Using Biogeochemical models in VM0042 projects – IME insights on applying VMD0053

AgreenaCarbon Project, Europe (Verra Project 4022).

Tessa Van Der Voort, Soil Scientist NMI Wageningen

Viridiana Alcantara-Shivapatham, Manager Agriculture Innovation, Verra

Gerard Ros, Soil Scientist Wageningen University/NMI Wageningen

nmi Soil for life

RAAK research program

SIA Regieorgaan

Aim webinar

Facilitate the VMD0053 set up by:

- Robust roadmap
- Lessons learnt
- Model validation report (MVR) instructions

AgreenaCarbon Project, Europe (Verra Project 4022).

AGENDA

- Model and project domain
- Data collection for modelling
- Model
  - Setup
  - Run
  - Evaluation
- Writing the VMD0053 Model Verification Report (MVR)
- Q&A

Model and project domain

Select optimal model
Practice changes
Crop functional groups
Emission sources
Prepare for model implications

Importance Biogeochemical (BGC) modelling in VM0042

- VM0042 supports soil carbon sequestration following improved agricultural land management

- **Quantification Approach 1: Measure and Model**
  - Measurement of soil organic carbon (SOC) stocks every five years
  - **BGC model** to predict effect of changes
  - Soil Organic Carbon (SOC), CH_4 + N_2O


Verified Carbon Standard

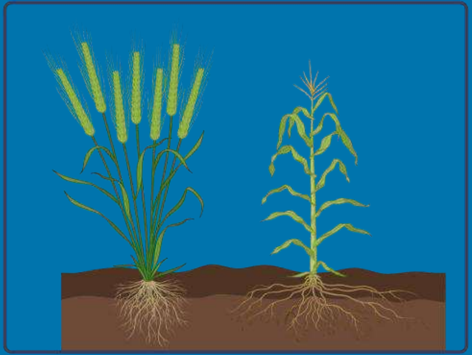
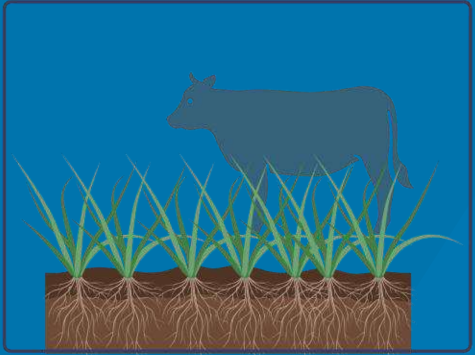
VCS Methodology

VM0042

IMPROVED AGRICULTURAL LAND MANAGEMENT

Main Agroecosystems and best model fits

Agroecosystem Type

Arable/cropland	Grassland/grazing	Rice paddies
		

RothC (Arable/cropland, Grassland/grazing)

- Soil Organic Carbon Stocks
- No N_2O/CH_4

DayCent (Rice paddies)

- Soil Organic Carbon Stocks
- N_2O & CH_4

Soil for life

VERRA

Other biogeochemical models can also be implemented, these are most common

Comparison Biogeochemical Models & implications projects

RothC (Rothamstead)

- Based on Rothamstead research
- Fully open source
- Python and R code available for free
- https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc
- GHG: Focus on soil organic carbon (SOC) stocks.
- No N_2O/CH_4

→ **Focus of Today**

DayCent

- Whole system C + N.
- Colorado State Uni - https://www.nrel.colostate.edu/projects/daycent/
- Commercial license for non-academic application
- To our knowledge no free open code available
- GHG: N_2O & CH_4, SOC

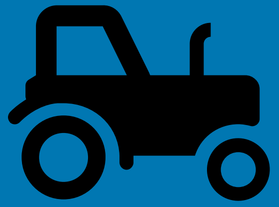
VERRA

Model selection & versioning is part of VMD0053 box 1

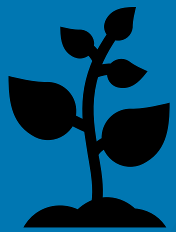
Practice Changes (PCs) and Crop Functional groups (CFGs)

- **Practice Changes** are changes in agricultural management which are additional, i.e. different from business as usual (BAU)

→Examples are: cover cropping, application of compost, stopping tillage or improved grazing practices.

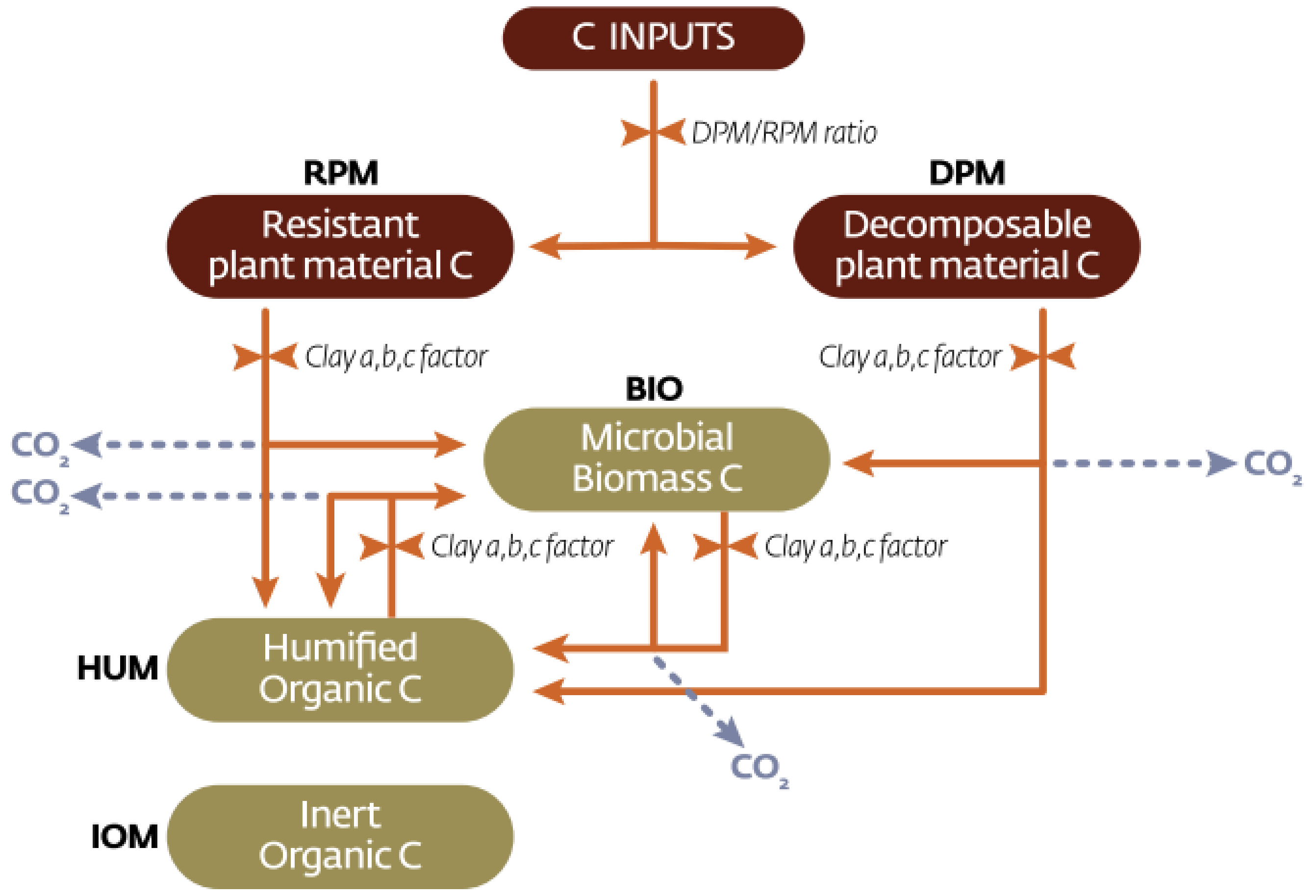


- **Crop Functional Groups** are groups of crops with similar properties, such as (non-)N-fixing, annual/perennial, C3/C4 etc.



- **Build and validate your model for each combination of PC* CFG**
- **Identify all PC*CFG and climate zones (CZ) and you will have defined the project domain (VMD0053 Box 2).**

Components and structure RothC



- Model for SOC turnover
- Non-waterlogged soils
- Considers soil type, temperature, moisture, plant cover
- T = 1/12 y
- Five compartments
- Process-based model

There are **default settings** for a range of ecosystems

Can be implemented easily with open data

GSOC-MVR protocol by FAO (2020) Annex 1: https://doi.org/10.4060/cb0509en

Components and structure RothC

$$\Delta Y = Y \times (1 - e^{-abckt})$$

Where:

ΔY	= the change in carbon stock over time (t C/ha);
a	= the rate modifying factor for temperature;
b	= the rate modifying factor for moisture;
k	= the decomposition rate constant for that compartment;
c	= the soil cover rate modifying factor;
t	= 1/12, since k is based on a yearly decomposition rate.

FAO (2020) Biogenic inputs: https://doi.org/10.4060/cb0509en

What PC is going to add carbon meaningfully?

Starting point:

- How saturated is your soil? (i.e. has it been depleted by intensive land-use?)
- What are the Business As Usual (BAU) practices?
- Can they be improved meaningfully?

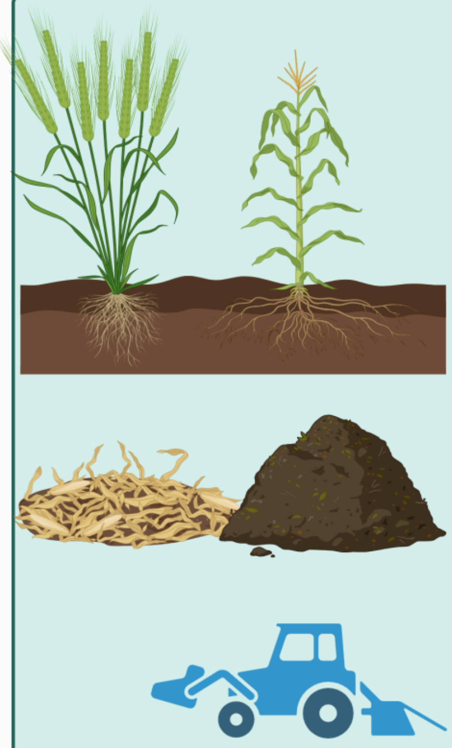
→ Identify areas which stand to benefit

→ Find win-win-win for climate, resilience and soil fertility

AgreenaCarbon Project, Europe (Verra Project 4022).

Practice Changes & model modifications RothC (1/3)

Arable/Croplands



nmi
Soil for life

Arable/Croplands	Practice Change	Model Change
Biomass Input	Cover cropping	Cover soil index (*c*) reduces decomposition of SOC
Biomass Input	Cover cropping, Organic manure, Residue, increased production (irrigation)	FAO (2020) contains a list formulae & values **Carbon_input** = ΣC input except agricultural product Derived from estimated yield + existing factors --> data on Δyield, Δresidue/manure --> ΔC_input Carbon inputs often increase under practise changes
Soil Structure	No tillage (sand-rich)	RothC decomposition = f(moisture, temperature, cover) Hyun & Yoo (2024) + Jordon et al (2022) found **Tillage Rate Modifiers** (0,1) that also modify decomposition Mostly effective in sand-rich soils. Impact **remains debated**

VERRA

Documentation model parameters is part of VMD0053 box 1

Practice Changes & model modifications RothC (2/3)

Grassland/grazing

nmi
Soil for life

Practice Change

Biomass Input

No bare soil any more

Regerative grazing management

- more recovery
- grazing time reduced
- organic manure in field

Model Change

Cover soil index (*c*) reduces decomposition

FAO (2020) has formulae & parameter values

Carbon_input =Σ All changed C input except agricultural product

Derived from estimated yield + existing factors

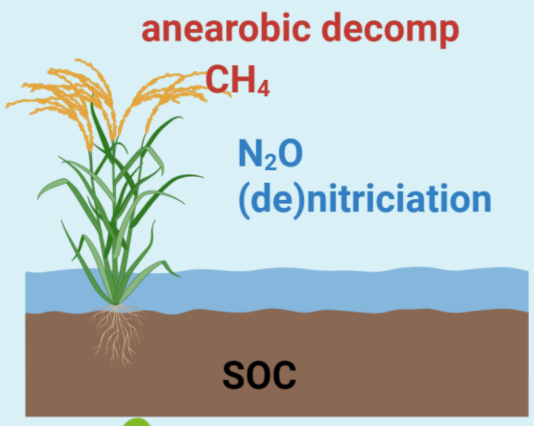
--> data on Δyield, Δresidue/manure --> ΔC_input

Optional: Root-to-shoot (R:S) may change

VERRA

Practice Changes & model modifications DayCent (3/3)

Rice Paddies | Practice Change | Model Change



nmi
Soil for life

Water

CH_4
Alternate wetting/drying
Direct seeding
Residue incorporation

→ Less anearobicity following changes parameters on irrigation, planting

Fertilisation

N_2O
Direct seeding
Optimal fertilisation
Biochar addition (aeration)

→ Less anearobicity, less excess nitrate, adapt parameters on fertilisation, amendments

VERRA

Qian et al., 2023: https://www.nature.com/articles/s43017-023-00482-1
Documentation model parameters is part of VMD0053 box 1

Modelling main steps

Data collection for modelling

1. Data to run the model (climate, soil data)
2. Data to calibrate model (i.e. adjust model parameters)
3. Data to validate the model (from literature data)

Data collection for modelling

1. Data to run the model (climate, soil data)
2. Data to adjust model parameters (calibration)
3. Data to validate the model (from literature data)

Data: to run the RothC model

Climate/weather data:

- Historic climatic records (10 years): **monthly average** rainfall, mean air temperature, evapotranspiration e.g. Copernicus AgERA5 (Bogaard et al., 2020)

This data is free, open and suitable for RothC

Soil properties data

- **Texture – clay content and bulk density** 0-30 cm
  - e.g. from national or global datasets such as FAO**:** FAO GloSIS or SoilGrids: soilgrids.org
- **Initial SOC stocks** for your area

  Tip: benchmark your SOC stocks to estimates from FAO to identify potential issues

Data collection for modelling

1. Data to run the model (climate, soil data)
2. Data to adjust model parameters (calibration)
3. Data to validate the model (from literature data)

Data: to adjust model parameters and calibrate model

VMD0053 defines calibration as: any process involving the adjustment of parameters and constants within a model so that the model more accurately simulates measured values.

Goal of calibration is to improve model performance

There are two key approaches:

1. **Use literature (or project)-derived data** to calibrate model

2. **Find more optimal parameter based on training dataset**

- Keep your training and validation dataset separate
- Consistency: same parameters for baseline and project scenario
- Defined at appropriate scale
- Use frequentist or Bayesian approaches

Tip: most projects are data-limited so it is better to use literature-derived calibration

Documentation on (split) calibration/validation datasets is part of VMD0053 box 1

Data for calibration

Carbon input

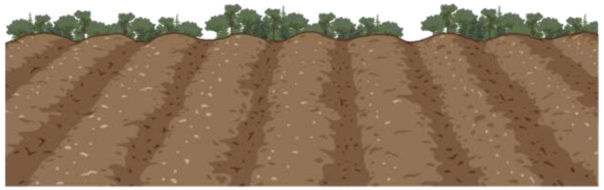
Practice Changes e.g.
- Cover cropping
- Improved grazing
- Amendments/manure
- Improved cropping
- Irrigation (more biomass)

Can be derived from literature or project

Adjusting RothC model parameters

Baseline

Business as Usual Carbon Inputs



Low carbon inputs

Project Scenario

Additional practise changes

Changed carbon inputs
FAO (2020) provides standard parameters and all equations on:
- carbon input annual crops
- carbon input perrenials
- caron input manure/organic amendments
- carbon input from cattle type and stock

R/S crop (literature)

DPM/RPM plant/manure (literature)

Soil cover indicator *c*

Documentation model parameters is part of VMD0053 box 1

Data for calibration

Tillage

Covers PC like

- Reduced tillage
- No tillage

Implement Tillage Rate Modifier (TRM)

This can increase or reduce decomposition.

Can be derived from literature

Hyun & Yoo (2024)
STOTE

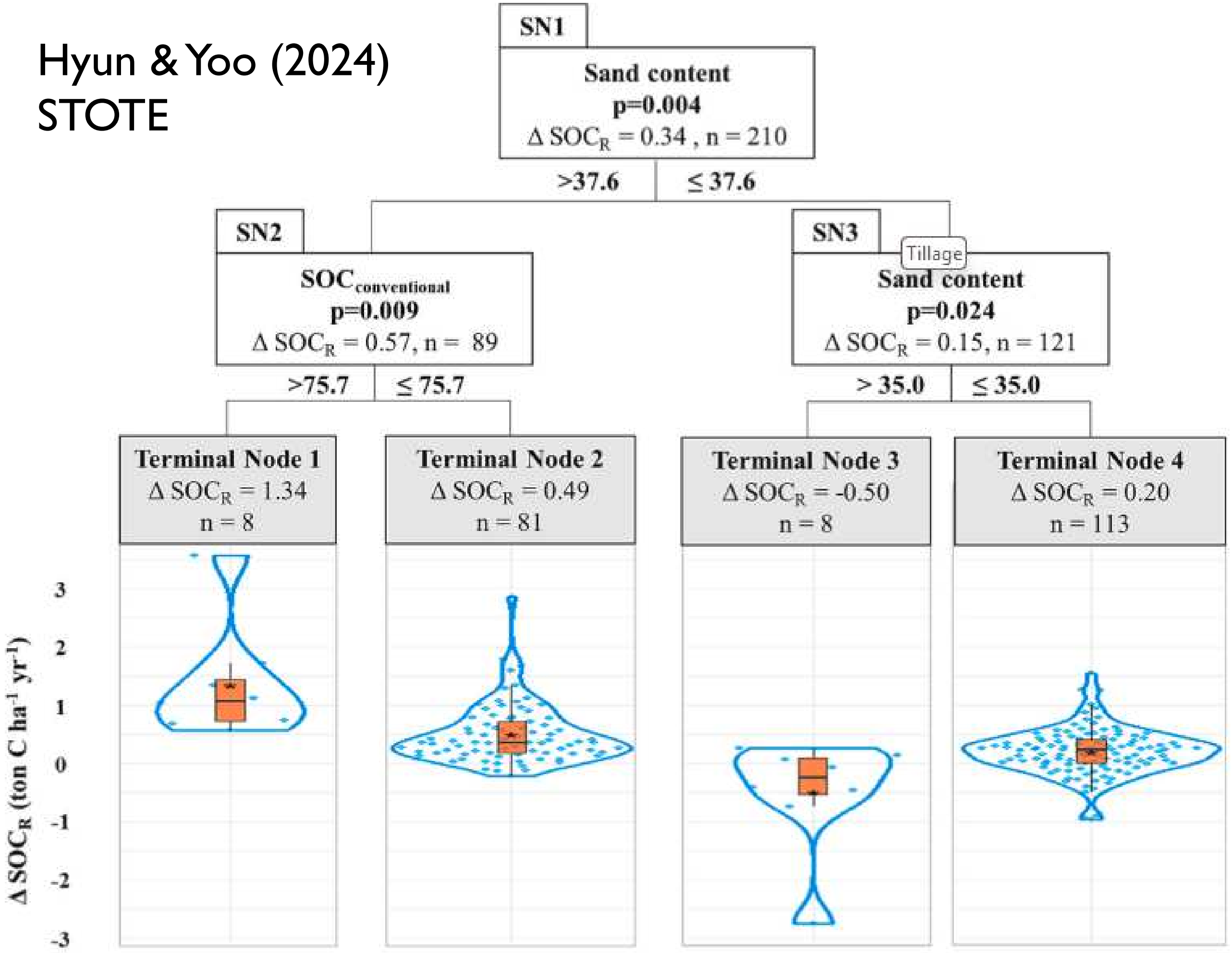


Table 3
Tillage rate modifiers of each group and pool estimates for conservation tillage (mean values of 30 population in parameterization process ±SE).

Terminal node (TN)	C Pools			
	DPM	RPM	BIO	HUM
TN1	1.54 ± 0.06	0.35 ± 0.01	1.42 ± 0.03	0.42 ± 0.01
TN2	1.71 ± 0.12	0.35 ± 0.01	0.38 ± 0.01	0.87 ± 0.01
TN3	1.54 ± 0.16	2.15 ± 0.03	2.38 ± 0.07	2.93 ± 0.01
TN4	0.72 ± 0.07	0.97 ± 0.02	0.99 ± 0.05	0.94 ± 0.02

Data for calibration

Find data in project

Can be used to e.g. improve RothC parameter on evapotranspiration, to adapt to your climate

Key Steps:

- Identify the parameter in RothC
- Use optimization method (e.g. R Nlopt)
- Split in a calibration and validation dataset. If you're data limited, use k-folding
- Target variable is SOC stocks
- Iterate parameter over set range and set size-step
- Use robust evaluation metric e.g. root mean square error(R)MSE
- Find best fit for parameter
- Evaluate impact of calibration on prediction carbon stocks.

Data collection for modelling

1. Data to run the model (climate, soil data)
2. Data to adjust model parameters (calibration)
3. Data to validate the model (from literature data)

Data for RothC

Collect data for validation

The project needs to **Validate** the model outcomes

Find literature with your practice change (PC) and crop functional group (CFG)

What to look out for in literature:

- Paired data
    - T = 0 and T = 1
    - BAU
    - Practice Change
    - At least four data points
    - For relevant CFG
    - → ΔSOC for baseline + project scenario

Goal for this data is for validation to show that the model results + confidence interval are close enough to measured data

Tip: Fujisaki et al., 2026: rich dataset https://www.nature.com/articles/s41597-026-06863-7

Tip: follow a structured literature research

Documentation on validation datasets is part of VMD0053 box 3

Data Gapfilling

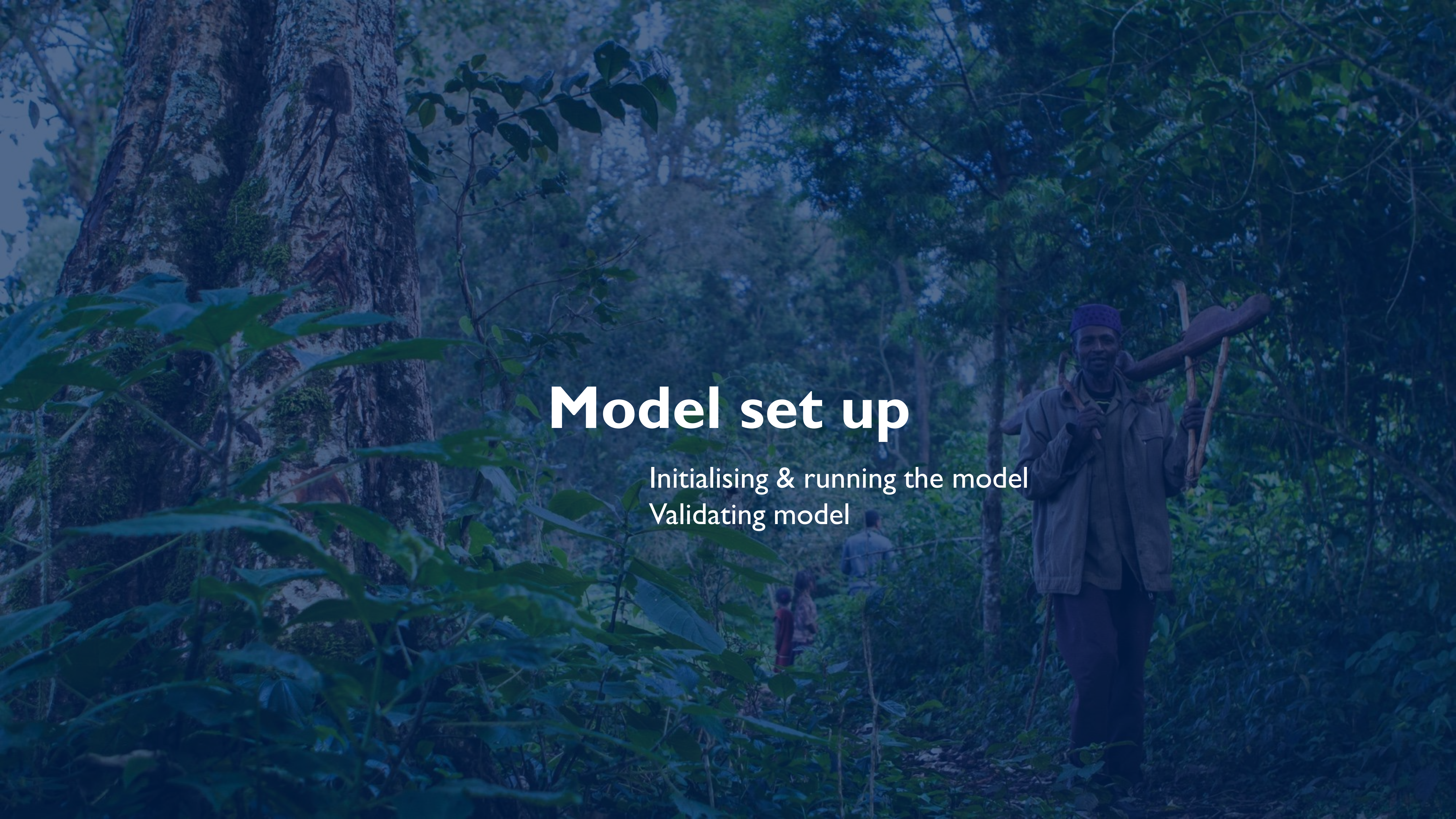
Get the most out of your data

Literature data may miss certain parameters such as bulk density or clay content

- Identify prevalent data gaps
- Choose good quality peer-reviewed sources for gap-filling (e.g. LUCAS/FAO/SoilGrids)
- Derive data from (previous) papers, such as location
- Document all gapfilling in detail.
- Check and document all units (common source of errors)
- Use Special Rule to for CFG's (VMD0053 v2.1 p.21): "*For studies used to validate model performance and uncertainty in the cropping PC, any CFG occurring within the experimental period of measurements may be counted toward validation.*"

Watch out for outliers in papers. E.g. if ΔSOC + 30 tC/ha

Documentation on validation datasets is part of VMD0053 box 3



Model set up

Initialising & running the model
Validating model

Model set-up

Initialisation RothC “spin-up”

Take the model to equilibrium

- Determine the distribution of SOC over the five compartments of RothC
- Run model iteratively
- **Complete** when estimates are <1% from SOC data

Tip: use for inert organic carbon (IOM):

IOM =0.049∗SOC^1.139 (Falloon et al., 1998)

After initialization you can ‘forward run’ it

Documentation on validation datasets is part of VMD0053 box 3

Model set-up

Initialization
RothC "spin-up"

Stabilize start + baselines

Two complementary steps to improve stability of the initialization:

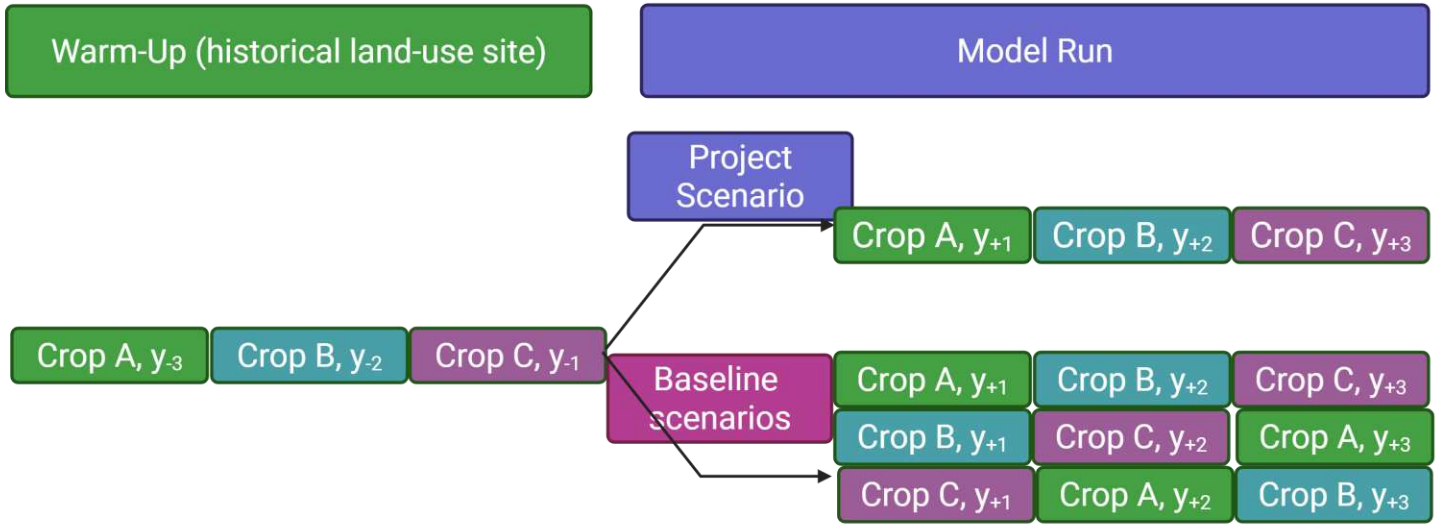
1. **Include 'warm up'**

Soil is unlikely to truly be at equilibrium after 'spin-up'.

Incorporate the effect of historic land use,

Implement a BAU for ten years.

2. **Include 'blended baselines'** in modelling the project



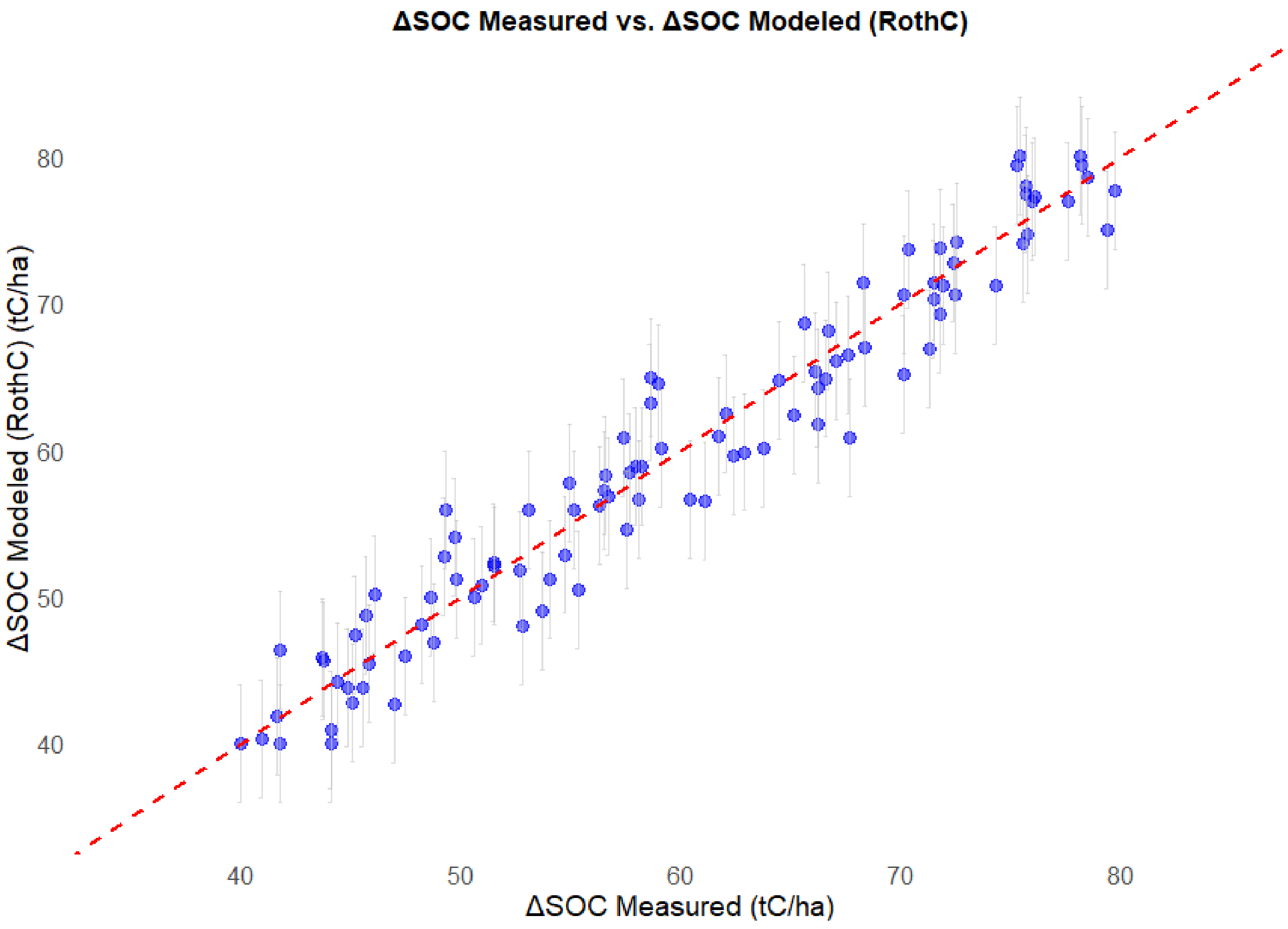
Model Validation

- Compare ΔSOC for measured + project
- For all unique combinations of PC* CFG

Validate results

The Project needs to **Validate** the model outcomes

Example of outcome of validation RothC and the literature



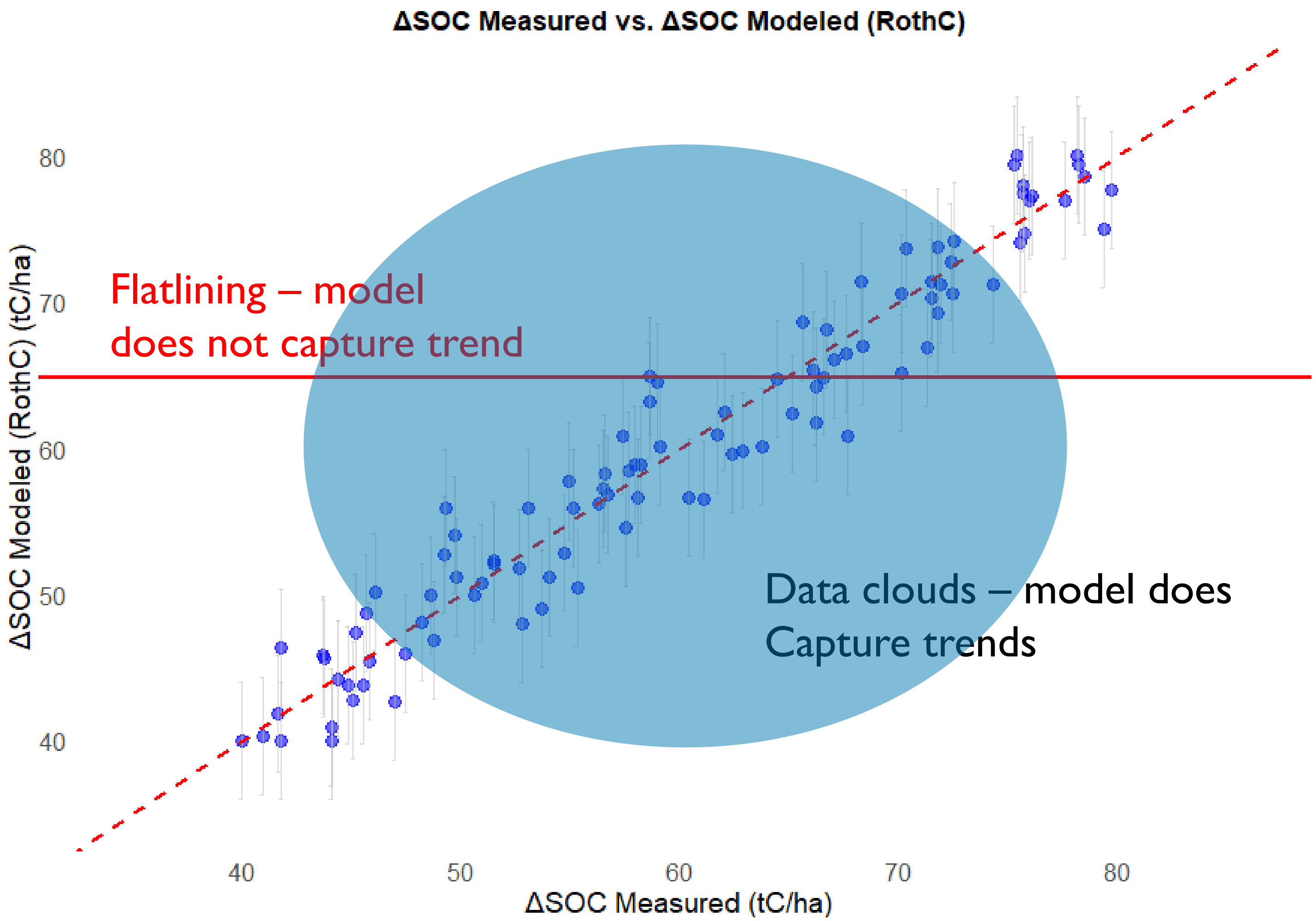
Model Validation

Validate results

The Project needs to **Validate** the model outcomes

Watch out for these red flags

Potential red flags for model evaluation



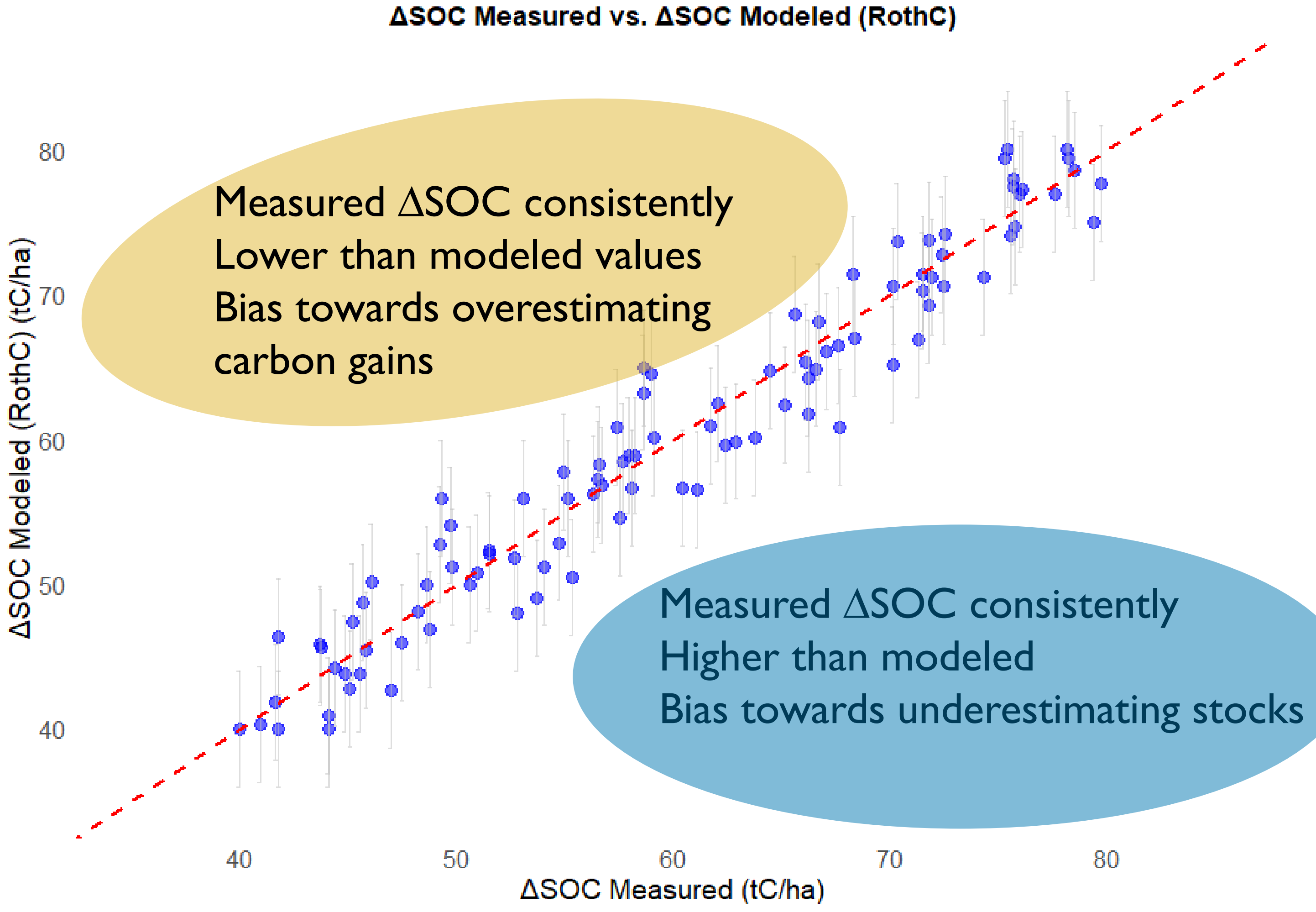
Model Validation

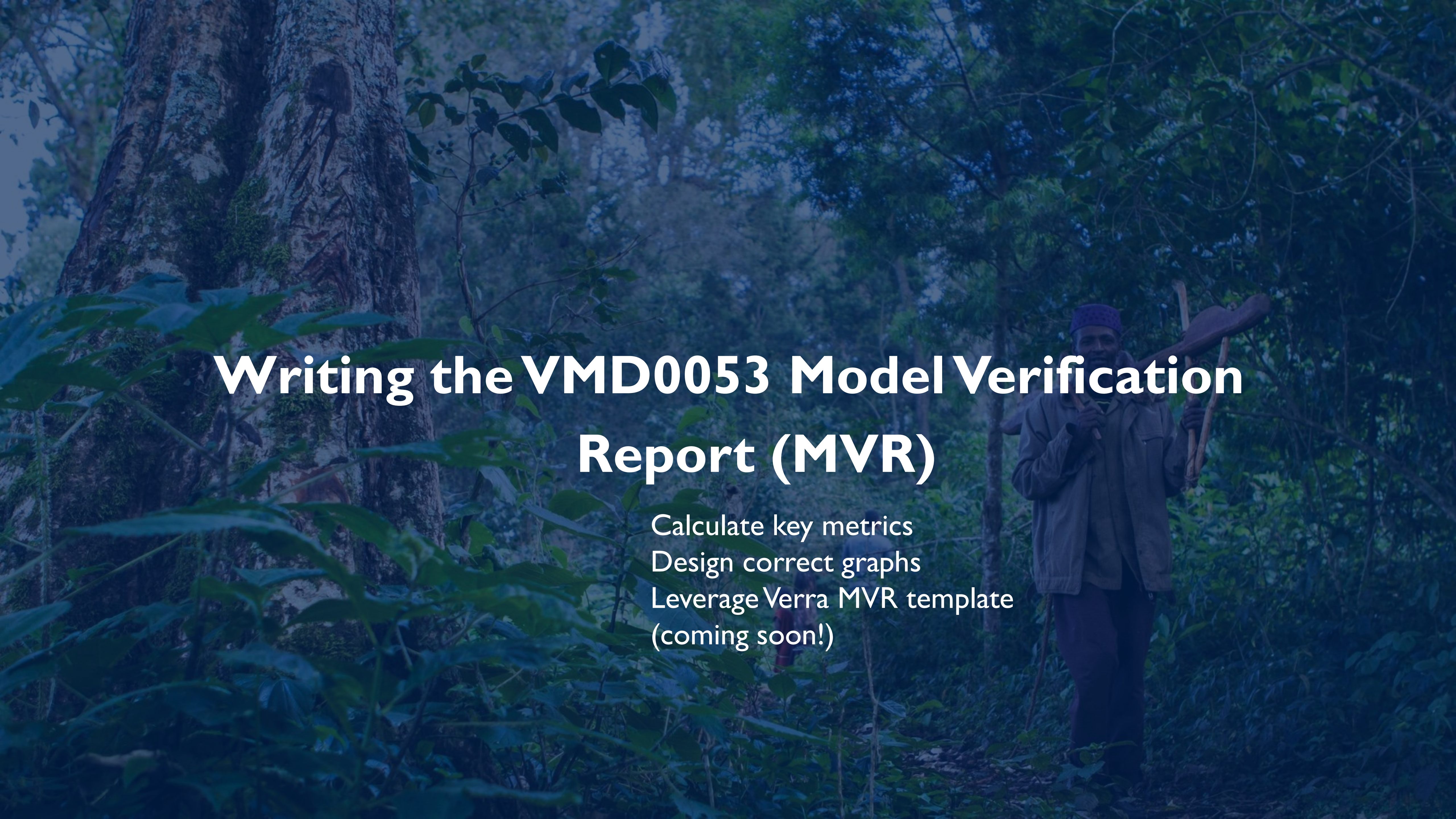
Validate results

The Project needs to **Validate** the model outcomes

Watch out for these red flags

Potential red flags for model evaluation





Writing the VMD0053 Model Verification Report (MVR)

Calculate key metrics
Design correct graphs
Leverage Verra MVR template (coming soon!)

MVR writing

Key Challenges

- Calculate bias
- Calculate the PMU
- Calculate the confidence interval

For each PC*CFG

Follow VMD0053 boxes

Verified Carbon Standard

VCS Module

VMD0053

MODEL CALIBRATION, VALIDATION AND UNCERTAINTY GUIDANCE FOR BIOGEOCHEMICAL MODELING FOR AGRICULTURAL LAND MANAGEMENT PROJECTS

Version 2.1

25 March 2025

Sectoral Scope 14

MVR writing

Bias calculation

Model should not over or underestimate measured values (unbiased)

You will also need to show bias < pooled measured uncertainty

$$bias = \sum_{i=1}^{n} (P_i - O_i)/n \quad (1)$$

Where:

P_i	=	Predicted (i.e., modeled) change in SOC, N_2O or CH_4 for the *i*th observation of the practice change
O_i	=	Observed (i.e., measured) change in SOC, N_2O or CH_4 for the *i*th observation of the practice change
i	=	Index of observation within study
n	=	Number of observations in study

Calculate for all PC*CFG
Calculate for all studies
Calculate mean all studies unweighted

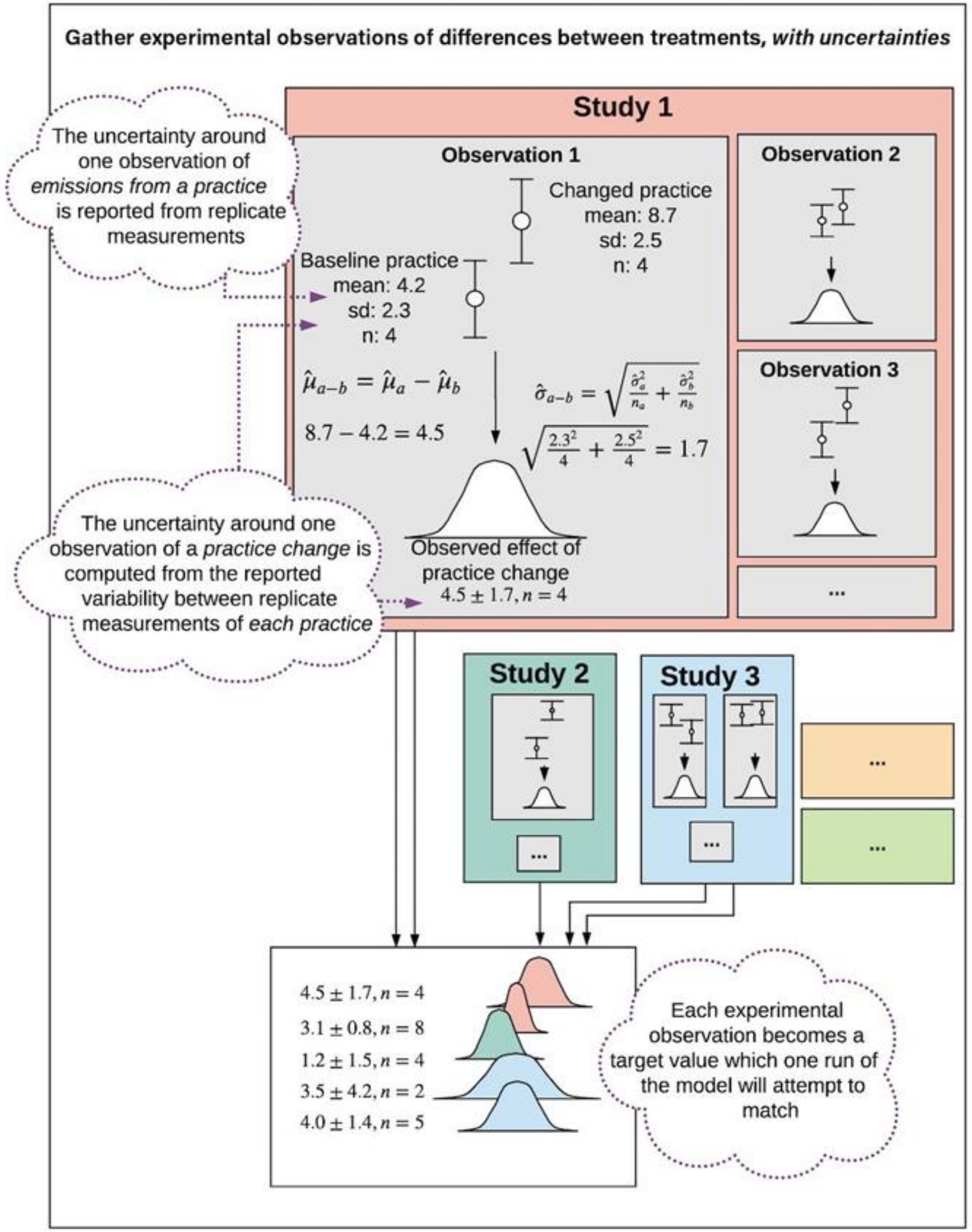
Documentation on validation datasets is part of VMD0053 box 4

MVR writing

Pooled Measurement Uncertainty (PMU) calculation

You will also need to show bias < pooled measured uncertainty

For each CFG*PC



VMD0053; Figure 4

MVR writing

Confidence Interval (CI)

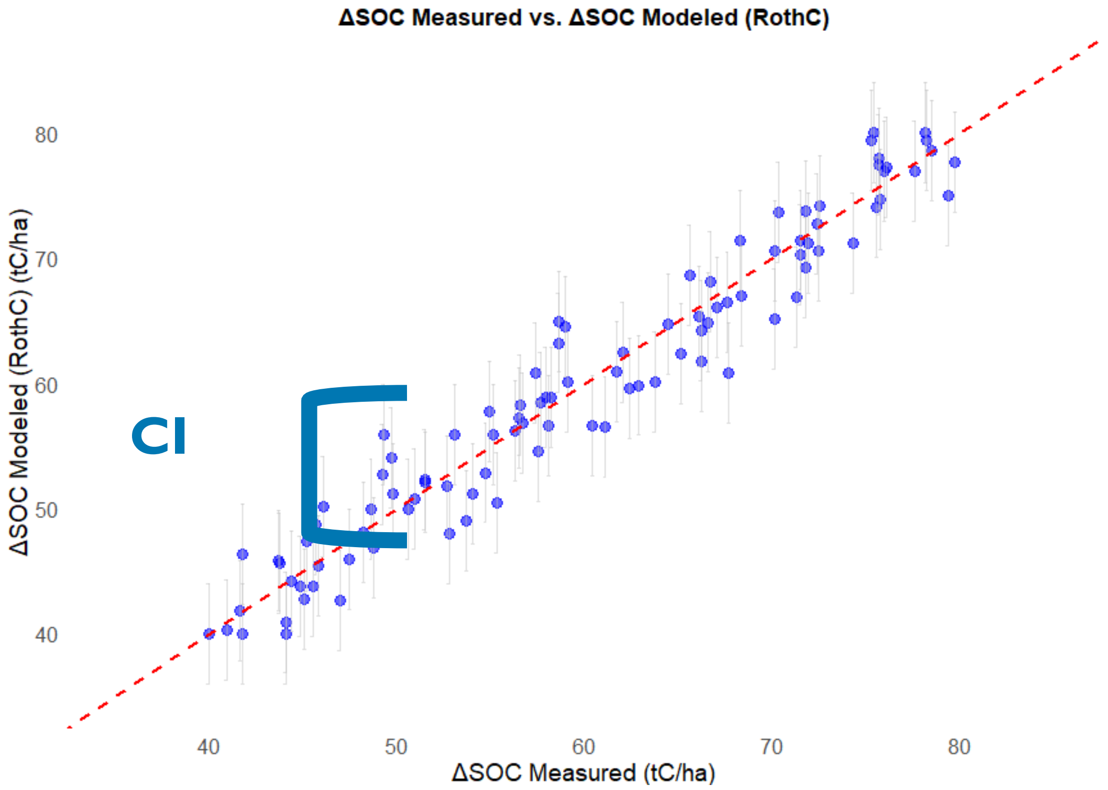
Calculate 90% confidence interval

Show that 90% of the model results fall into the 90% confidence interval

Generate 90% predictive intervals for *modeled* effects on withheld data (e.g., using k-fold cross-validation or similar) and compare to *observed* effects

$$\text{predictive\_interval}_i = \left[\mu_i - 1.64\sigma_{\text{model\_error}}, \mu_i + 1.64\sigma_{\text{model\_error}}\right]$$

Figure 6 VMD0053



Documentation CI, residuals, MSE is part of VMD0053 box 5

Q&A

THANK YOU

Get in touch

Questions?

Nutrient Management Institute Wageningen

Tessa.vandervoort@nmi-agro.nl

www.nmi-agro.nl

Many thanks to:

Verra and NMI Team

RAAK Sentinel Research project Team

AgreenaCarbon Project, Europe (Verra Project 4022).

Useful links for data modelling

Changing biogenic inputs FAO (2020) Annex 1:

https://doi.org/10.4060/cb0509en

Open Global Climate dataset AgEra5 (Bogaard et al., 2020):
https://cds.climate.copernicus.eu/datasets/sis-agrometeorological-indicators?tab=overview

RPM/DPM ratio's and decay manure sources (Wageningen):
https://www.handboekbodemenbemesting.nl/bemestingsadviezen/organische-stofbalans/aanvoerbronnen-effectieve-organische-stof/

AgreenaCarbon Project, Europe (Verra Project 4022).

References

Black, C., Brummit, C., Campbell, N., DuBuisson, M., Harburg, D., Matosziuk, L., Motew, M., Pinjuv, G., & Smith, E. (2025). *VM0042 | Improved Agricultural Land Management*
Coleman, K., & Jenkinson, D. S. (2014). *RothC-A model for the turnover of carbon in soil Model description and users guide*.
FAO. (2020). A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes – GSOC-MRV Protocol. In *A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes – GSOC-MRV Protocol.* FAO. https://doi.org/10.4060/cb0509en
Fujisaki, K., Ferchaud, F., Clivot, H., Bruni, E., Guenet, B., Pichot, C., Versini, A., Baudin, F., Bispo, A., Peylin, P., Martin, M. P., Jensen, J. L., Eriksen, J., Chenu, C., Gregory, A. S., Glendining, M. J., Merbach, I., Beaudoin, N., Mary, B., … Barré, P. (2026). Data from long-term experiments in temperate croplands to evaluate soil organic carbon models. *Scientific Data*, *13*(1), 482. https://doi.org/10.1038/s41597-026-06863-7
Hyun, J., & Yoo, G. (2024). Modification of the RothC model to evaluate the inconsistent effect of conservation tillage on SOC stock and a suggestion of a national-scale assessment framework. *Science of the Total Environment*, *907*. https://doi.org/10.1016/j.scitotenv.2023.168010
Jordon, M. W., & Smith, P. (2022). Modelling soil carbon stocks following reduced tillage intensity: A framework to estimate decomposition rate constant modifiers for RothC-26.3, demonstrated in north-west Europe. *Soil and Tillage Research*, *222*. https://doi.org/10.1016/j.still.2022.105428
Prout, J. M., & Coleman, K. (2024). *Rothamsted-Models/RothC_Py: RothC code in Python language*. https://github.com/Rothamsted-Models/RothC_Py
VCS Verra. (2024). *VMD0053 v.2 Model Calibration, Validation and uncertainty guidance for the methodology for improved agricultural land management, greenlined*.

AgreenaCarbon Project, Europe (Verra Project 4022).