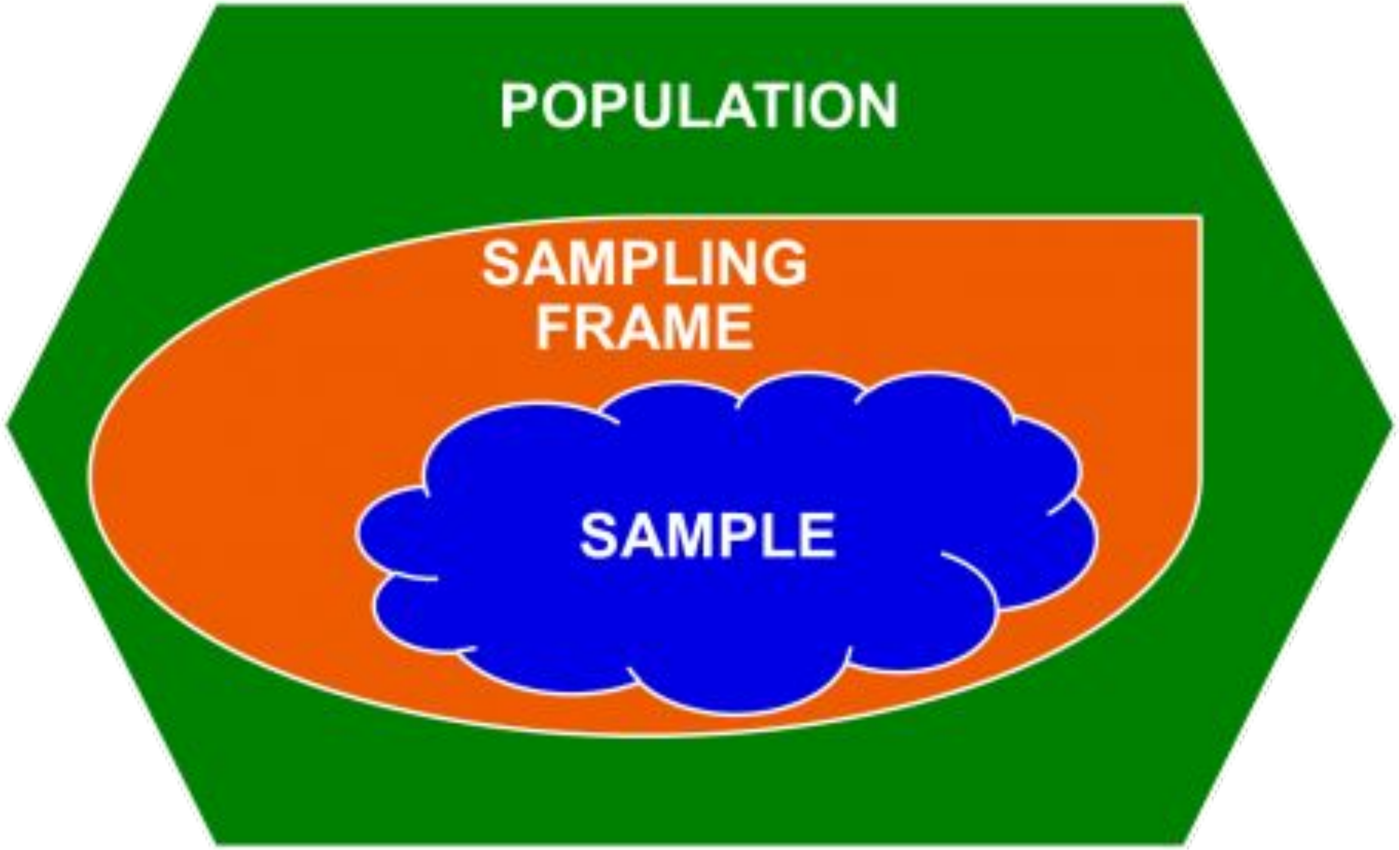


Sampling Methods

Soil Preparation/Laboratory Analysis

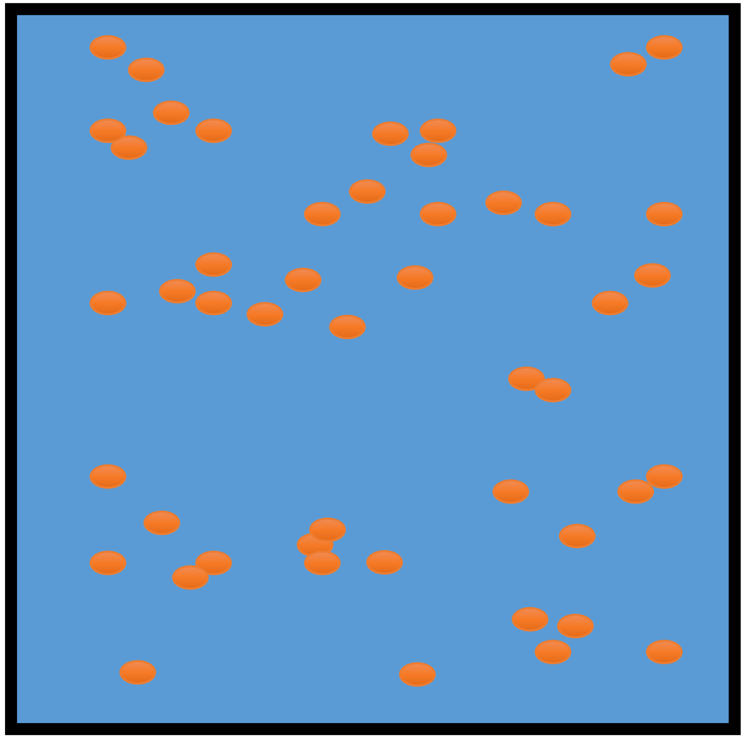
Calculate SOC Stock Change and GHG Emissions

Samplin g Design

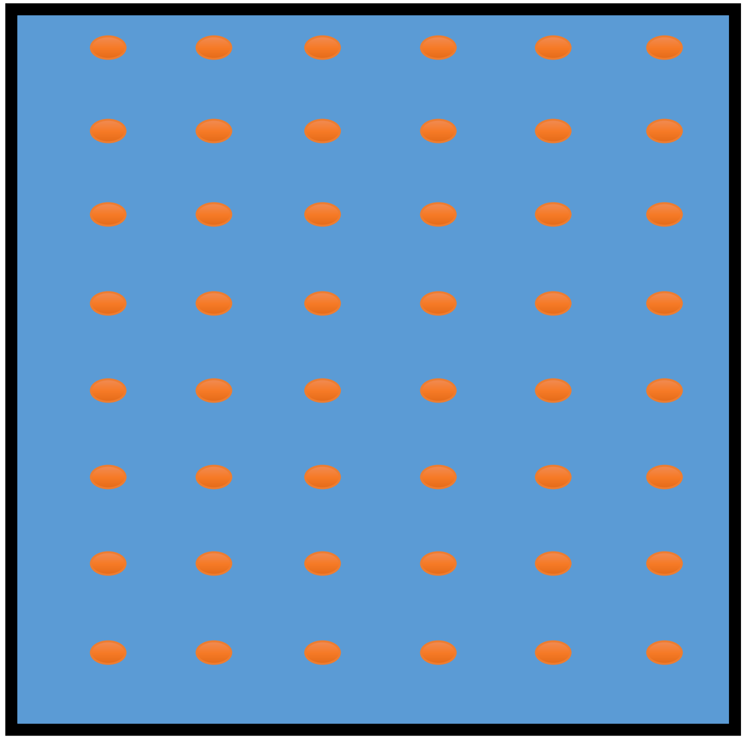


Sampling Design

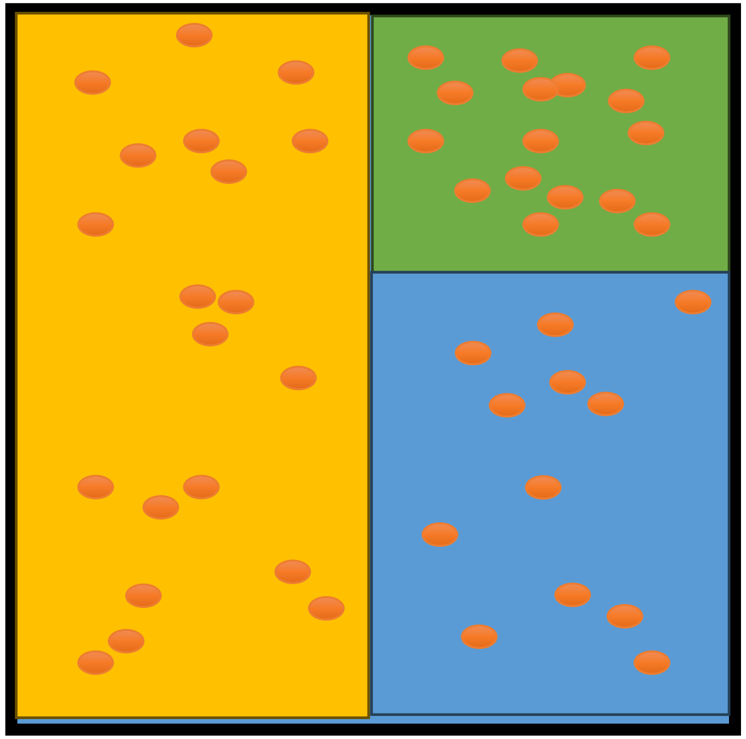
Project Domain



Simple Random Sampling

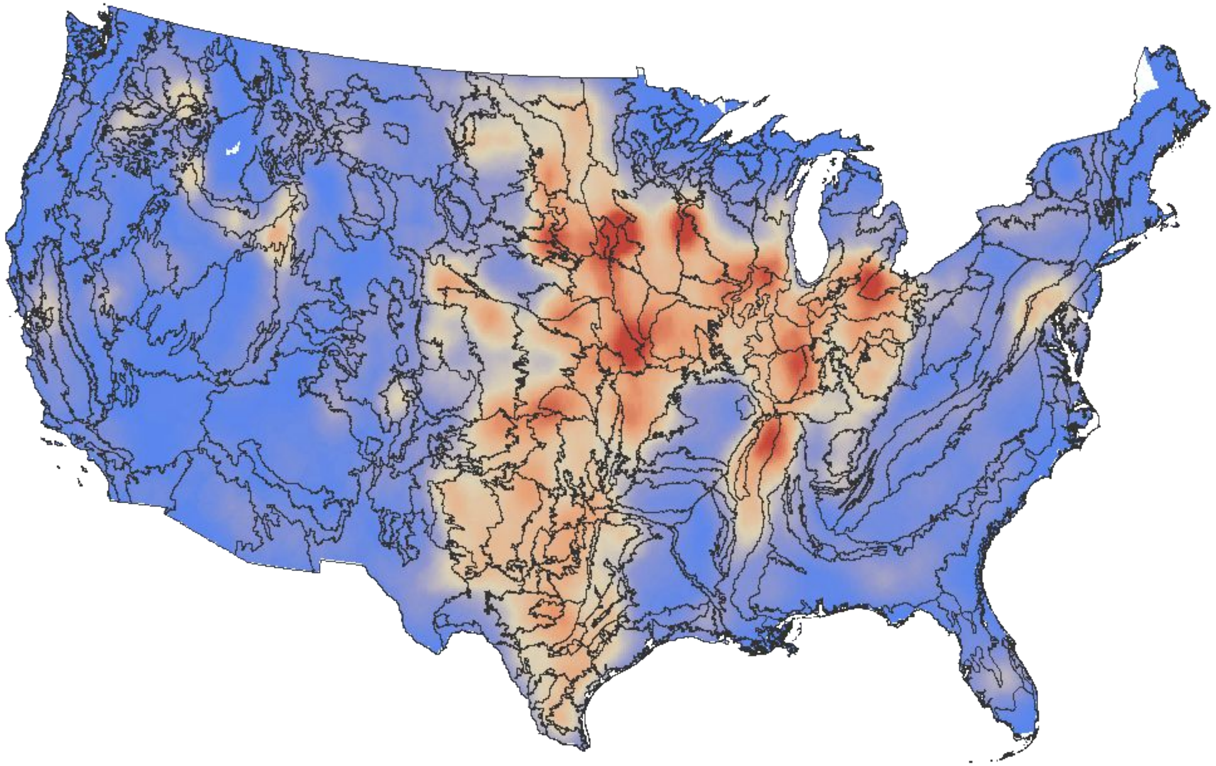


Systematic Random Sampling

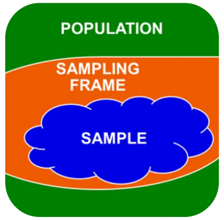


Stratified Random Sampling

Scale is Important!



Measurement-Based Approach



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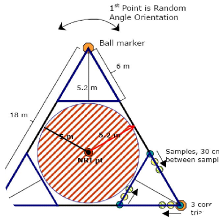
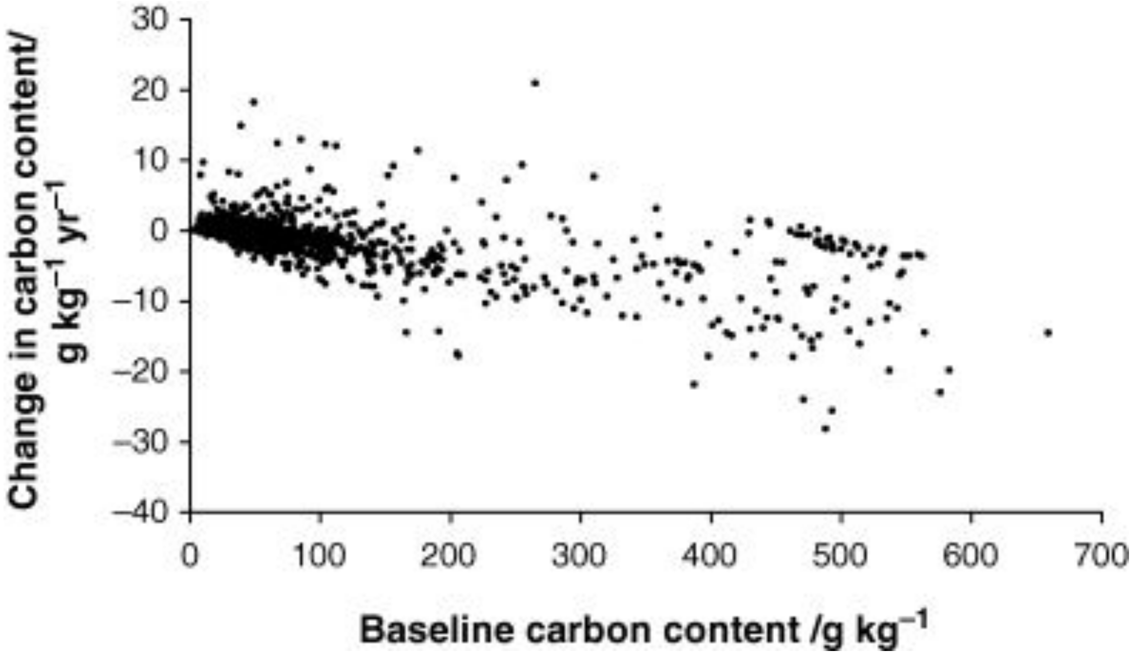


Sampling Methods

Soil Preparation/Laboratory Analysis

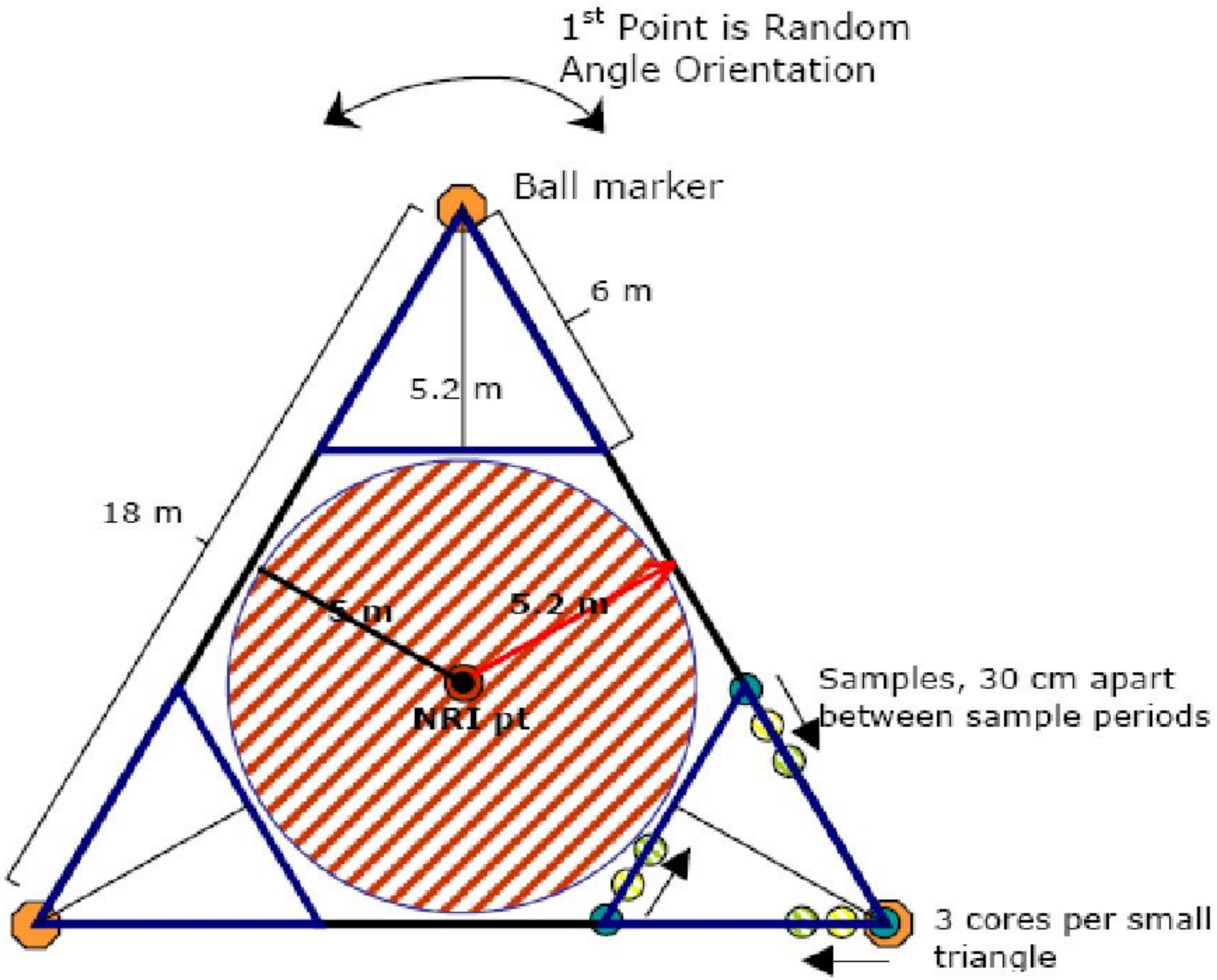
Calculate SOC Stock Change and GHG Emissions

Regression Toward the Mean



Lark et al. 2006, European Journal of Soil Science

Sample Plot



1st Point is Random
Angle Orientation
Ball marker
6 m
5.2 m
18 m
5 m
5.2 m
NRI pt
Samples, 30 cm apart
between sample periods
3 cores per small
triangle

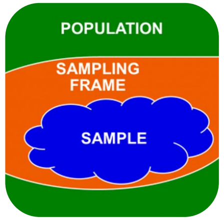
Field Sampling Considerations

- Cores v. soil pits
- Depth of sampling
- Segmenting samples
- Manual coring vs. mechanized

CH_4 and N_2O Emissions

Challenges/Opportunities	Flux chamber method	Eddy covariance method
Scientific application	• Measures fluxes at fine scales. • Highly suitable in studying treatment effects (i.e. fertilizer, irrigation, varieties, cropping systems) on gas exchane. • Flux data are used to verify/calibrate process-based GHG models.	• Measures fluxes at farm or ecosystem level (larger scales) • Quantify gas exchange in response to environmental conditions and land management. • Flux data are used to verify/calibrate process-based GHG models.
System requirement/Cost	• Flux chamber, gas sampling supplies, gas analyzer • 40,000-50,000 USD (manual) • Less labor requirement	• Fast-response, sophisticated instruments and data software • 90-120,000 USD (fully automated) • Labor intensive, high level of expertise
Data accuracy/Management	• Errors may be large with gas sampling, gas detections, linearity assumptions of gas concentrations • Huge effect on environmental factors (e.g., temperature, moisture) • Less continuous time series of data generated	• Some assumptions in flux calculations • Errors may be large due to gap filling, and correction factors for flux calculations • Less impact on environmental conditions • More continuous time series of data generated

Measurement-Based Approach



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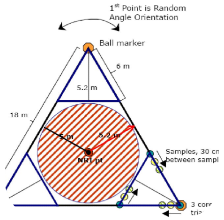


Sampling Methods

Soil Preparation/Laboratory Analysis

Calculate SOC Stock Change and GHG Emissions

Soil Preparation

Field-moist Soil Sample in Bag

Mass soil in bag
Air-dry empty plastic bag

8mm Sieve

Mass empty, dried coin envelope → 8mm Plant Frac
Oven-dry 1-3 days 60ºC → Dried 8mm Plant Frac
Mass envelope

Mass empty, dried coin envelope → 8mm Rock Frac
Oven-dry 1-3 days 60ºC → Dried 8mm Rock Frac
Mass envelope

8mm Soil Frac

Air-dry 2-3 days

Air-Dried 8mm Soil
Mass Soil & empty plastic bag

8mm Soil Archive (500g)

Bag remaining in original plastic bag

2mm Sieve (75g)

Mass empty, dried coin envelope → 2mm Plant Frac
Oven-dry 1-3 days 60ºC → Dried 2mm Plant Frac
Mass envelope

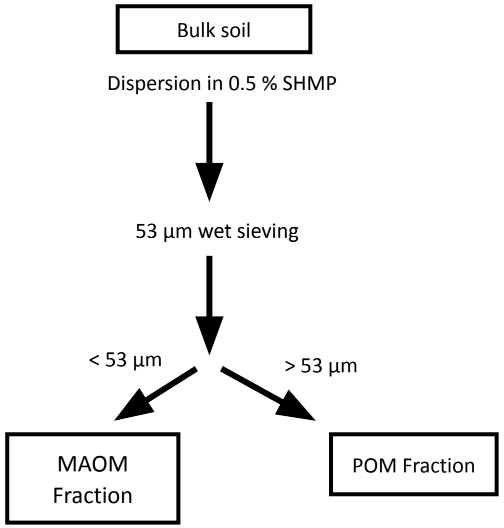
Mass empty, dried coin envelope → 2mm Rock Frac
Oven-dry 1-3 days 60ºC → Dried 2mm Rock Frac
Mass envelope

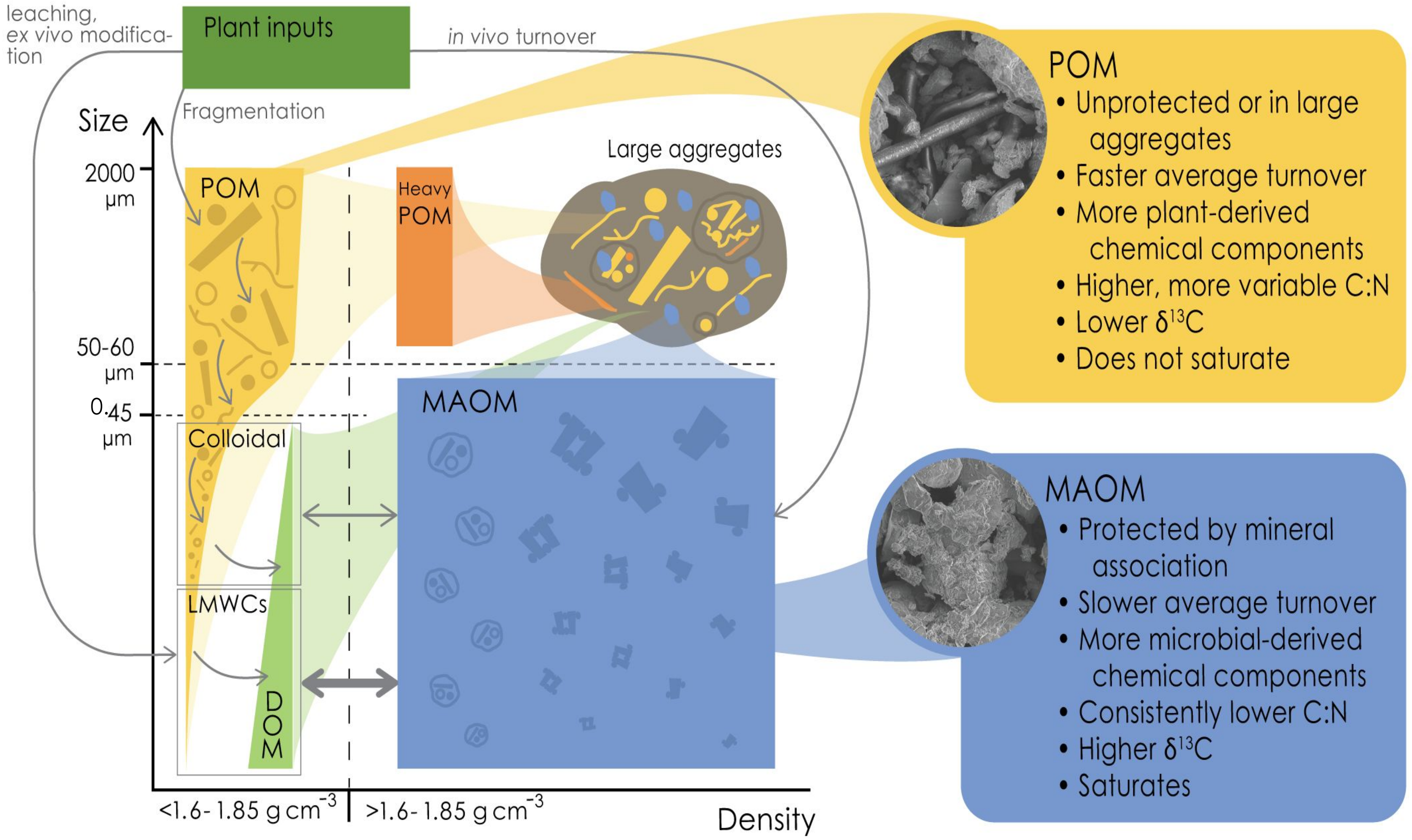
2mm Mineral Soil

Mass Soil → Save in labeled plastic bag

Mass AL pan → 50g Sub-sample
Oven-dry 1-3 days 105ºC → 50g Oven-dried Sub-sample
Mass dried Soil
Save in Labeled Vial

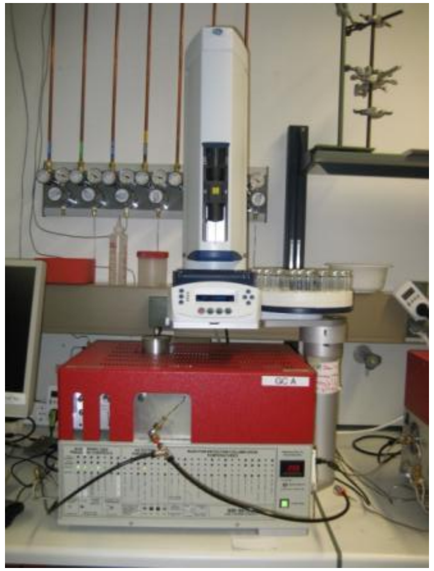
Further Fractionation



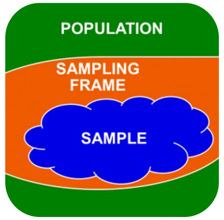


Lavallee et al., 2020, Global Change Biology; Leuthold et al. 2022, Encyclopedia of Soils in the Environment

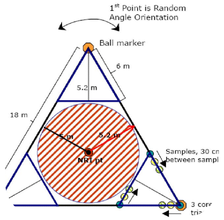
Laborator
y Analyses



Measurement-Based Approach



Sampling Design



Sampling Methods

Soil Preparation/Laboratory Analysis

Calculate SOC Stock Change

Estimating Soil C Stocks Changes with Confidence Intervals

Standard Survey Statistics

$$\Delta SOC = SOC_t - SOC_{t-1}$$

$SOC = soil\ organic\ C\ stock\ at\ time\ t\ or\ t-1$, t = time

$$SOC = \sum_i w * (C_{org} * d_b * D) * (1 - R_f)$$

W = survey sampling weight, C_{org} = organic C concentration, d_b = bulk density of fine earth, D = depth, R_f = rock fraction, i = sample

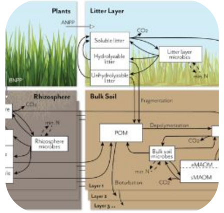
$$\sigma^2 = \sum_{h=1}^{H} N_h^2 \left(\frac{1}{n_h} - \frac{1}{N_h} \right) s_h^2$$

N_h = total number of possible samples in stratum h, n_h = number of samples within stratum h, s_h^2 = is the sample standard deviation of stratum h, h = specific stratum, H= total number of strata

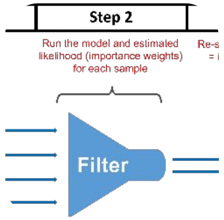
Estimate and 95% Confidence Interval

Similar approach for CH_4 and N_2O emissions

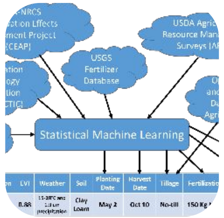
Model-Based Approach



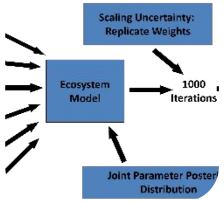
Select/Develop Model



Calibrate/Evaluate

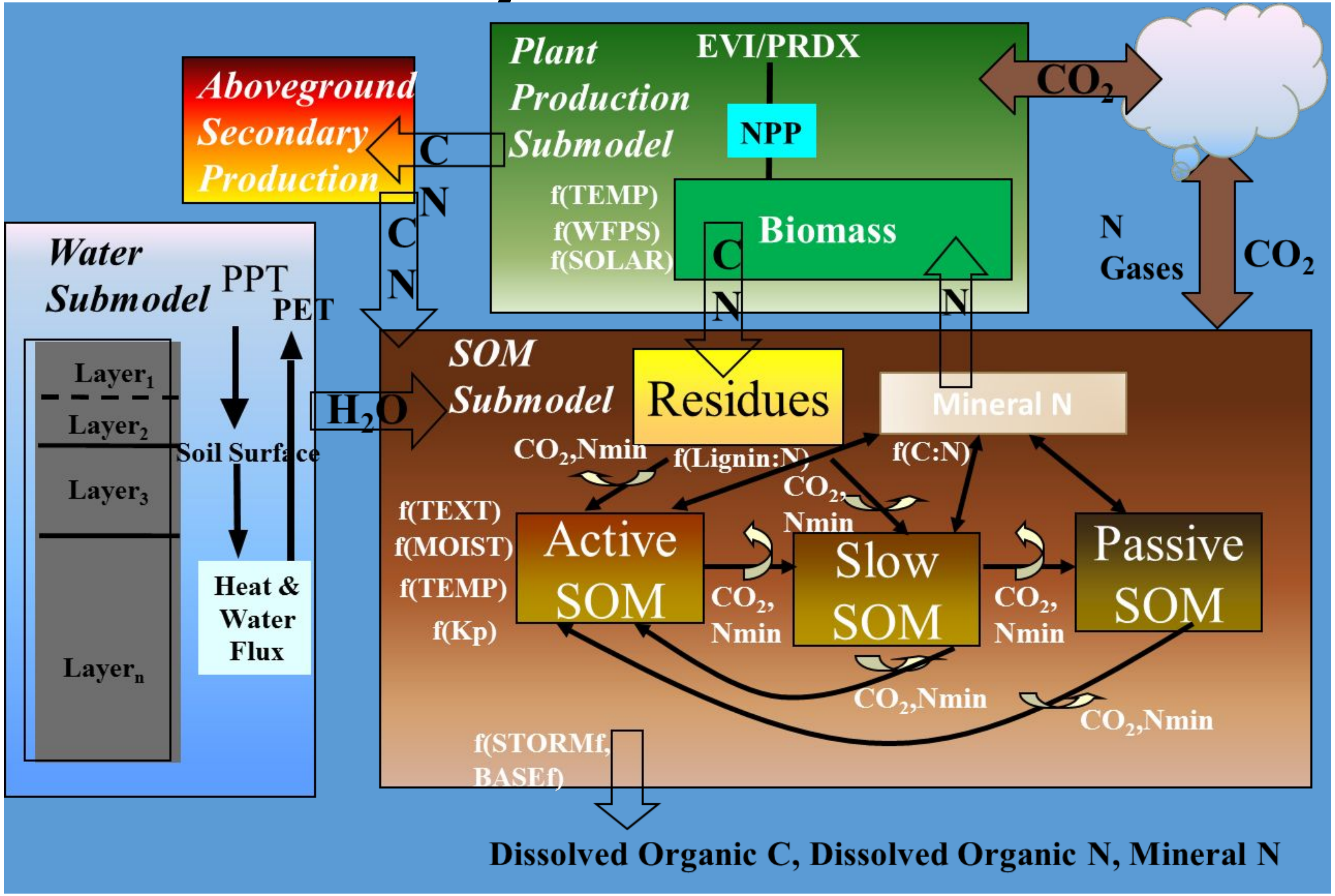


Input Driver Data

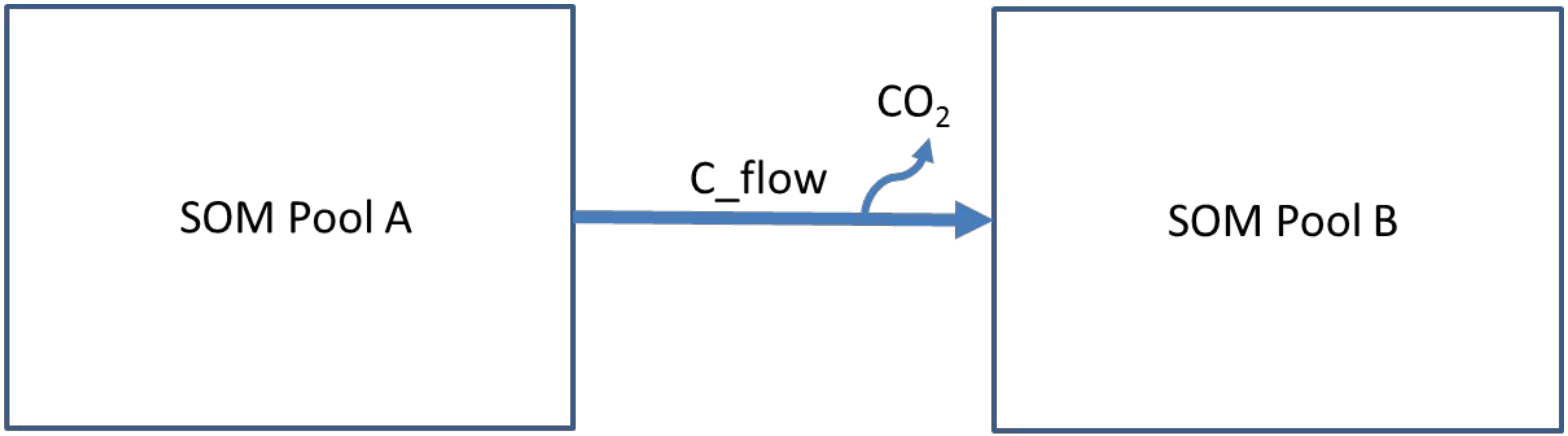


Application/Estimation

Ecosystem Models



Parton et al. 1987, SS
Parton et al.
1998, Global and
Planetary Change



$$C\_flow\_a\_to\_b = SOMa * Ka * CDI * pH_{effect} * cult_{effect}$$

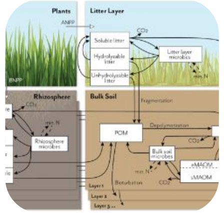
$$CO_2\ respiration = C\ flow * fco2$$

CDI = climate decomposition index = f(temperature, moisture) (a.k.a. defac)

Ka = first order linear decay rate for SOM pool A (fix.100)

fco2 = fraction of flow lost to heterotrophic respiration (fix.100)

Model-Based Approach



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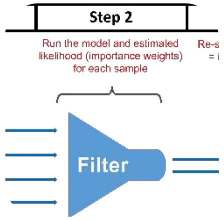

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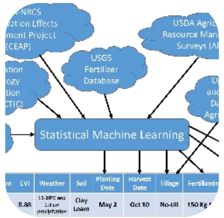

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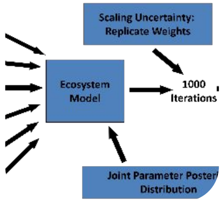
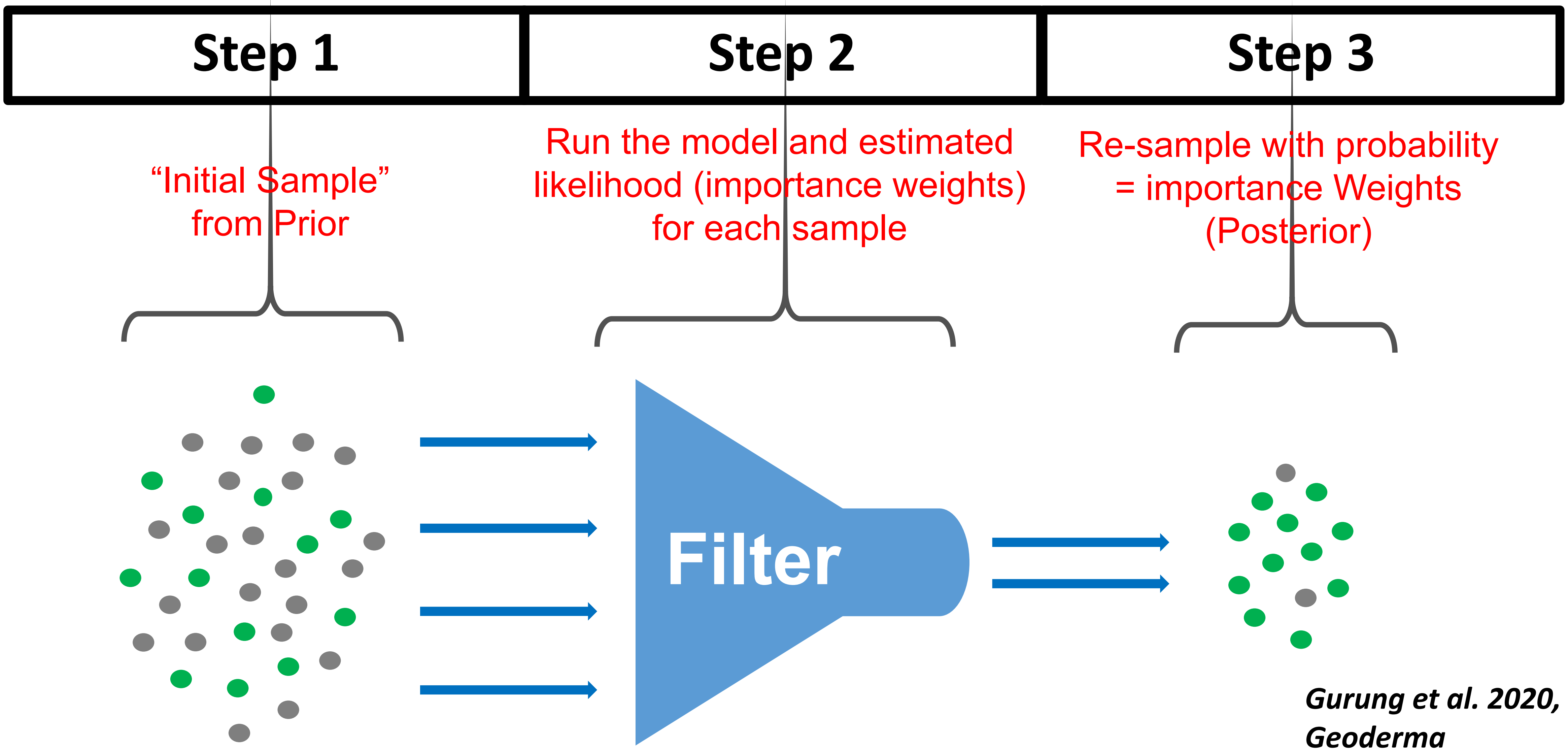
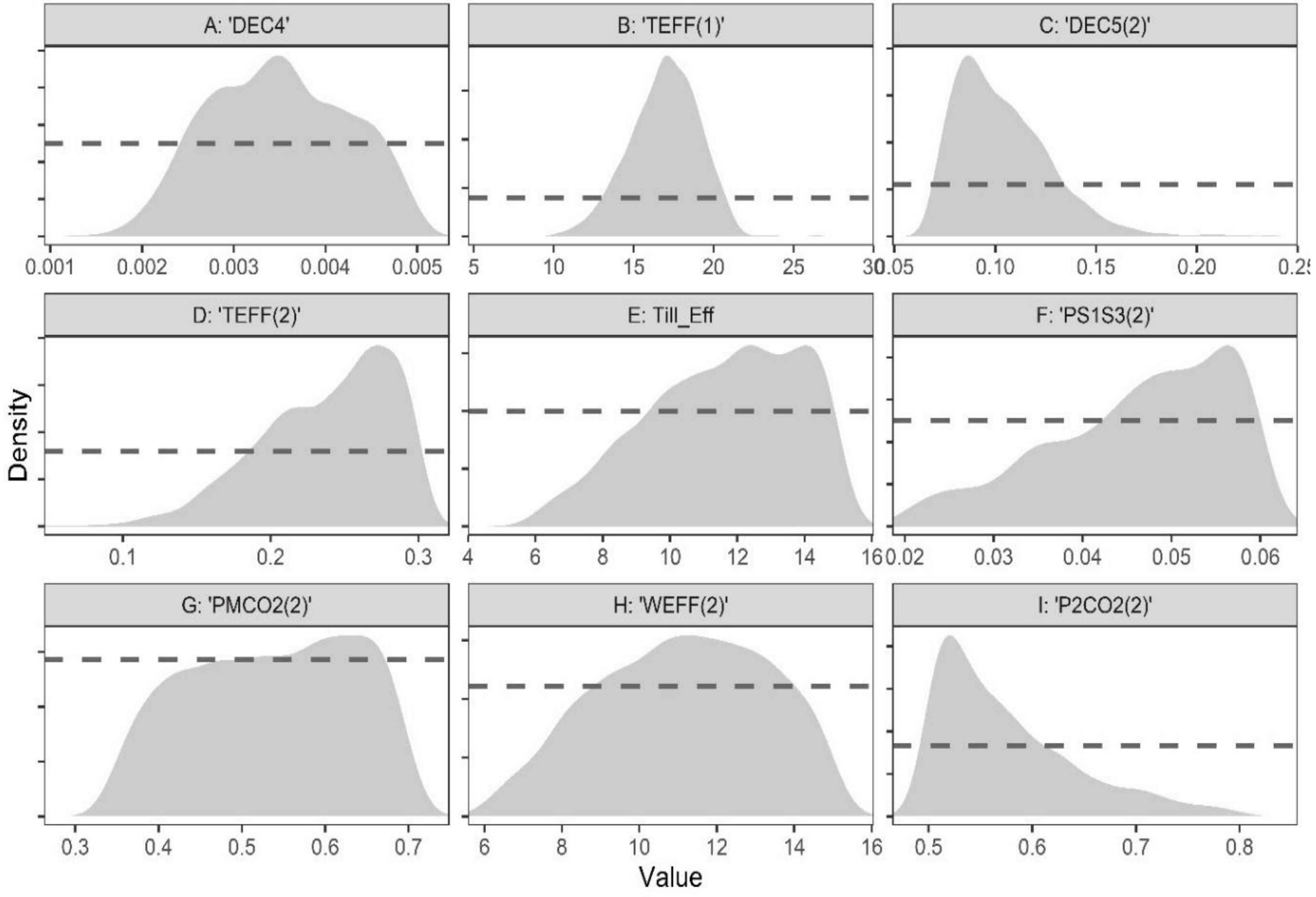


Application/Estimation

Bayesian Parameterization

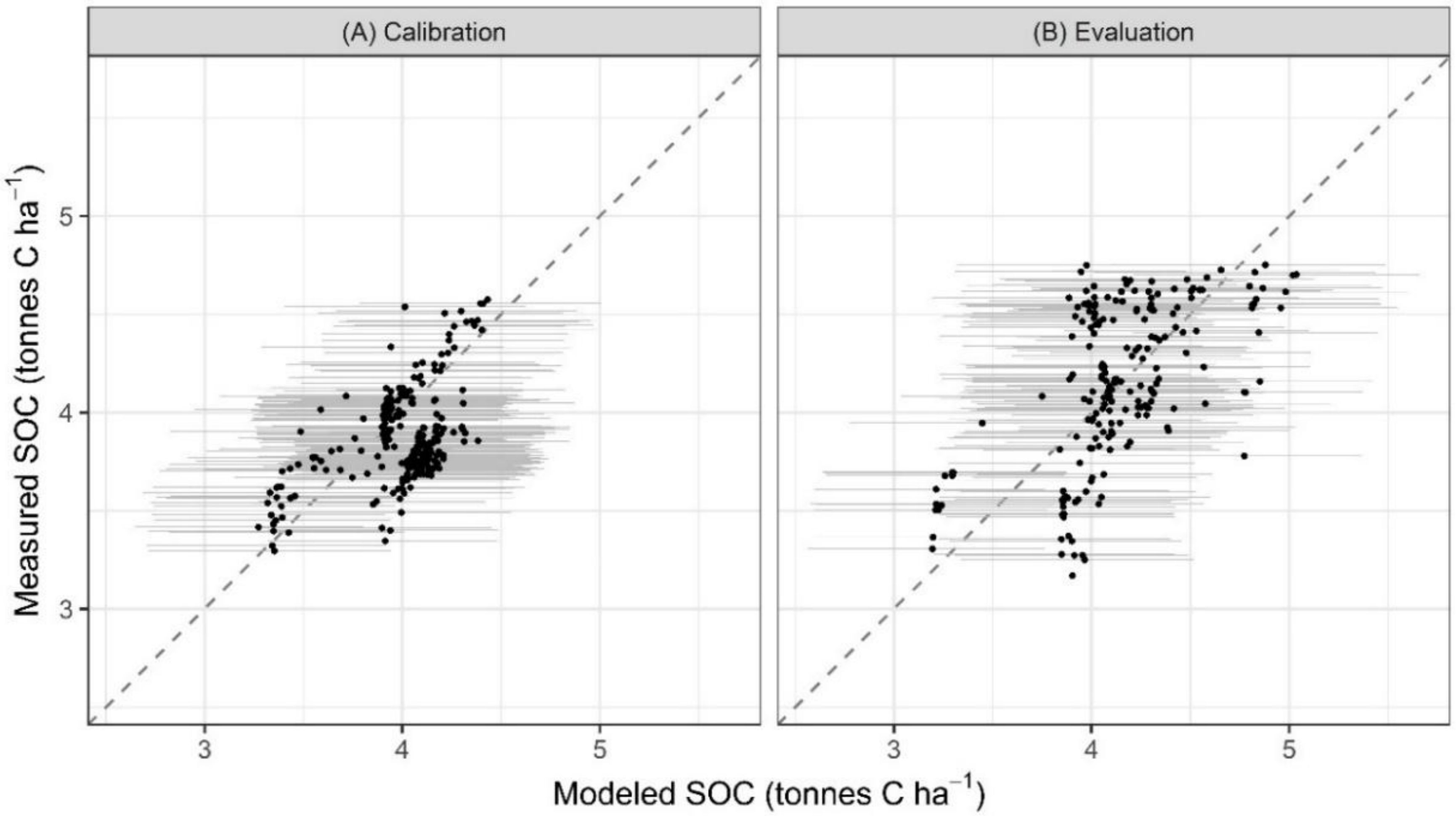


Gurung et al. 2020, Geoderma



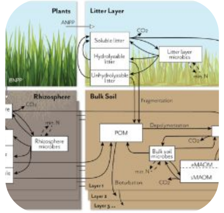
Gurung et al., 2020, Geoderma

Bayesian Calibration – Soil Organic C

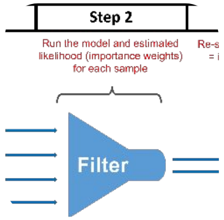


Gurung et al. 2020, Geoderma

Model-Based Approach



Select/Develop Model



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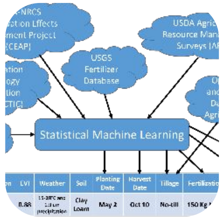

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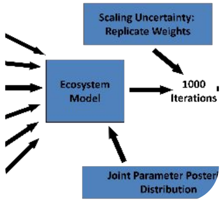
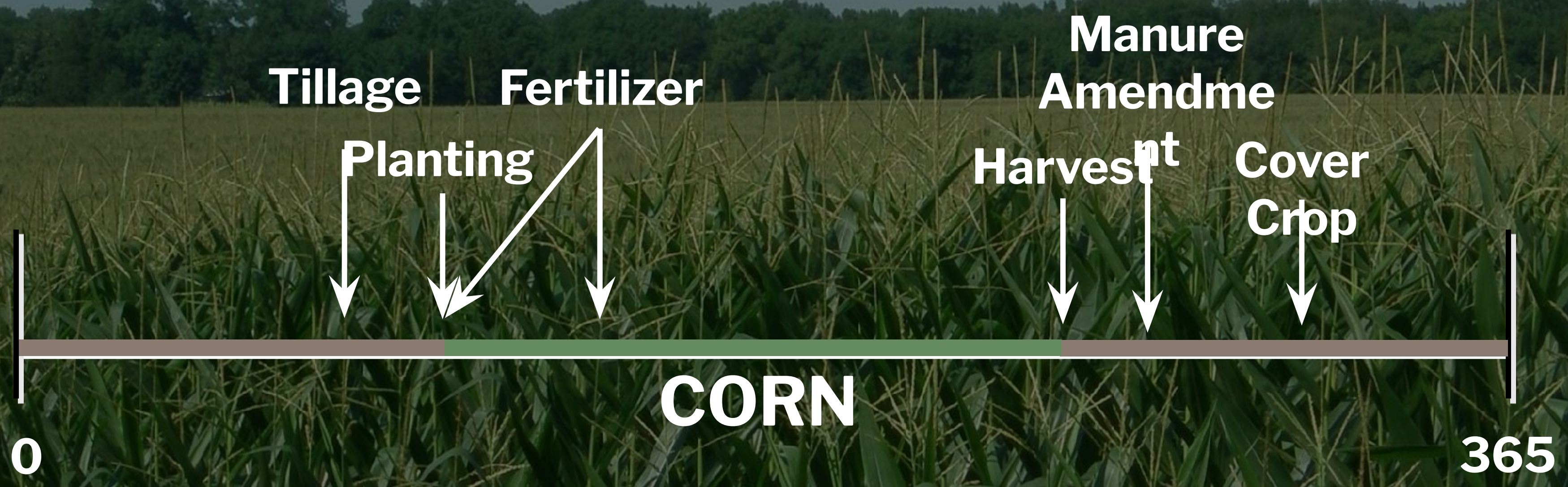


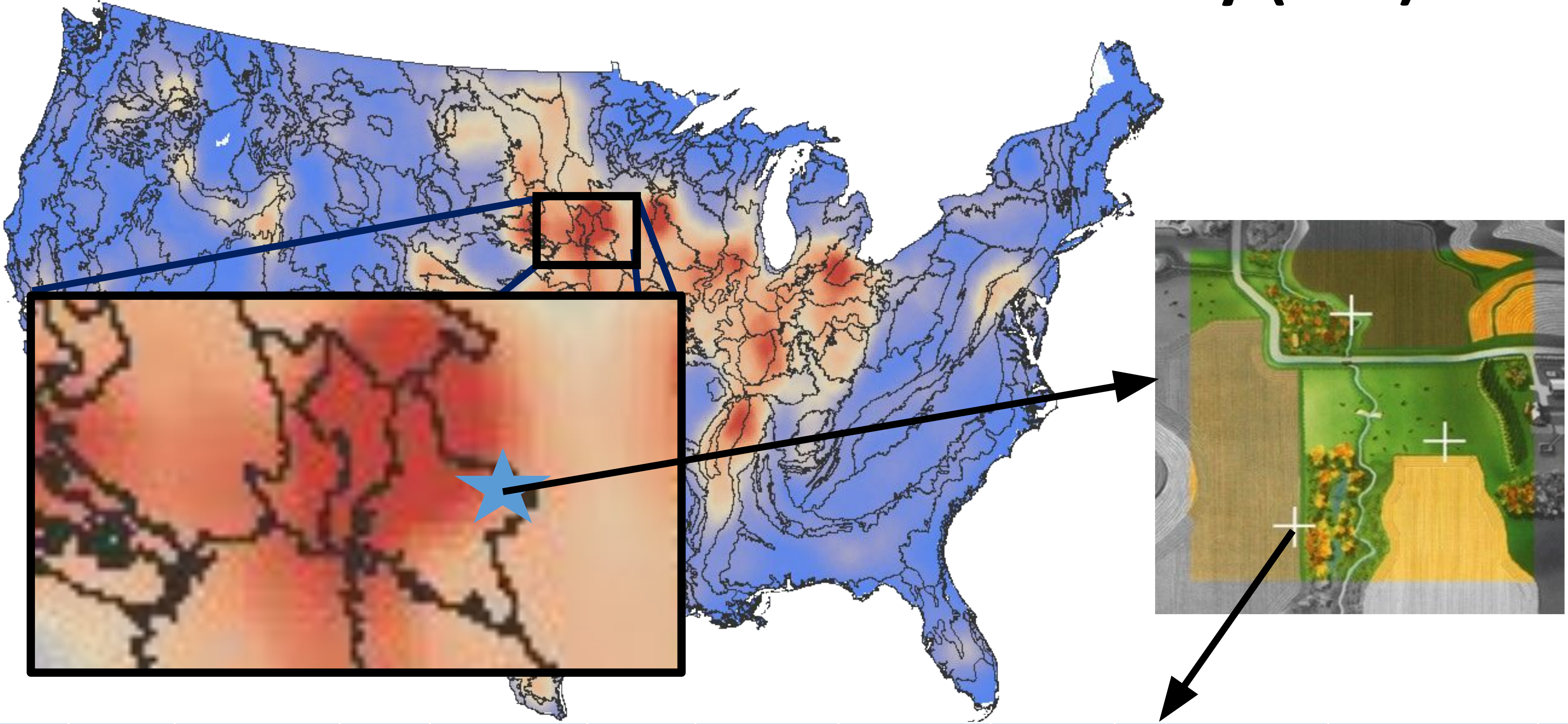
Application/Estimation

Ecosystem Model Simulation

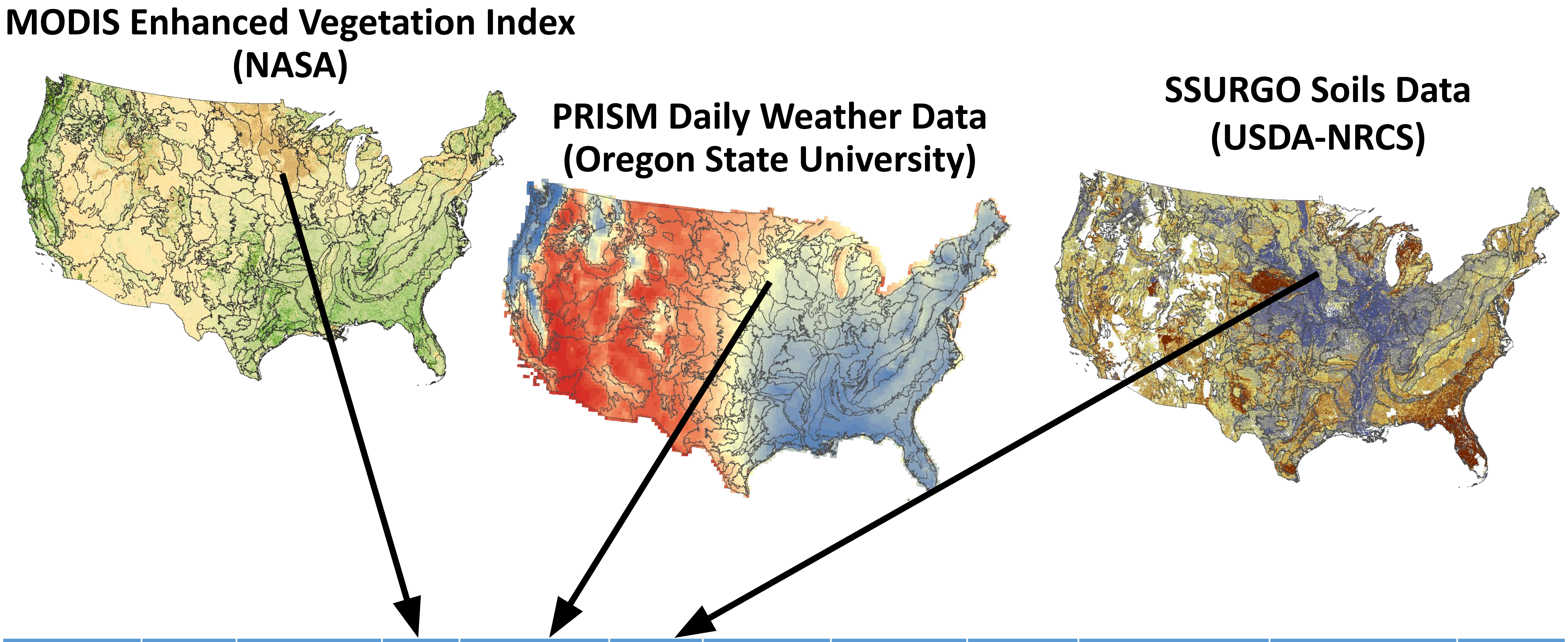


Need information for every year in the time series!

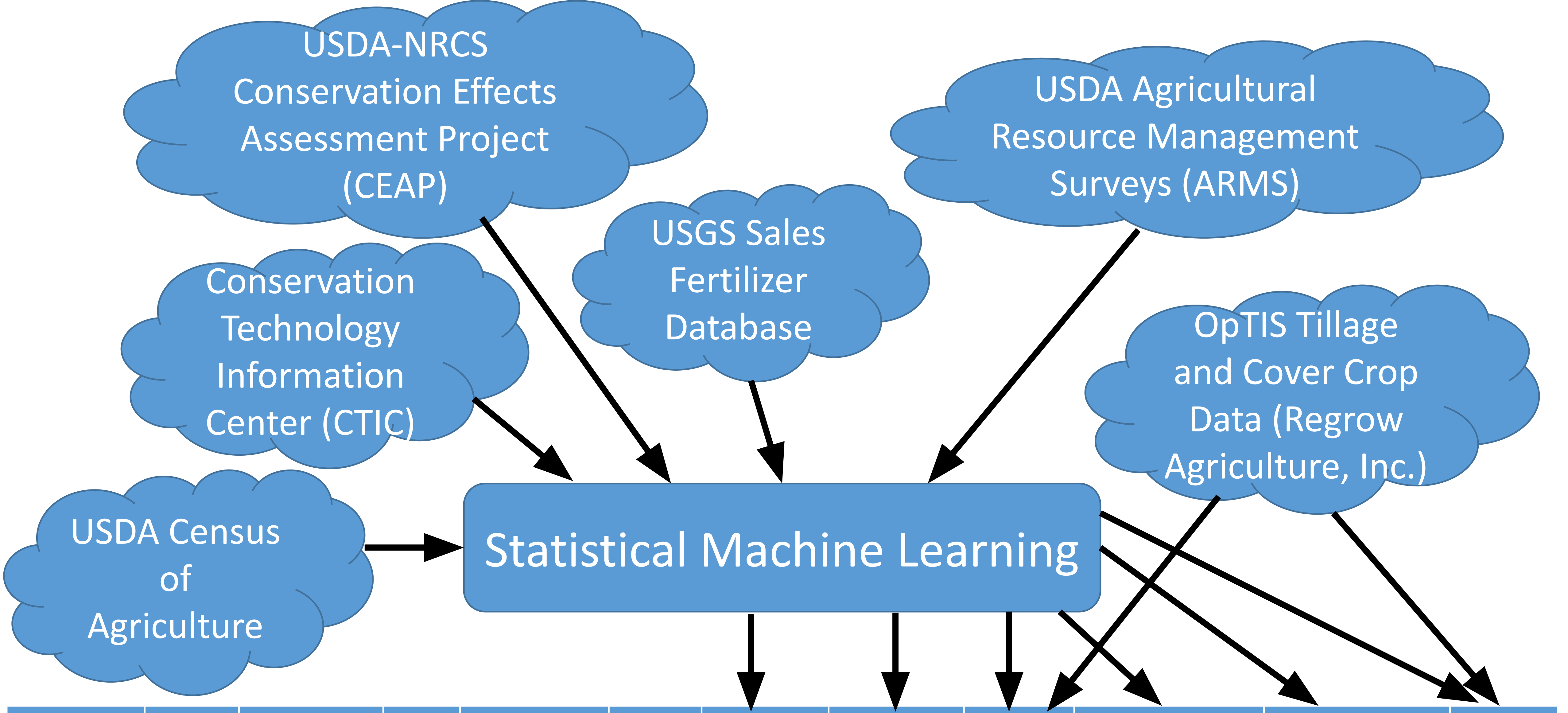
USDA-NRCS National Resources Inventory (NRI)



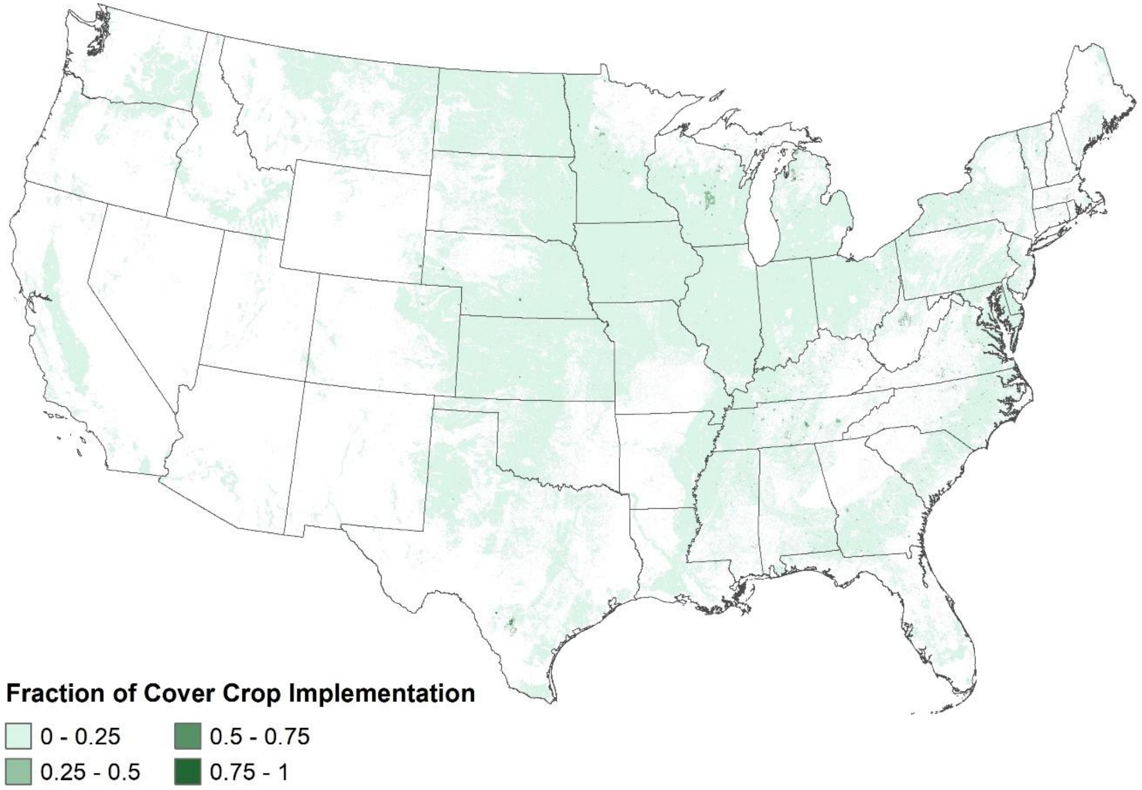
Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrigated	?	?	?	?	?	?	?	?	?

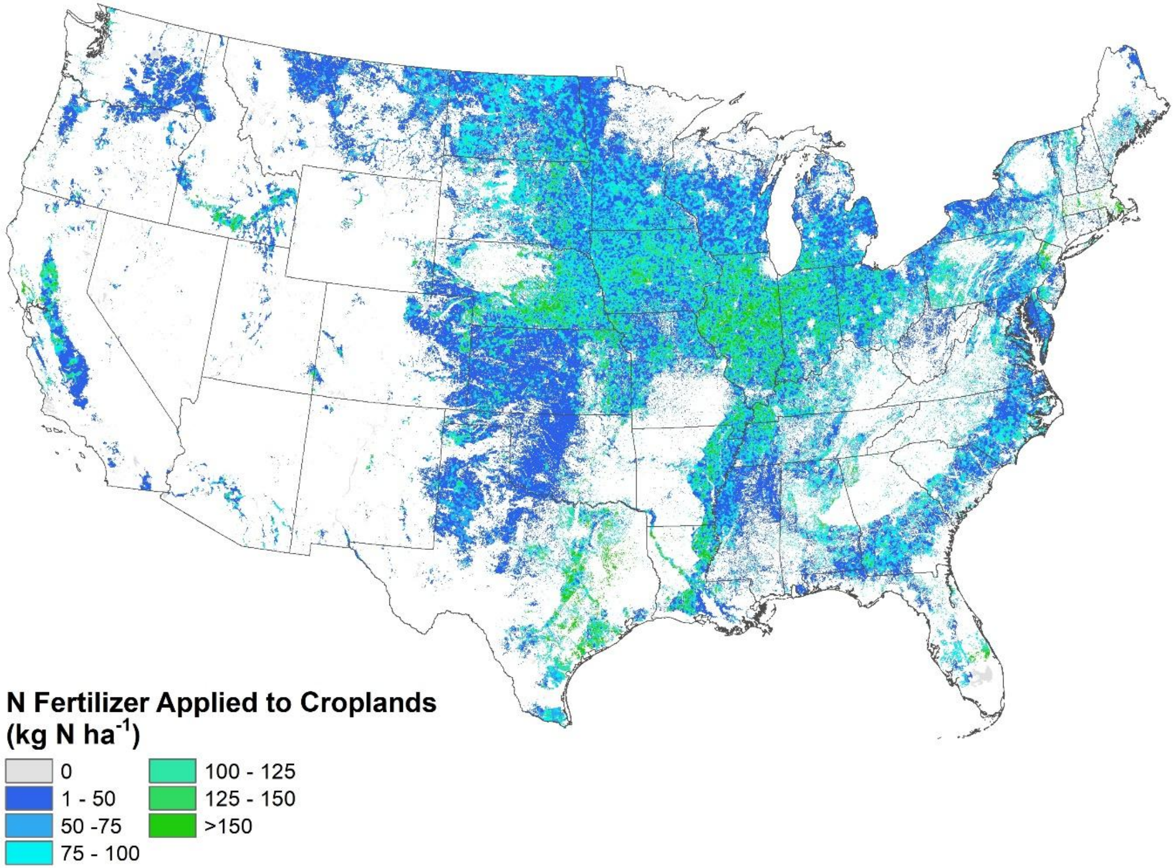


Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrig ated	0.88	15-28°C and 1.9 cm precipitation	Clay Loam	?	?	?	?	?	?

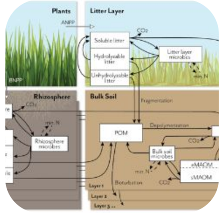


Land Use	Crop	Irrigation	EVI	Weather	Soil	Planting Date	Harvest Date	Tillage	Fertilization	Manure Amendment	Cover Crops
Cropland	Corn	Non-irrig ated	0.88	15-28°C and 1.9 cm precipitation	Clay Loam	May 2	Oct 10	No-till	150 Kg N/ha	2 tons/ha	none


Fraction of Cover Crop Implementation
0 - 0.25
0.25 - 0.5
0.5 - 0.75
0.75 - 1


N Fertilizer Applied to Croplands
(kg N ha-1)
0
1 - 50
50 -75
75 - 100
100 - 125
125 - 150
>150

Model-Based Approach



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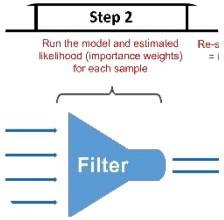
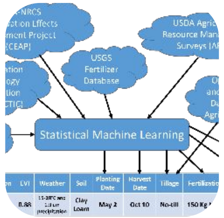


Calibrate/Evaluate



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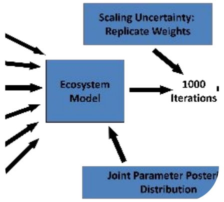


Application/Estimation

Monte Carlo Simulation Framework

USDA-NRCS NRI Data
USDA-NASS CDL
USDA-ERS ARMS Data
USDA Census Data
USDA-NRCS CEAP Data
USGS Fertilizer Data
AAPFCO Fertilizer Data
OpTIS Cover Crop and Tillage Data (Regrow Inc.)
EPA Manure Production Data

Management Data

Imputation 1

Imputation 2

Imputation 3

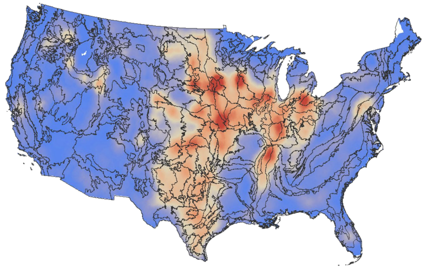
Imputation 4

Imputation 5

Imputation 6

Ecosystem Model

Scaling Uncertainty: Replicate Weights

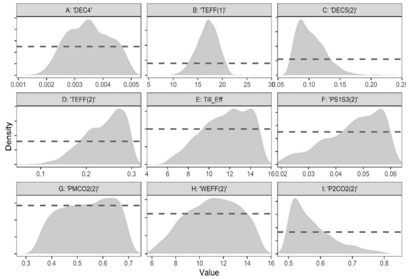


1000 Iterations

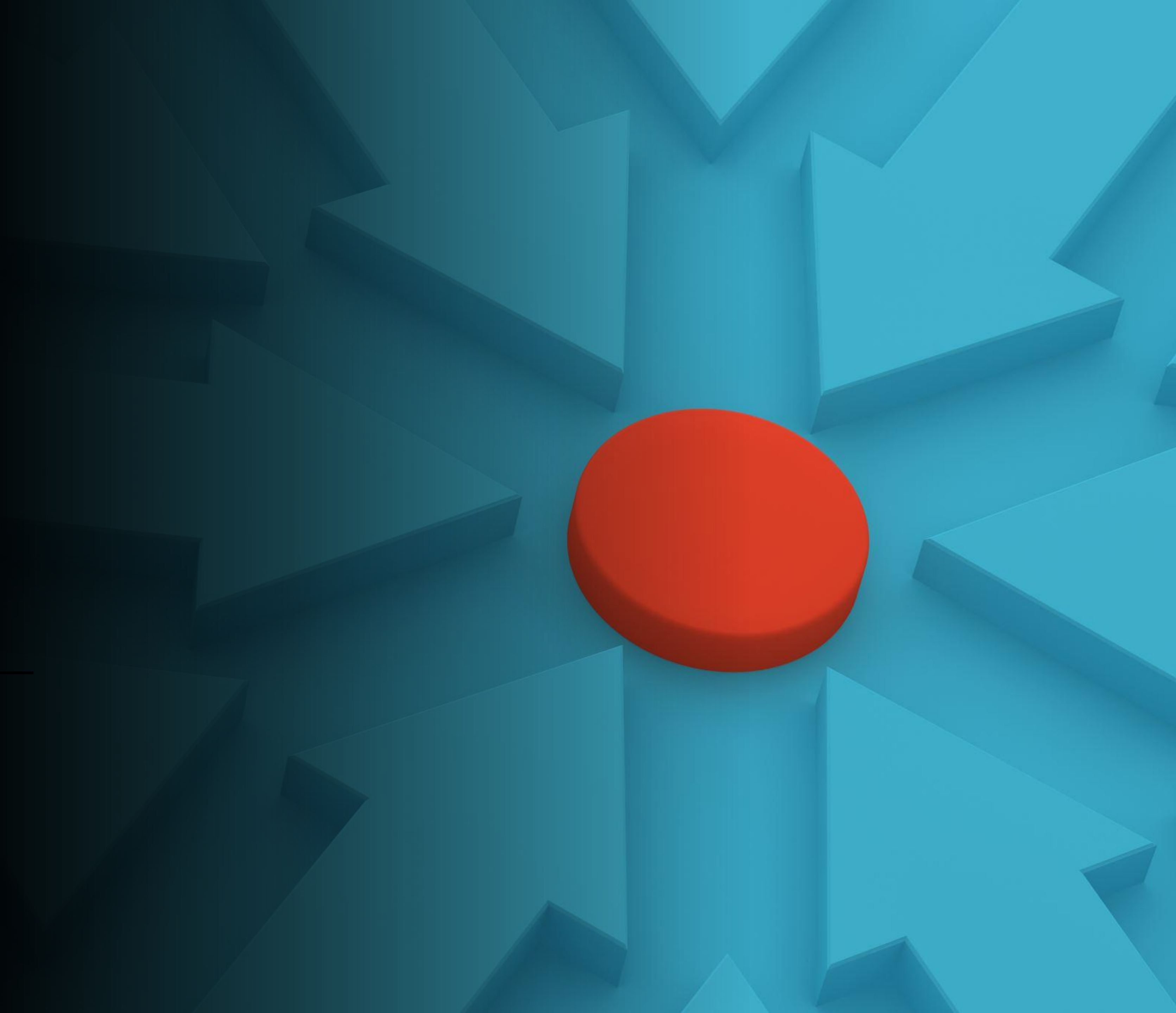
Results

Estimates and 95% Confidence Intervals

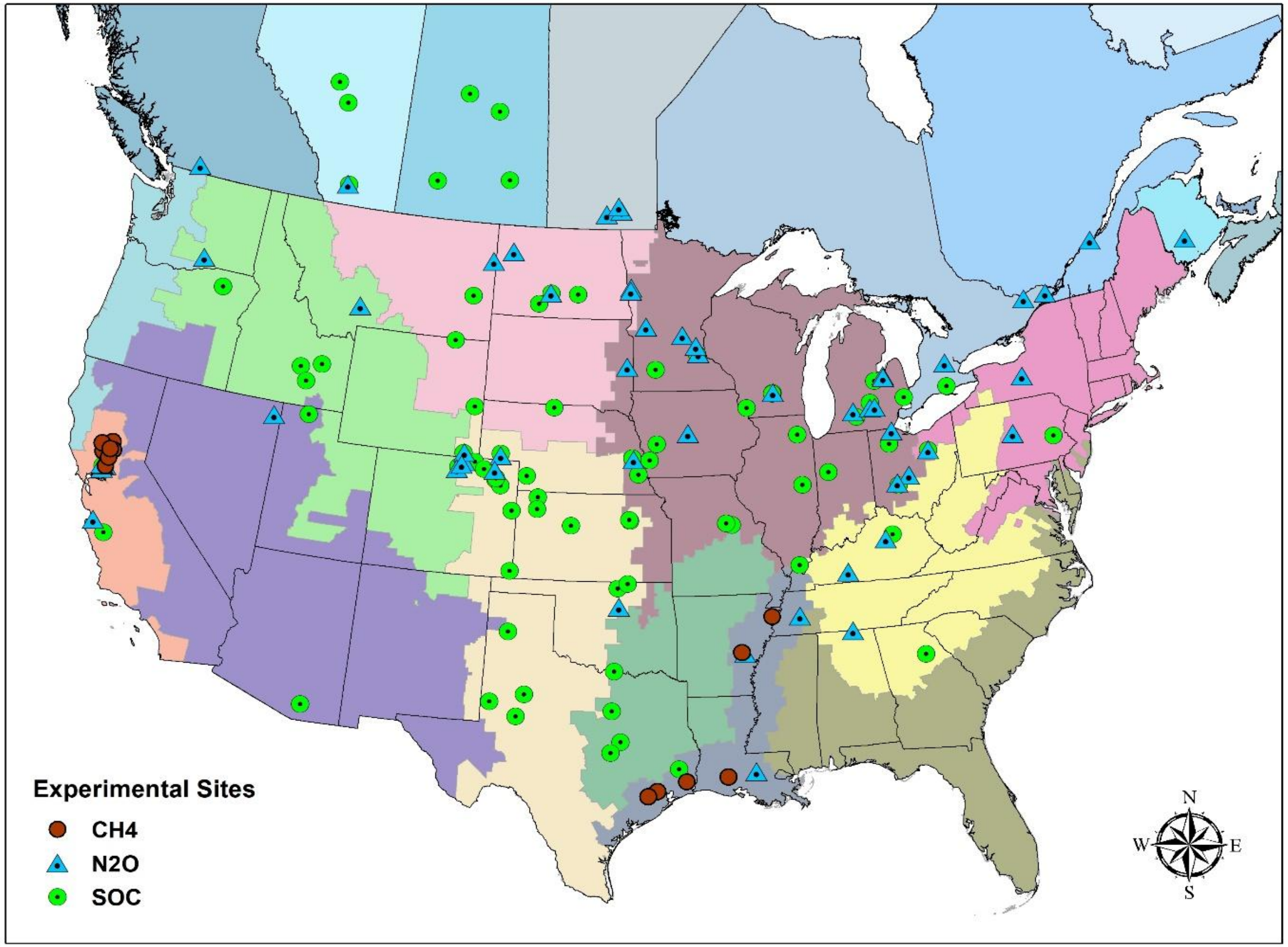
Joint Posterior Distribution for Parameters



Opportunities for Reducing Uncertainty

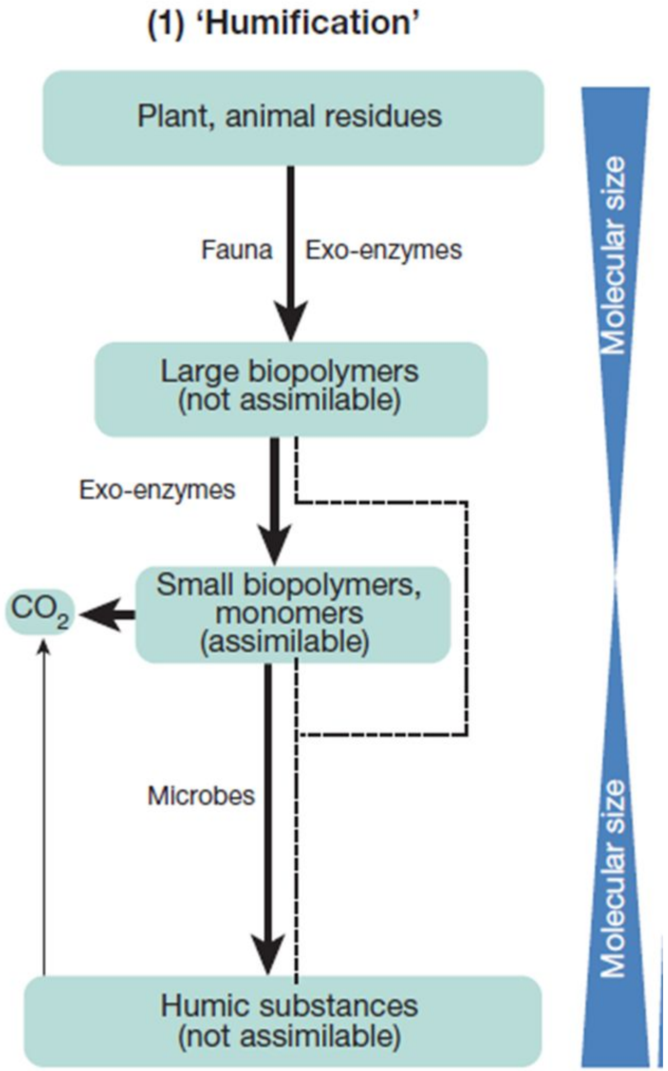


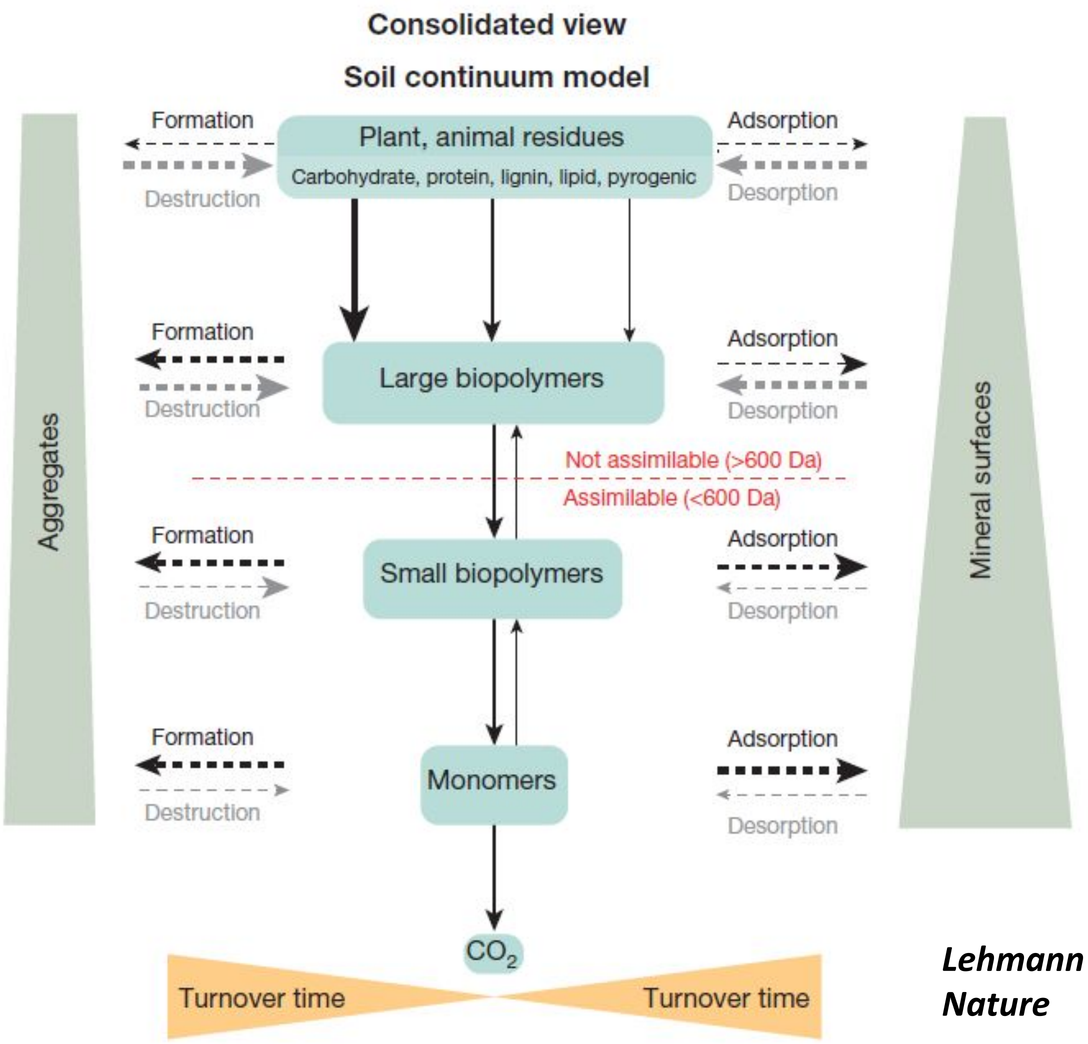
Opportunity 1: Observations/Measurements



Expand observational networks, increasing measurements of soil C and GHG emissions

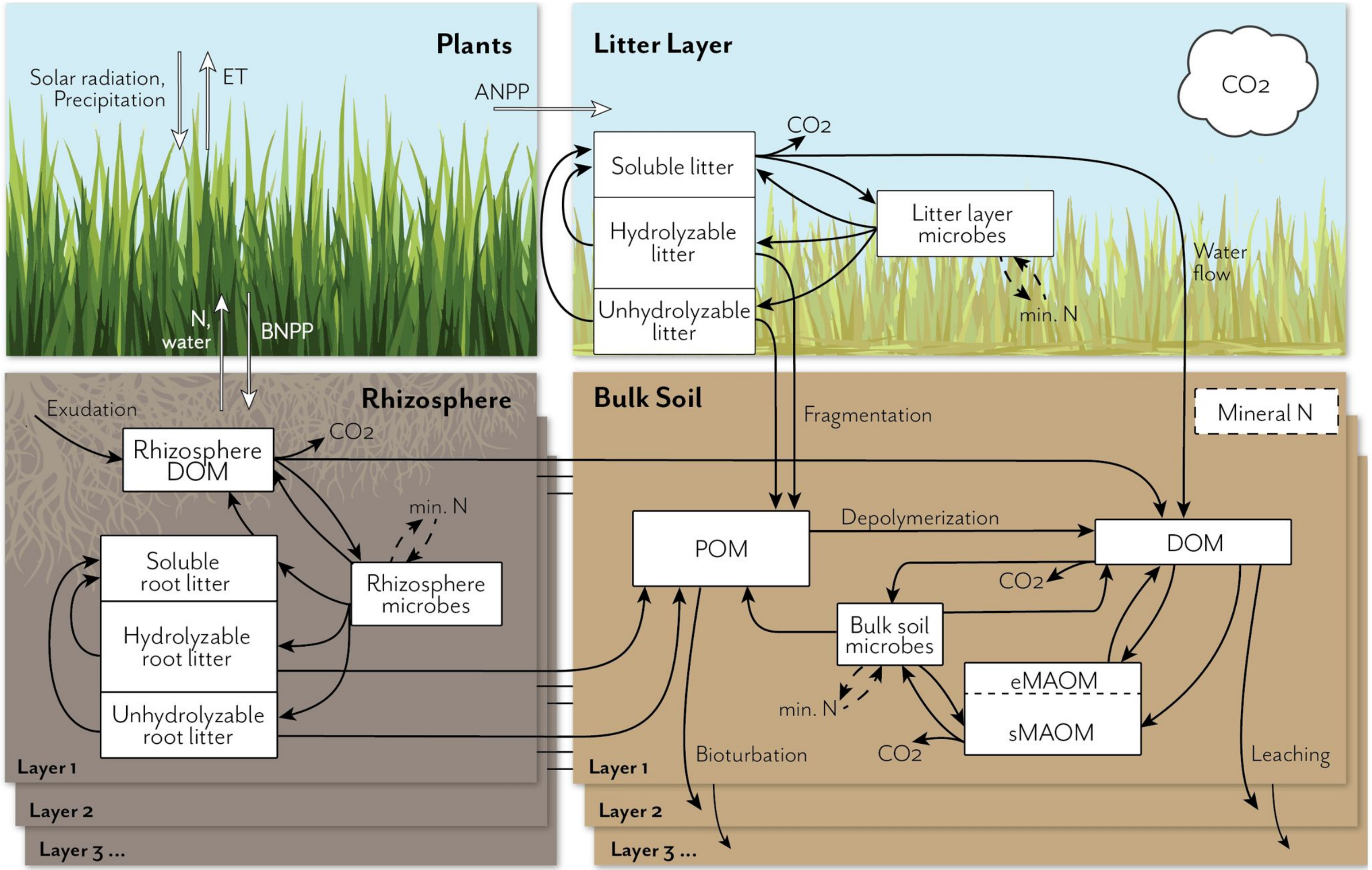
Opportunity 2: Advancing Our Understanding





Lehmann and Kleber, 2015, Nature

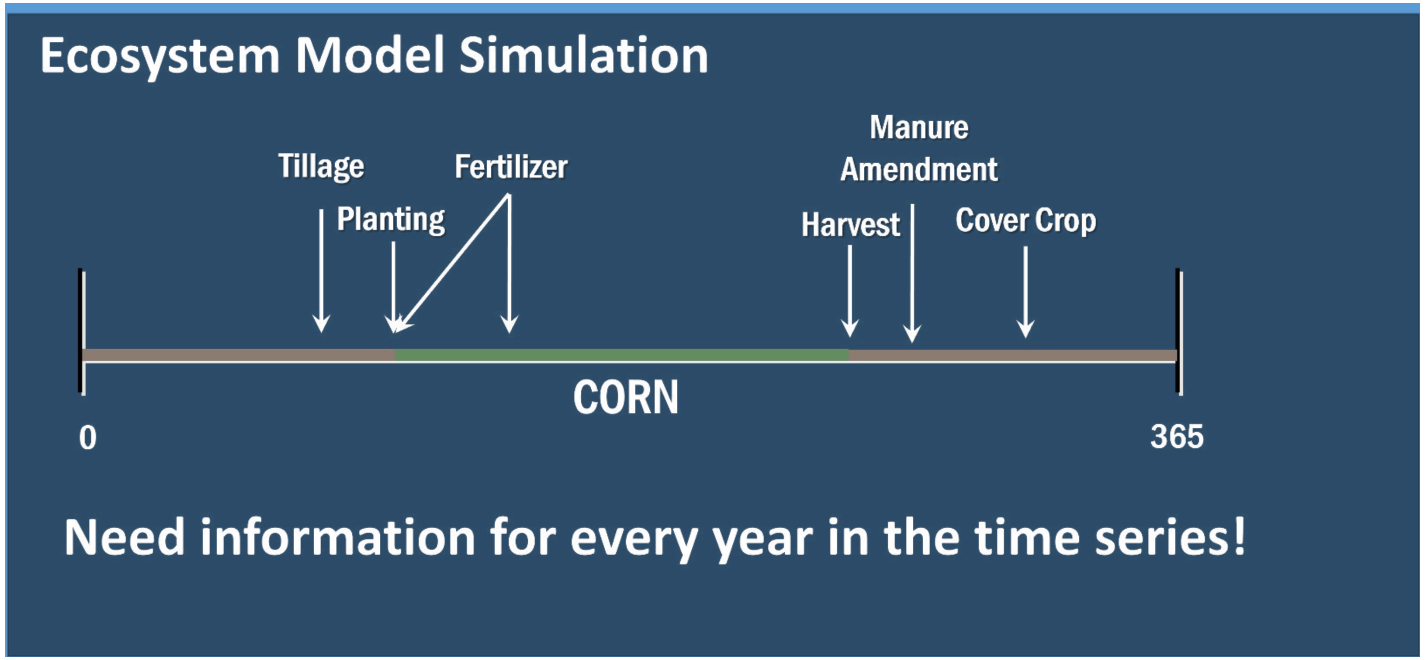
Opportunity 3: Improving Models



Zhang et al., 2021
Biogeosciences

Operationalize new generation of models, incorporate new driver data (remote sensing data products), and evaluate AI

Opportunity 4: Improving Management Practice Datasets



Develop new surveys and remote sensing products to fill gaps in management data

Thanks for your Attention!

NREL

United States Environmental Protection Agency

USDA

Colorado State University