On Field Soil Carbon Measurement

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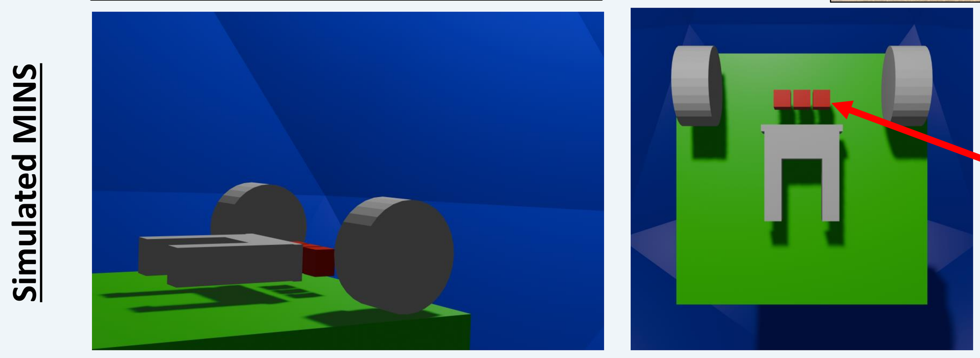
Mobile Inelastic Neutron Scattering System

The MINS System

The Mobile Inelastic Neutron Scattering System (MINS) is designed for measuring elements of soil in a mobile setting. Pulled by a tractor and leveraging inelastic neutron scattering, carbon levels are measured at various points of a field, generating a map of elemental concentrations.



The MINS is modeled in software for simulation.

Figures A – Real vs Virtual MINS Render (Side) (Top)

Mapping Soil Carbon with Core Harvest vs MINS

Speed and Cost

The MINS system is a cost and time saving measure. The analysis is done on site, such that samples are not sent to a lab.

Precision

The lab environment provides exact measurements of carbon content in harvested samples. The MINS detects energy caused by inelastic neutron scattering to predict the levels of carbon in regions close to the detector.

Carbon Mapping

The mins system can scan the field which could give more accurate representation of the carbon on the field.

Lab Analysis:
↑ Precision ↑ Cost ↓ Speed
MINS System:
↓ Precision ↓ Cost ↑ Speed

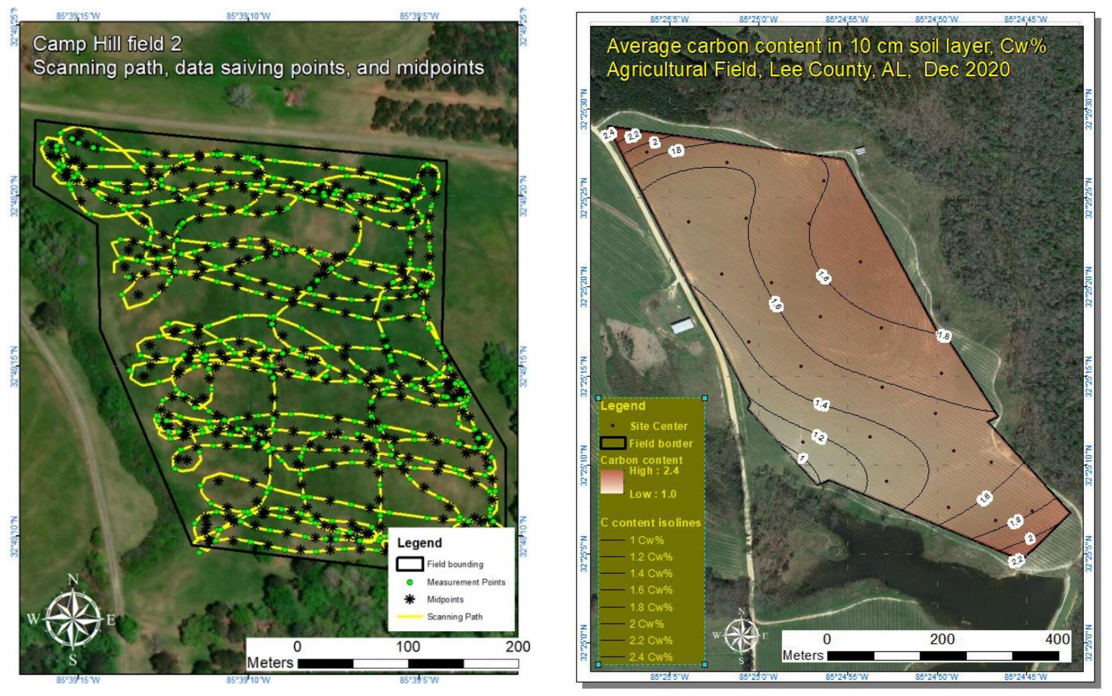


Figure H – MINS Pathing vs Core Placement

Figure I - ContraMP320 Neutron Generator (DT)

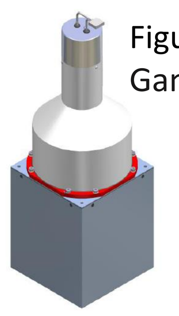


Figure J - NaI Gamma-Detector

Scanning Carbon on Field

The Mobile Inelastic Neutron Scattering System in Action

Future Work - Simulation Comparison

The next steps are to simulate whole fields to measure the difference in precision between MINS and core harvesting.
Materials in MCNP cannot be defined functionally. Instead, the concentration function is transferred into MCNP code by cutting the regions into tiny sections and sampling the midpoints of each section with the soil function as the material of each cell.
The code to do so is in development.

Core Harvest and Simulation

Core Harvest Method

Core harvesting is the general method to determine soil carbon content. Cylinders dig up soil cores that are taken to a lab for analysis. This provides an exact measurement for carbon content. Vertical slices are taken and individually measured.

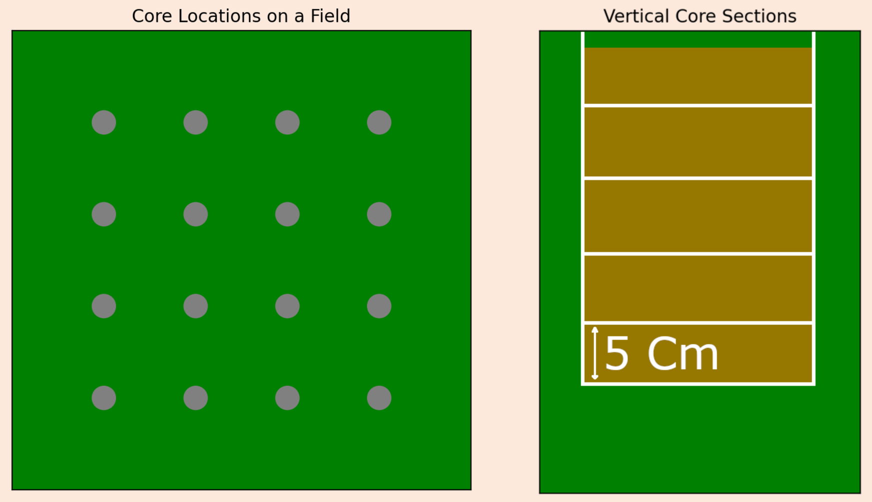


Figure G – Core Placements and Vertical Slices

Soil Simulation

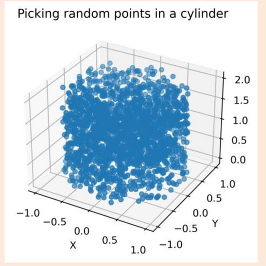
The carbon content of soil can be described as a function:

$$F(x,y,z) = Carbon_{concentration}: |F| \le 1$$

This can be used to simulate concentrations of carbon in fields.

Core Harvest Simulation

Defining cylinder positions and picking uniformly random points inside them determines the carbon concentrations that would be found in the lab.



Simulating Neutron Scattering

Inelastic Neutron Scattering

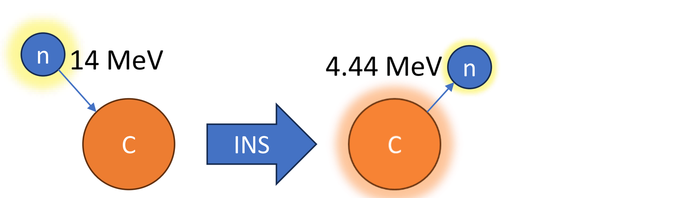


Figure B – INS

Inelastic Neutron Scattering (INS) can occur when a neutron hits certain elements such as carbon. After collision, energy from the excited atom scatters out inelastically, shooting out at a lower energy level. A neutron hitting a carbon atom with 14 Megaelectron Voltz (MeV) of energy, will bounce off with 4.44 MeV of energy

Monte Carlo Neutron Particle Sim

MCNP6.2 is used to simulate the paths and effects of particles as they travel in a system. Single simulations take between 5 to 7 days for results to be calculated on a single node. The results provide spectrums that match the detector readings.

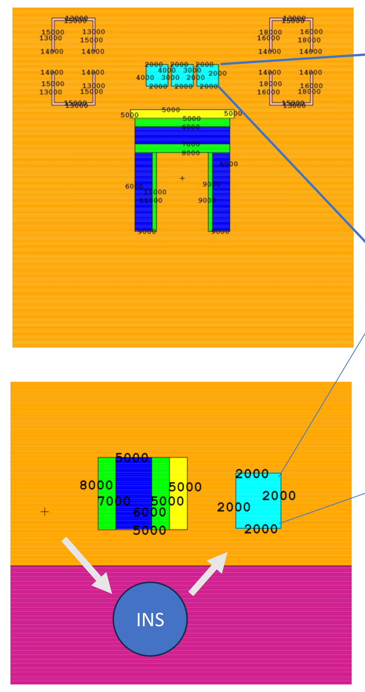


Figure C – MINS in MCNP6.2 (Top) (Side)

INS Spectrums and Peak Fitting

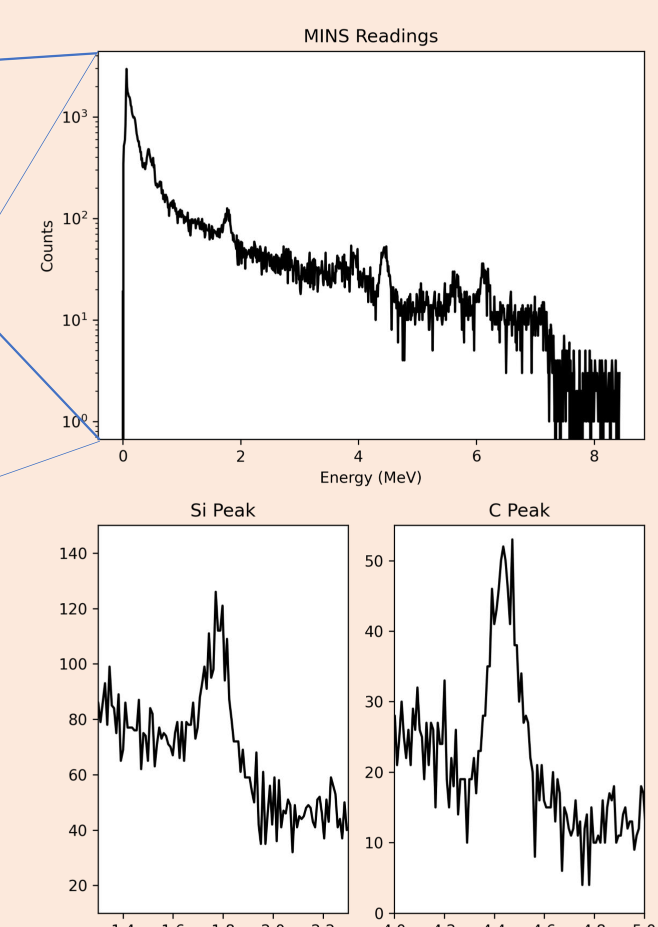


Figure D – Simulated MINS Readings

Spectrums

Over a set amount of time, neutrons are emitted. The detector measures energy levels. The energy levels are sampled. Spectrums are recorded by the detector. INS causes spikes around specific energy levels. The spike can be described with a peak function that is approximately gaussian:

$$Ae^{\left(\frac{x-x_0}{\sigma}\right)}$$

Peak fitting

A baseline function describes underlying energies not part of the peak.

$$ae^{-p(x-x_0)} + b$$

The sum of the peak and baseline are fitted onto the spectrum. The peak area is calculated.

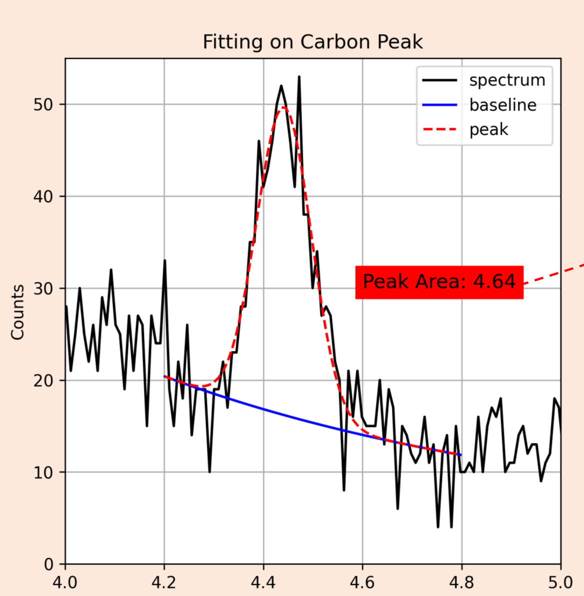


Figure E – Peak Fitting

Calibration to Peak Areas

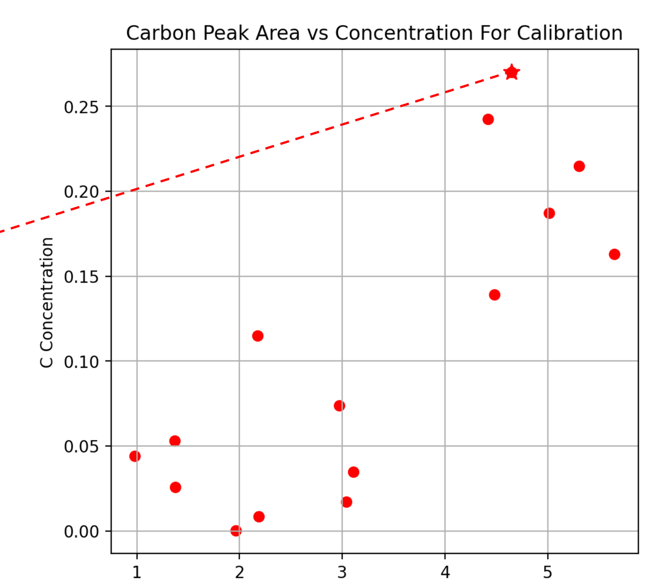


Figure F – Peak Areas and Carbon Conc.

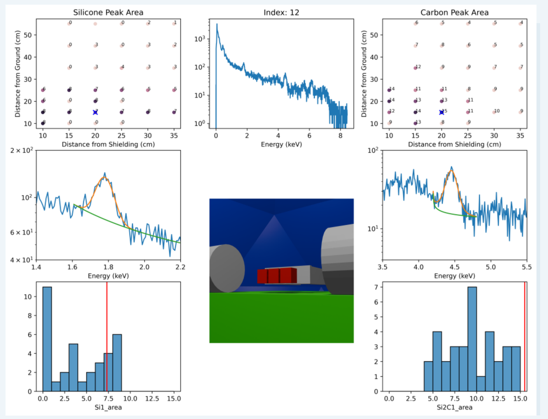
The peak areas are correlated to the carbon content of the soil. The function:

$$\frac{C_{Pk\ Area} - K_1 * Si_{Pk\ Area}}{K_2}$$

Is fit to describe the relationship. Calibration is done on known soil compositions. The calibration is consulted during measurement to find the concentrations.

Optimal Detector Positioning

Peak fitting is used to determine the optimal placement of the detectors. 20 cm from the shielding, and 15 cm from the ground. This configuration has the most sensitive peak area.



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Codebase

This work is developed publicly. The peak fitting python package, frontend web app, soil simulator, and miscellaneous work can be found at github.com/JoseACortes/MINS.