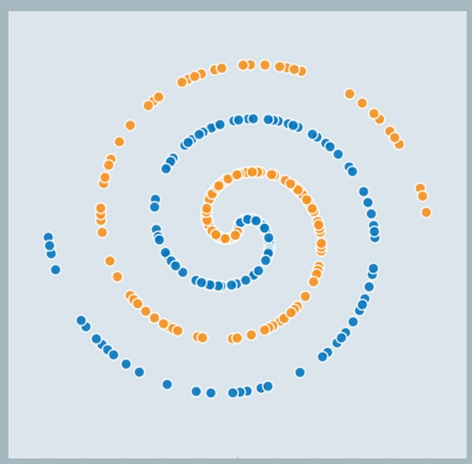
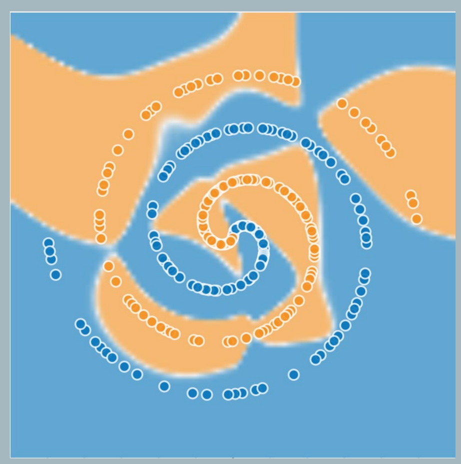
Estimating Soil Organic Carbon with Physics-Informed Neural Networks

James Sargeant

Supervisors: Prof Shyh Wei Teng, Prof Manoranjan Paul, Prof Manzur Murshed and Mr David Brennan

Problem and Motivation

- Accurate Soil Organic Carbon (SOC) readings are essential for farm management, carbon farming & market access
- Measurement is expensive at approx. $500 per sample
- Science-based estimation using soil and vegetation indices does not use all spectral information
- Estimation using neural networks only considers data, not any underlying science, as illustrated below:

Find blue/orange areas → Valid, but limited solution

Small improvements in SOC accuracy are worth millions of dollars across the farming community.

Proposed solution

Combine Spectral data and Indices in a Physics-Informed Neural Network (PINN):

- Soil and vegetation indices guide the network to an initial, scientifically-based solution
- Refine solution using all spectral data

Observed benefits of PNNs in other disciplines:

- Less data needed
- Solution valid outside data range
- Faster convergence to a solution

Science:

- For many soil properties, including SOC, reflectance at one wavelength is often linearly related to reflectance at another wavelength. Soil complexity degrades this relationship
- Soil & Vegetation Indices more resilient to roughness & moisture than raw satellite wavelength bands

Novelty: PINNS not previously used for SOC Estimation

Experimental design

Dataset:

- Finland and Sweden subset of the European Land Use/Cover Area frame Survey (LUCAS)
- 2,500 wavelengths resampled to 13 Sentinel-2 satellite bands
- 6,376 SOC measurements and spectra in dataset
- SOC: Range 0 – 560 g/kg, mean 110 g/kg

Single Index:

- Inverted Red Edge Chlorophyll Index (IRECI)
- IRECI good predictor of SOC (R^2 ~ 0.65 for dataset)

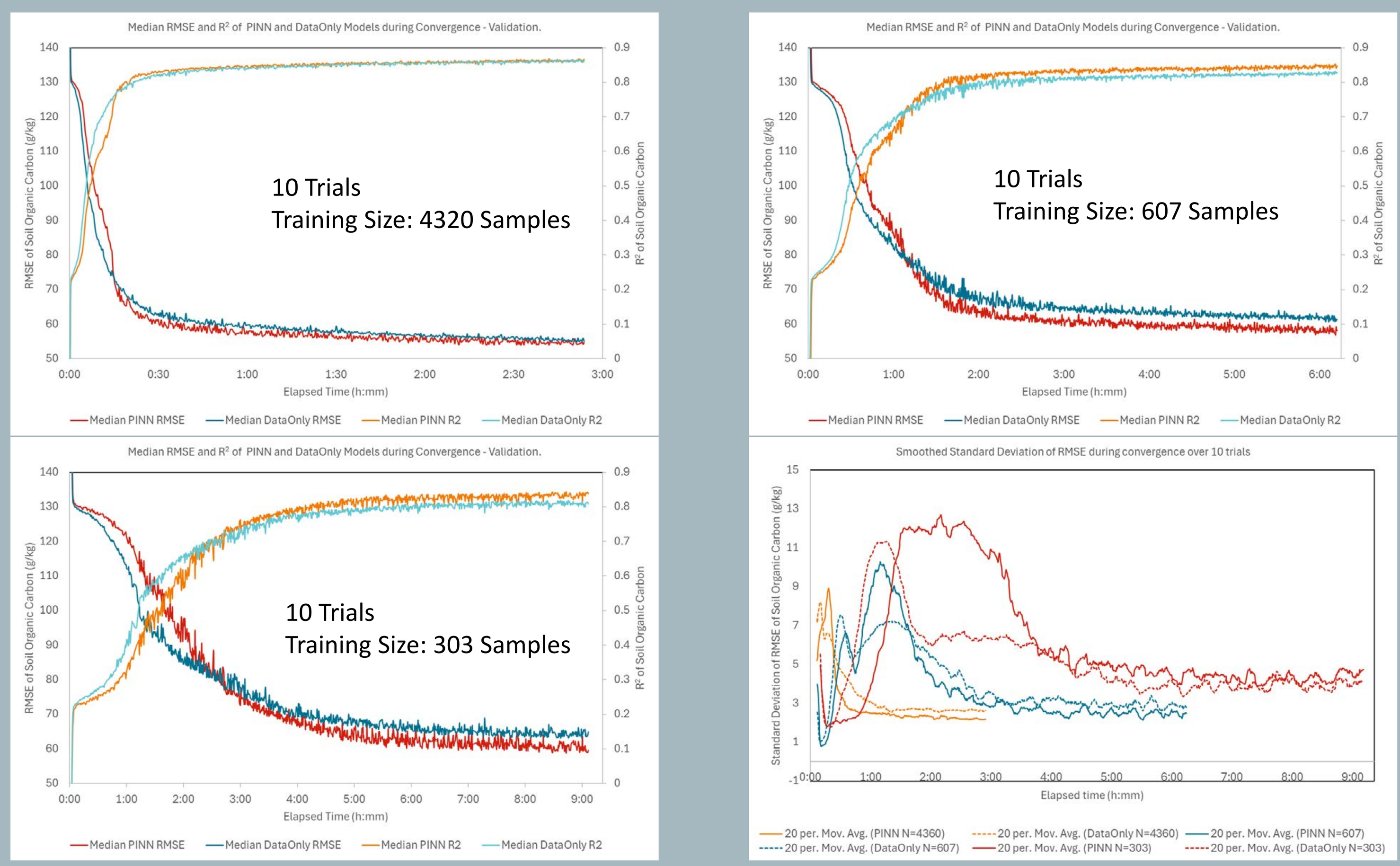
Neural Network Model:

- 2-stage Convolutional Neural Network similar to neural network model architecture found in literature
- Index incorporated in loss function, not model input

PINN version compared with Data Only version of same model using identical training and validation sets.

Preliminary Results

- PINN method accuracy better than Data Only method as sample size decreases
- PINN method more robust to noise than Data Only method for larger sample sizes



Future research includes the use of multiple indices and application of PINNs in Wimmera farms.

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Federation University
Charles Sturt University
Deakin University
Wimmera CMA
Australian Government Department of Industry, Science and Resources
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