# Managing Quantification Uncertainty in Agricultural Carbon Markets

## Executive Summary


Uncertainty is a fact of life. Commuters in large cities become adept at balancing the uncertainty and potential rewards of different routes and methods of transport. For example, driving to work may offer comfort and the potential for time-savings over taking a train, but traffic introduces uncertainty in arrival times. On average, the car might be faster, but the uncertainty in that length of time is greater than taking the train, so the commuter must weigh these options against their own priorities. In carbon accounting, there is uncertainty in every metric, whether or not it is explicitly considered in the final quantification. For example, measurement of gas flow from a landfill requires use of a flow meter. Rather than quantify and account for the uncertainty from these meters, the GHG crediting programs will specify allowable metering technologies which are shown to be accurate for the flow ranges expected to be experienced by the project. In addition, they require periodic calibration, with adjustments for excessive drift to correct any bias.

For agricultural carbon projects, which rely on dynamic, biophysical systems, there is potential for much higher levels of uncertainty, and there is no simple, inexpensive option for regular recalibrations. In addition, for protocols such as the Soil Enrichment Protocol, which do not specify the model to be used, rigorous accounting for uncertainty is required to avoid projects using inaccurate tools without adjusting the final credit totals to reflect that uncertainty.  Managing quantification uncertainty arising from errors in sampling, measurement, and modeling increases confidence in the real-world effect of agricultural carbon credits. Carbon markets based on terrestrial soil carbon sequestration – particularly agricultural soils – are promising from the perspective of scale and readiness but have been hampered in part due to concerns around the certainty of the quantification. To be clear, any agricultural carbon avoidance and/or removal projects should account for uncertainty. Here we discuss sources of uncertainty and risk mitigation strategies for the growing agricultural carbon market, including 1) properly assessing the level of uncertainty in each project and 2) applying a reasonable deduction to the number of credits generated within the project to ensure that the resultant credits can be considered "real."

Credit buyers, legislators, and government agencies can play a positive role in supporting carbon projects that prioritize appropriate uncertainty management:

- **Buyers** should purchase credits from suppliers who are transparent about their uncertainty management strategies and who have rigorous uncertainty accounting.
- **Legislators** should understand the key criteria of uncertainty accounting in carbon markets and ensure that private carbon crediting projects that receive public funds or support are verified by

third parties. Furthermore, policymakers should support active and increase funding for research and development in agricultural carbon measurement, modeling, and quantification.

Though the discussion in this document is largely focused on carbon accounting in agricultural systems, the core concepts around uncertainty would apply to any sector. All carbon accounting involves sources of uncertainty, but not all carbon accounting approaches deal equally with quantifying and making adjustment for that uncertainty.

## Basics of Uncertainty in Carbon Accounting

In carbon accounting, the uncertainty of a project's sequestration and abatement is the range of values that are scientifically consistent with the measurements. For agricultural offset projects, that range of values can be rather wide, with much of that spread attributed to the difficulty of predicting soil carbon using models. As such, it is critical to ensure a high bar for confidence is set for agricultural carbon programs upfront. Requirements may be easier to satisfy over time as modeling science and technology advance. It is unreasonable to expect that uncertainty can be fully eliminated, but steps can be taken to mitigate different sources and transparently communicate about them. The goal should be find the balance of uncertainty with practicality that allows for credible accounting of impact at a large scale.

Uncertainty is inevitable for ecological processes like carbon cycling, and thus for natural climate solutions (NCS), given the difficulty of direct physical measurements of fluxes and stocks of gases across natural sinks across the globe. Unlike accounting of industrial carbon emissions and direct agricultural emission reductions via fertilizer and fuel or energy management, agricultural soils do not have "point sources" for measurement of GHG fluxes and carbon storage. Managing uncertainty is therefore necessary for scaled NCS markets. Environmental integrity can be upheld by defining, accounting for, and complying with acceptable levels of uncertainty. Registries like Verra and the Climate Action Reserve provide guardrails for acceptable levels of uncertainty in carbon accounting projects and often apply deductions to reduce the possibility of overissuing credits and to incentivize project developers to mitigate uncertainty. Generally, thresholds used for these deductions originate from International Panel on Climate Change (IPCC) guidance[1]. If uncertainty is not accounted for prior to credit issuance, or if lenient uncertainty thresholds are used, the resulting credits may fail the key offset quality criterion of being "real." Realness signifies that credits are the result of complete and accurate accounting based on proven and conservative methods.

## Uncertainty and Soil Carbon Sequestration

Uncertainty can stem from different components of the carbon quantification process, including sampling, measurement, and modeling (see Figure 1). Sampling error results from measuring only a portion of a project area. Sampling error can create a bias (a tendency to over- or under-estimate) when certain parts of the project tend to fail to be sampled. Given the spatial and temporal variability of soil carbon, it would be physically laborious and highly expensive to sample at a frequency and density high enough to drive sampling uncertainty down enough to be able to detect a real, short-term change with confidence in a single field.

[1] See 2006 IPCC Guidelines, Volume 2, Chapter 2, Tables 2.2 – 2.6

Measurement error refers to accuracy of a given measurement. Project developers and protocols should account for measurement-related uncertainty (although most do not). For example, loss on ignition is an analytical method used to assess total and organic soil carbon concentrations in a soil sample that, while widely used, has high uncertainty. Conversely, dry combustion is both accurate and precise, but even this best-in-class approach has small amounts of associated error, which contributes to overall uncertainty. At the same time, dry combustion in laboratories remains costly and labor-intensive, presenting a need for new, less-costly, yet still precise technologies. The development of new measurement techniques that do not contribute a large amount of measurement error and are not labor intensive or costly should be incentivized, as should easy to deploy, inexpensive, and less precise solutions that could deliver sufficient accuracy by enabling high sampling rates. Uncertainty can also be reduced by aggregating numerous fields, resulting in an average measurement that is relatively accurate. This benefit of aggregation also applies to model results.

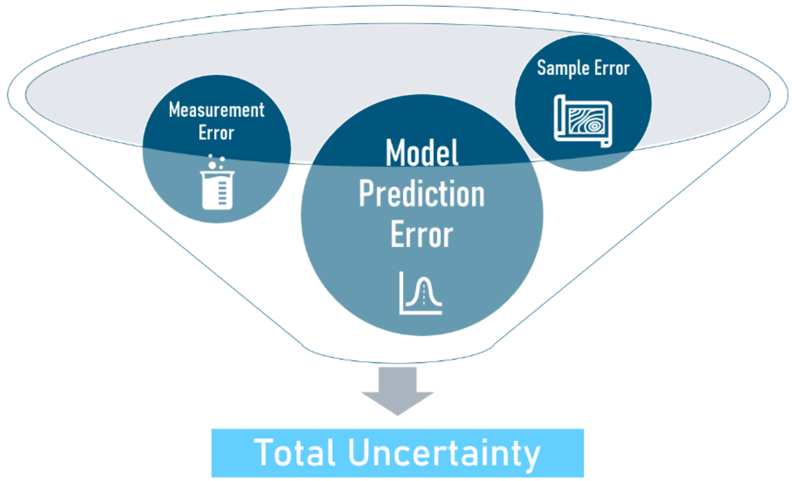


*Figure 1. Comprehensive accounting for uncertainty requires consideration of sample error, measurement error, and model prediction error.*

Model prediction error assesses how well a model forecasts the response variable. Most carbon offset protocols have treated model predictions as truth or fixed, non-random, error-free quantities. For example, many protocols employ the use of default equations based on simplifying assumptions without accounting for associated uncertainty. A new breed of soil carbon protocols treats model predictions differently, acknowledging and accounting for the potential for errors in model predictions[2]. Fortunately, model predictions and uncertainty can be continually improved via expansion of soil libraries and remeasurements of soil organic carbon (SOC) stocks. Models used should be updated and continuously improved over time with new data, from both inside and outside the project.

Figure 2 provides examples of how uncertainty outcomes can change based on different sample designs and the volume of validation data available for a particular model.

[2] https://www.climateactionreserve.org/how/protocols/soil-enrichment/#models

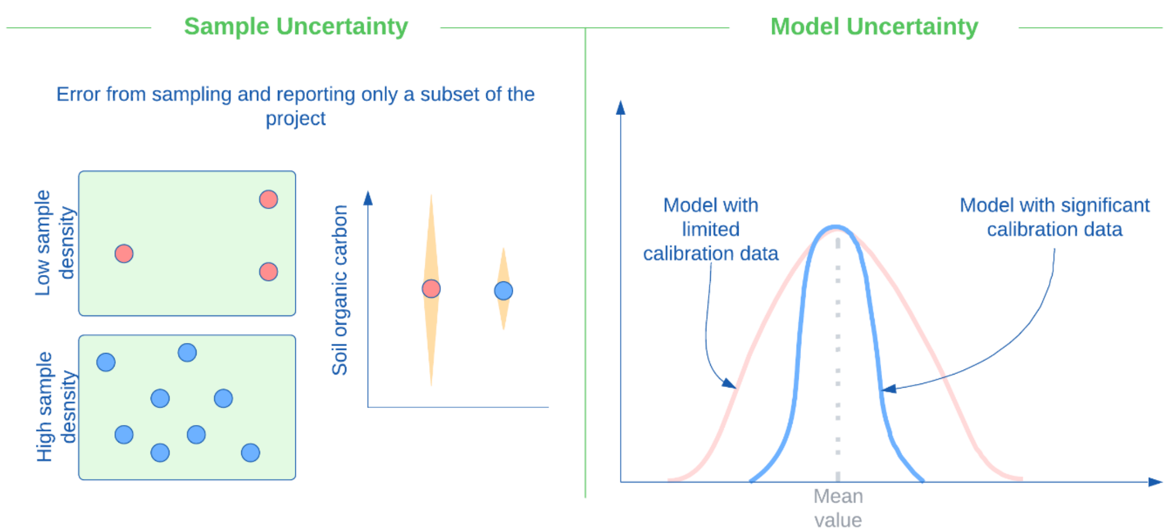


*Figure 2. Overview of uncertainty quantification in Carbon project sampling and modeling. Project uncertainty is affected by (A) sample uncertainty (i.e., field variability) and (B) model uncertainty. Field level averages calculated from few samples vs. multiple samples results in wider variability in soil organic carbon stock estimations. Field data are used to calibrate biogeochemical models to tune their parameters and improve their predictive power. With additional validation datasets, model uncertainty can be reduced.*

## Mitigating Quantification Uncertainty in Agricultural Carbon Projects

Agricultural carbon accounting projects should account for uncertainty, while also recognizing that driving uncertainty to zero is impossible. Uncertainty exists in all parameters of soil carbon measurement, reporting, and verification (e.g., additionality, permanence, reversal, leakage) and needs to be incorporated into protocols through conservative assumptions and requirements, as well as uncertainty accounting designed to mitigate the risk of overestimation or loss of carbon. But at the end of the day, carbon accounting must accept some level of uncertainty, and for uncertainty to remain in project impact estimates. There are multiple uncertainty management models in carbon markets, and similar to the insurance world, uncertainty accounting and management is not unprecedented. We must remember that each carbon offset is applied against a buyer's own footprint. This footprint is developed through accounting methods that tend to be far less certain than those employed by the carbon project itself. So long as conservatism is maintained in both instances, it is reasonable to use offset credits with some level of inherent uncertainty.

Controlling for uncertainty involves two components: 1) estimating the magnitude of uncertainty; and 2) applying a reasonable and conservative deduction to the quantification of credits. Different programs and methodologies strike this balance through different scopes of uncertainty estimation and different approaches to the resulting deduction.[3]

[3] Australia, a leader in soil carbon sequestration, uses a measurement-based approach and harnesses the probability of exceedance. Exceedance probability is a statistical term that describes the probability that a certain value will be met or surpassed in a set period and can be used to predict natural phenomena such as floods (Kunreuther 2002).

Registries should embed requirements in protocols that encourage project developers to reduce uncertainty and enable buyers to interpret confidence in their credits. Historically, methodologies have penalized projects for the extent to which their "relative uncertainty" exceeds a threshold such as 10% or 15%.[4] That rule makes it hard to interpret each credit: when a buyer looks at a credit they bought, they do not know the likelihood that it corresponds to at least one tonne of climate benefit, because under this type of rule that likelihood depends on the number of credits generated by the project. This particular shortcoming is addressed by the uncertainty deduction rule used in the Australian government's soil carbon protocol (and later adopted by the Reserve in v1.1 of the SEP[5]): the confidence is the same for every credit (and equals a probability that is chosen by the protocol). This approach encourages greater accuracy and precision and would assist buyers to better interpret confidence in the credits they purchase, which in turn better incentivizes carbon markets to manage uncertainties. Ultimately, registries should develop common tools and guidance for uncertainty accounting to reduce the effort for project developers and verifiers.

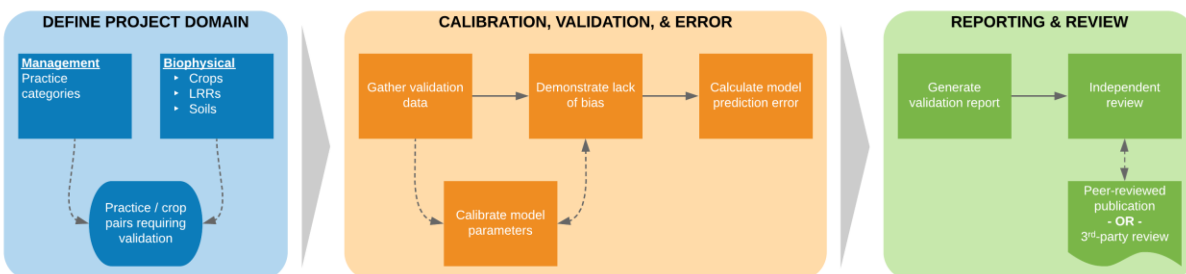


*Figure 3. Process flow for the approval of model calibration, validation, and quantification of uncertainty. Adapted from Verra VMD0053 Model Calibration, Validation, and Uncertainty Guidance for the Methodology for Improved Agricultural Land Management.*

Project developers estimate and account for uncertainties along the way, including the sources mentioned above (sampling, measurement, modeling). These entities follow the requirements of the registry and protocol adopted, which determine how uncertainty is addressed. A hybrid measurement and modeling carbon accounting approach introduces multiple sources of uncertainty to a project, which the project developers must then account for while also allowing crediting on an annual basis. However, an approach without measurement or modeling may still result in higher uncertainty on the same timescales (e.g., using SSURGO, a national soil database, for model initialization may introduce greater uncertainty than direct measurement of model inputs). Although any well-formulated and executed approach could account for uncertainty, hybrid approaches are employed because we are unable to confidently measure net changes in soil carbon on an annual basis and because business-as-usual emissions are hard to measure directly, while models alone are untethered to the reality on the

[4] Relative uncertainty is the margin of error of the estimated total divided by that estimated total
[5] https://www.climateactionreserve.org/wp-content/uploads/2022/06/Soil-Enrichment-Protocol-V_1.1-final.pdf

ground without incorporation of direct measurements. Even if approaches were 100% accurate and precise, real variability in the system would mean that we would not always detect the overarching trend on such a short timescale. However, **accounting for model prediction error enables accurate use of models on annual timescales**, and the missing data that can arise when crediting on such fast timescales can be addressed using innovative post-stratification methods (see Jackson Hammond et al. 2021 for more details).

Uncertainty can be reduced by maximizing the number of samples taken, using more precise measurement technologies, and distributing measurements across time and space to maximize coverage, capture variability, and expand datasets used to train and calibrate models. Multiple fields and farms should be grouped together across crop types, practices, geographies, climates, and other dimensions to buffer against individual field and/or grower risk, and to allow for the scaling of sampling, data collection, and quantification. Stratification can be used to account for variability across heterogenous populations and outcomes. Ultimately, verifiers should confirm that the project developer adequately followed uncertainty management requirements.

Advances outside a carbon project can also reduce uncertainty, thereby decreasing the cost of producing carbon credits. Peer-reviewed studies of agricultural measurements can reduce the uncertainty of models. Researchers should continue advancing biogeochemical models and document the combinations of crops, soils, and environments for which each model has been validated and has known accuracy and precision. Previously collected data should be shared in as much detail as possible to enable uncertainty quantification and better calibration of models (e.g., share both the average of a treatment's outcome as well as the sample size and standard deviation). More data should be gathered on new measurement techniques and technologies to better quantify the associated uncertainty. Uncertainty of novel technologies should be decreased to appropriate levels before being used for offset project accounting. Additional innovations[6] in soil carbon and soil health research as well as commercial soil processing and analyses would improve soil model baselining and reduce overall uncertainty.

[6] Areas of innovation include in-field soil property measurement, remote sensing of soil properties, improved lab analytical methods, soil & emissions data on erosion & biogeochemical cycling, and database(s) of soil emissions and soil organic carbon measurements.

Perhaps most importantly, projects should always be transparent about their quantification of uncertainty and the performance of their chosen model against measured values. Figure 4 shows one method of summarizing model performance, excerpted from the model validation report for DayCent-CR 1.0.2.[7]

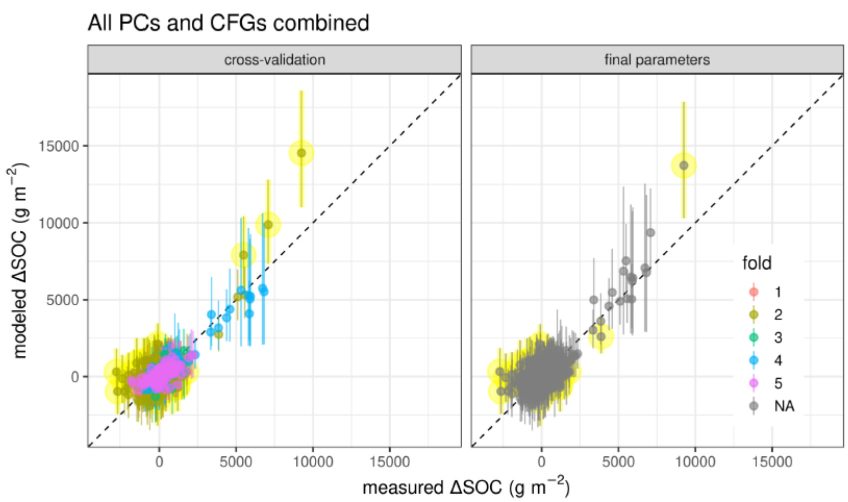


*Figure 4 (Figure 65) model predictions versus measurements of SOC change in all practice changes and crop types obtained during cross-validation (left) and with final parameter sets (right). Error bars show 90% prediction intervals.*

## The Role of Credit Buyers and the Government in Encouraging Robust Accounting and Management of Uncertainty

Significant scientific effort is directed towards quantifying and addressing uncertainty whether soil carbon credits are to be used in an inset or offset market. High-integrity NCS credits can be created with rigorous accounting for uncertainty. Ultimately, buyers should ask credit suppliers if and how they have controlled for uncertainty. Buyers should not focus on the magnitude of uncertainty deductions alone – a small uncertainty deduction does not necessarily imply a higher-quality[8] project, and a higher-quality project with less uncertainty might have a higher absolute uncertainty deduction because the deduction rule is more stringent. Rather, buyers should focus on credits generated with rigorous uncertainty accounting. Confidence levels signal the rigor of an approach and refer to the percent with which you are sure that each credit corresponds to at least one tonne of $CO_2$e abated or removed. Buyers should ask which sources of uncertainty were quantified and which were not, as some methodologies leave important sources of uncertainty unquantified and hence those sources are not reflected in the widths of confidence intervals.

Legislators and governmental agencies should ensure that any private market programs supported by the public sector use government-approved protocols and undergo third-party verification; this will ensure the use of rigorous uncertainty approaches. Policymakers should form consensus around what rigorous uncertainty accounting should look like, and ensure it is standard across any protocols approved/certified through legislation like the Growing Climate Solutions Act or actions taken by agencies such as the USDA.

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[7] https://www.climateactionreserve.org/wp-content/uploads/2022/11/CAR1459_model_val_DayCentCR_1.0.2.pdf

[8] Offset Quality Initiative, Ensuring Offset Quality: Integrating High Quality Greenhouse Gas Offsets into North American Cap-and-Trade Policy. 2008. Last accessed at https://www.c2es.org/site/assets/uploads/2008/07/ensuring-offset-quality.pdf on 2021-07-30

Further, it is imperative to increase federal funding for research and development associated with agricultural carbon measurement, modeling, and quantification. Research that can help improve biogeochemical models should be provided with increased and long-term funding. This could include the development and funding of a network of sites in which comprehensive, high density, and high frequency field level data is taken across a variety of agricultural systems and geographies. The data collected from the site network should be open and available for research and technological advancement. Funding should be directed towards the development and expansion of soil libraries for the storage and classification of physical samples and detailed digital data.

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This policy brief is part of a series developed by Indigo Ag, in collaboration with our scientific and policy thought partners. Other past and future topics include data interoperability, a general overview of agricultural GHG emissions, soil health, additionality, permanence, and others. All Indigo policy publications may be accessed at: https://www.indigoag.com/carbon/science/advancement.