Regional mapping of phenoforms

GSSC Seoul 2023

D G Rossiter
Guest Researcher
ISRIC-World Soil Information, Wageningen (NL)

27-Jun-2023

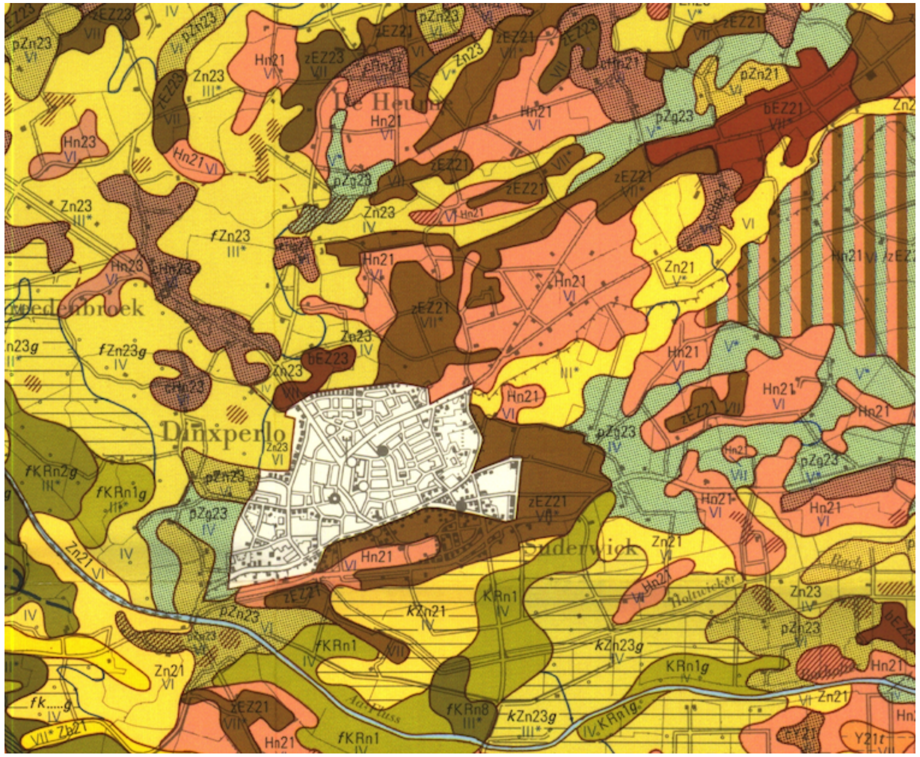
Classes vs. properties

- **properties**: each separately mapped
  - vary continuously in space (discretized for DSM)
- **classes**: “natural” clusters of groups of properties in 3D *pedogenetic* space
  - also form clusters in 2D *geographic* space
  - including relation betwen horizons, qualitative properties
  - holistic; complex interactions between properties
  - “more than the sum of the parts”
  - the product of pedogenesis (**long-** and **short-term**)

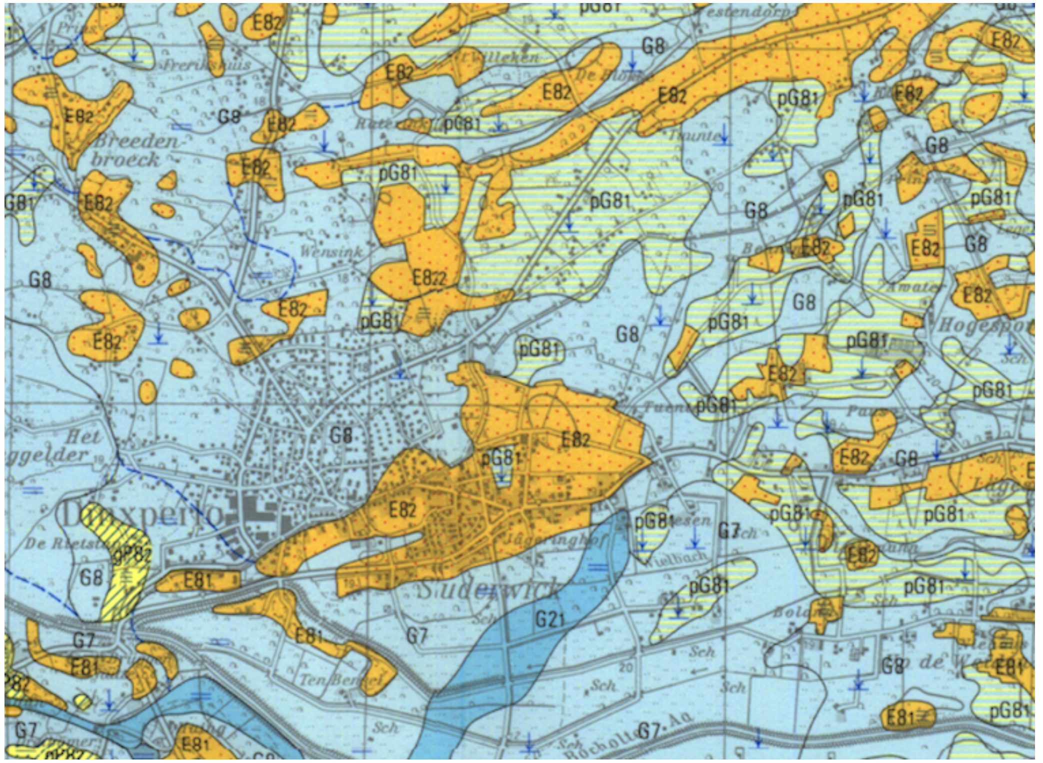
Why map classes instead of properties?

- **classes** are the *units of management*
  - landscape is divided according to land user's perception of classes
  - these are the units of *technology transfer*
    - e.g., siting experiments → spatializing the results
- individual **properties** can be managed but not holistically
  - e.g., managing pH: liming also depends on buffering capacity, which depends on CEC, which depends on clay proportion and mineralolgy, OM …

Soil class maps



Aalten West, Sheet 41 (NL), Scale 1:50k



Bocholt, Sheet 4104 (D), Scale 1:50k

(cross-border mapping comparison 1983)

Genoforms and Phenoforms

Two types of soil classes:

- **Genoform**: the *dominant form* of a "homogeneous" soil landscape element
  - "soil classes as identified by the soil classification system used as the basis for detailed soil mapping in a given area" [1]
  - not necessarily (or often) the "unaltered", "natural" form
- **Phenoform**: variants of a genoform with *substantially changed functionality*
  - "*persistent but reversible* non-cyclical variants of a soil genoform with sufficient physical, chemical or biological differences to *substantially affect soil functions*" [1]

Central concept of “genoform” – mappable area with similar soils, one pedogenesis, variability due to slight differences in pedogenesis.

Hydragric Anthrosol, near 江苏扬州 Yangzhou, Jiangsu province, PRC

A **new genoform** due to removal of topsoil and stones

This can never revert to the original genoform.

Near Mandres, Amari municipiality, Crete (GR)

A **phenoform**: trees and organic layer (characterizing the genoform) removed to promote heath growth

Changed functionality: infiltration, filtering, soil biology…

Within 20 years +/- new heath will have reached another genoform

Within 40 years +/- (if no further intervention) forest cover will have caused this to match the current genoform

Twekkelo (NL), map unit Hn21 Gleyic Podzol, weakly loamy fine sand

Link to the 5 C's

Following the definitions of McBratney *et al.* [2]

- **Capability** based on **genoform**
  - *potential* ability to perform ecological functions
  - this could be a (partially) anthropogenic genoform
- **Condition**
  - *actual* ability to perform ecological functions
  - partially reflected in **phenoform**
  - does not include seasonal or temporary changes in condition

Related work

- Dobarco et al. "**pedogenons**" [3]
  - *f(s ,cl ,o ,r ,p ,t)* where *t* = "period from the origin of soil formation up to the **reference time**"
  - in their paper, the condition prior to substantial human direct soil management
  - but can be any reference time

Mapping phenoforms - which?

Defining the mapping legend

1. Identifying *relevant* and *significant* phenoforms - in the local context - with *substantially changed functions*
2. Giving them meaningful names
    - linked to *changed functionality* and/or *management options*
    - e.g., “severely compacted”, “strongly saline”, “unstructured” …

Mapping phenoforms at scale

- **How to distinguish phenoforms** in **routine survey** over **large areas**?
    - (**within-field** by yield monitors, on-the-go sensors, clustering … not possible at scale)

1. **remote sensing + transfer model** → vegetation/surface conditions → phenoform

2. **digital soil mapping** (DSM) (*scorpan* factors vs. training observations)

3. **inference from DSM of sets of properties** (post-clustering)

Mapping phenoforms - currency

- Mapping interval / **currency**
  - phenoforms can alter to other phenoforms in a **5–20 year period**
  - mapping must be current enough to allow target action or correct model output
    - so, map every few years
    - method must be scalable in time, i.e., fairly **rapid** and **cheap**

Mapping methods

- **Direct**
  - **remotely sense** the land surface → transfer model → surface condition(s) → phenoform
  - best on bare soils and with surface-soil phenoform conditions

- **Indirect**
  - **infer** soil condition by correlative methods (“machine learning”)
  - similar to DSM for soil properties
    - relevant covariates, e.g., time-series of vegetative indices (VI)
  - crop condition → soil condition, but what is the cause?
    - e.g., stunted growth due to root-limiting layer (compaction) or poor fertilization?
    - can (partially) solve with management data — over large areas?

The DSM approach

- find **representative sites** of the phenoform(s)
- find **covariates** sensitive to the phenoform(s)
- develop **correlative models** (“machine learning”)
- **post-processing**, e.g., modal filters/spatial clustering to management units

Mapping phenoforms via soil constraints

Ma and Minasny [4] list *soil constraints* which have been mapped:

- **physical**: permeability, rockiness, soil compaction, soil bulk density, available water capacity, soil slaking index, soil thickness
- **chemical**: soil acidity, salinity, sodicity, alkalinity, soil nutrients, toxic metals

These can be features of the *genoform* only (e.g., stoniess) and always have characteristic values for the genoform.

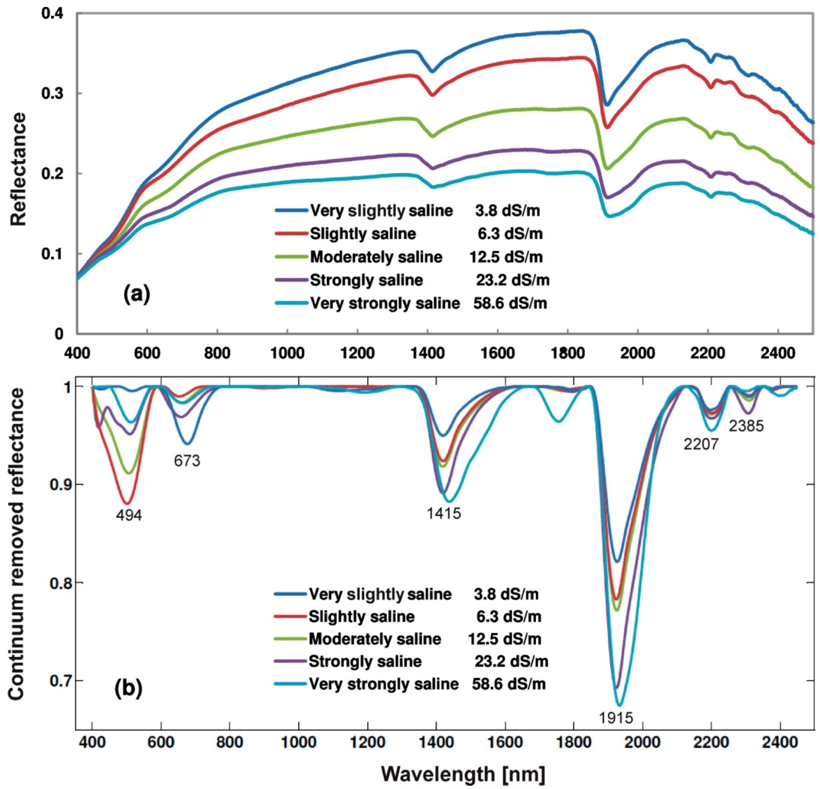
Their *difference* from the *dominant value* of the genoform can indicate a *phenoform*.

They must be able to *revert* to the genoform with appropriate management.

(See also Richer-de-Forges *et al.* [5])

Direct mapping by remote sensing

e.g., salinity from bare-soil spectra



Cliza, Cochabamba province, Bolivia

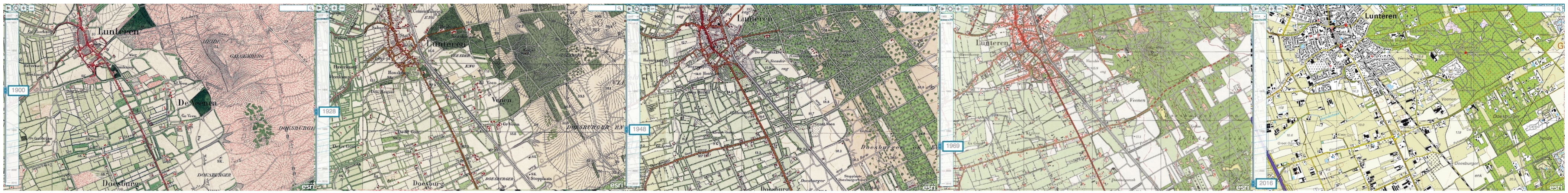
source: doi:10.3390/rs61110813

Inferential mapping by remote sensing

- e.g., subsoil compaction, structure degradation (the original example from Droogers & Bouma) [6]
  - detect by differential crop performance, especially under water stress
- e.g., salinization
  - infer from crop condition

Inferential mapping by historical land use

- relict soil conditions from long-term land use on an original genoform
- but these may be stable new genoforms (e.g., plaggen)



near Lunteren (NL)

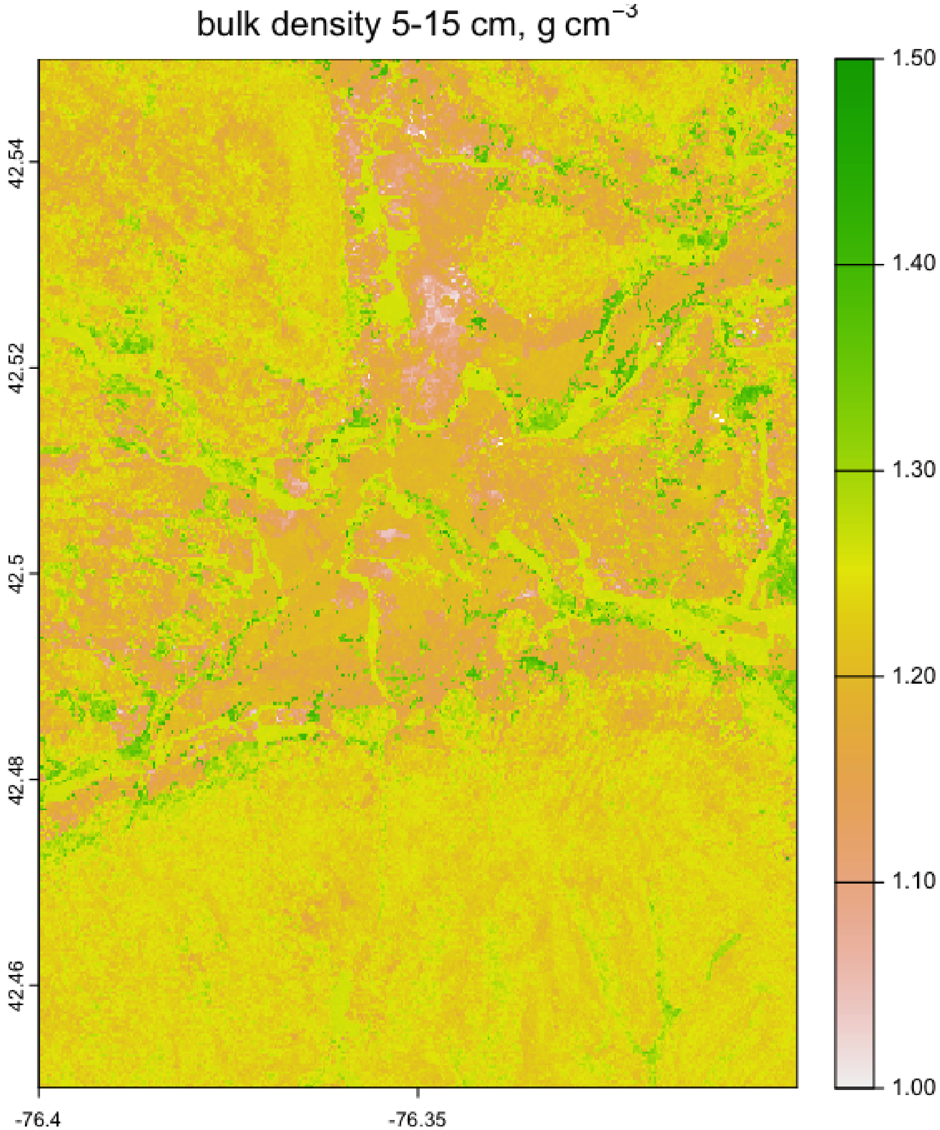
Inferential mapping by DSM techniques

1. Define mapping legend (phenoforms in the study area)
2. Training points, each labelled with their phenoform or (combination of) soil conditions
3. Conventional DSM workflow, e.g., classification random forests
4. Post-processing: create minimum management units (according to users' needs)

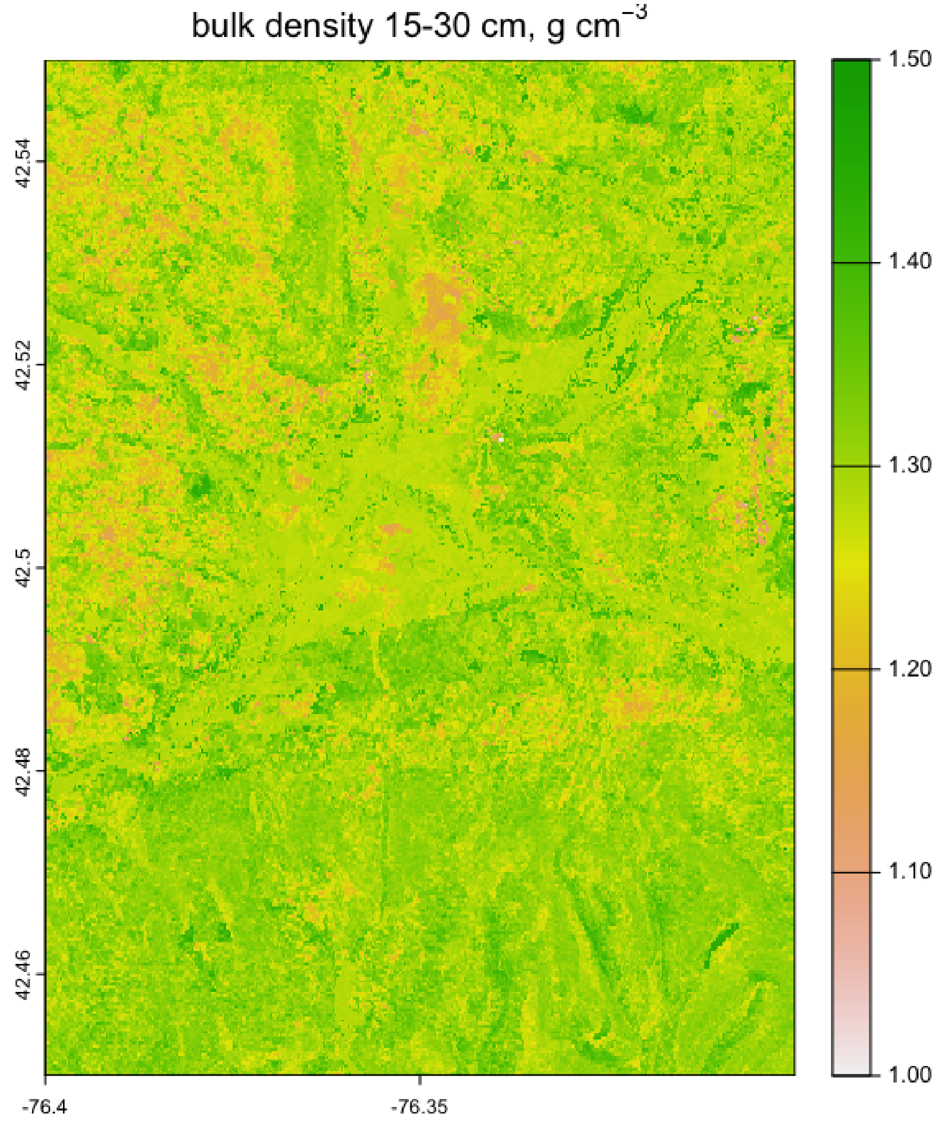
Simulated example: compactiom

1. DSM of bulk density in the 05-15 and 15-30 cm depth slices
    - source: POLARIS 30 m [7]
2. Difference
    - **compaction** in upper subsoil vs. bottom half of plow layer
3. Threshold
    - here, 95% quantile, but in practice a limit from field knowledge
4. Phenoforms: non/compacted

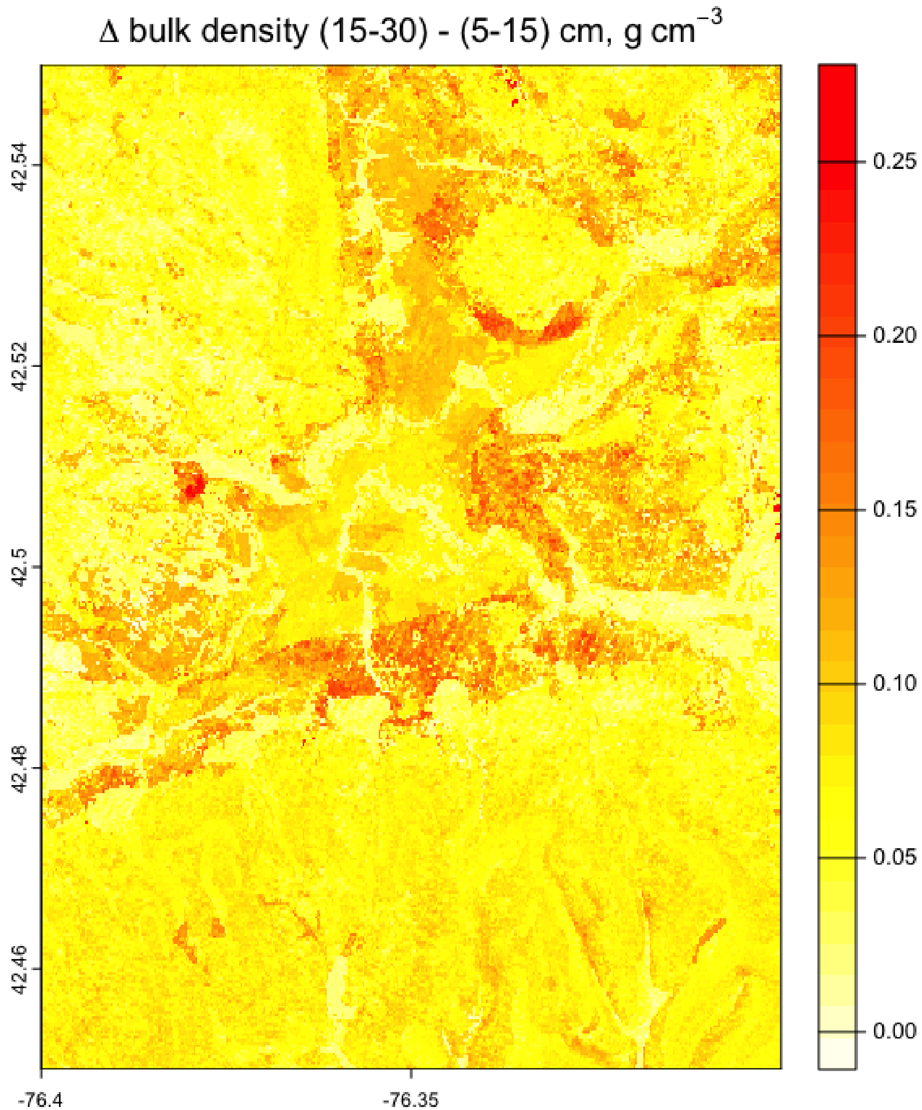
5-15 cm



15-30 cm

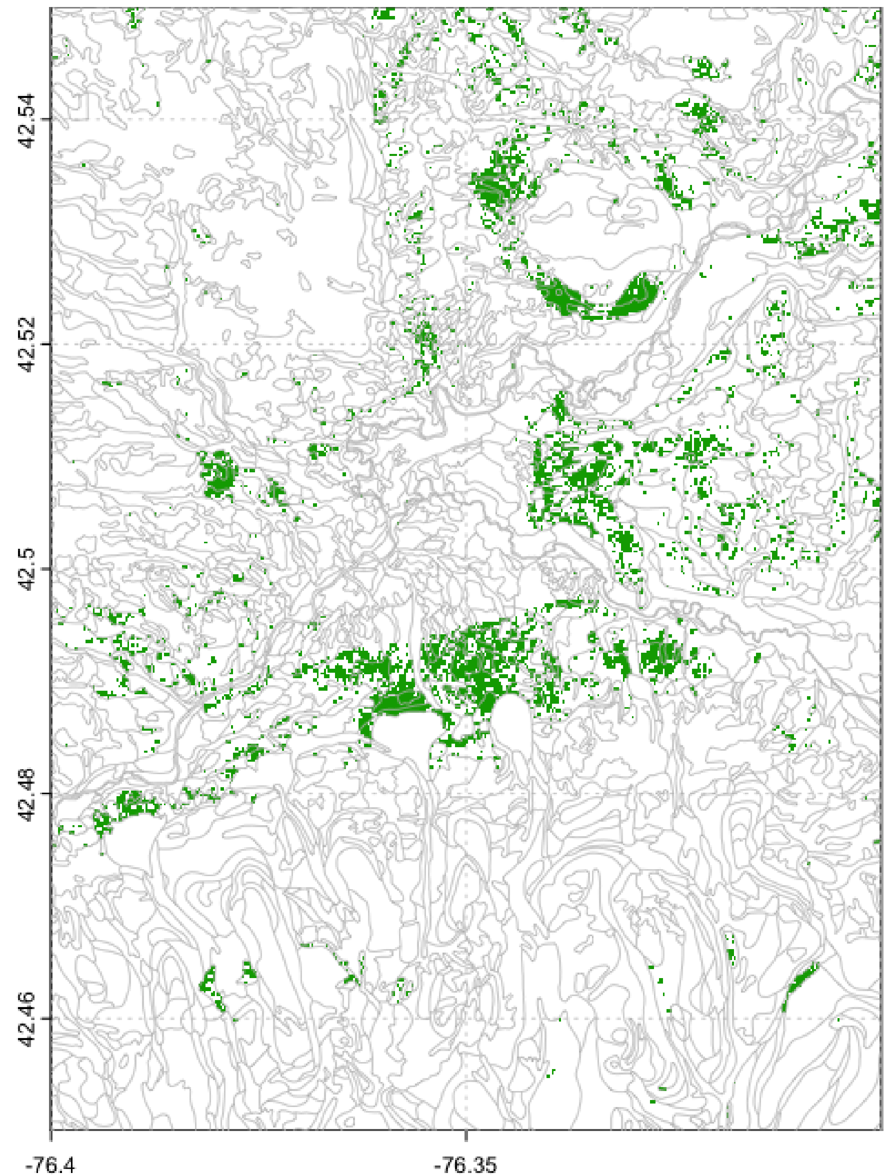


difference [15-30] - [5-15]



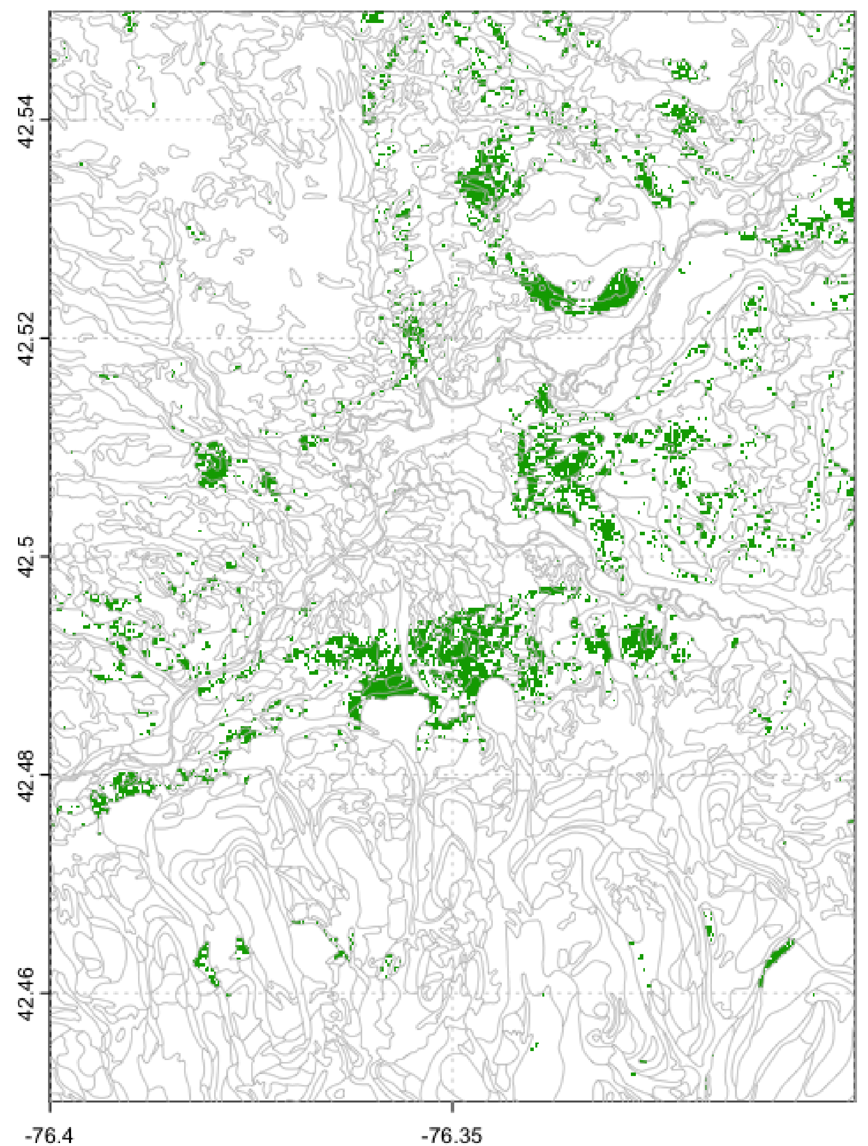
...

threshold ≥ 95% percentile of Δ



Possible “compacted” phenoforms

Note phenoform within map unit (polygons outlined in grey)



Next step: case studies

- What is feasible?
- Which methods are best in which contexts and for which kinds of phenoforms?

ISRIC
World Soil Information

References

[1] D. G. Rossiter and J. Bouma, “A new look at soil phenoforms definition, identification, mapping,” *Geoderma*, vol. 314, pp. 113–121, Mar. 2018, doi: 10.1016/j.geoderma.2017.11.002.

[2] A. McBratney, D. J. Field, and A. Koch, “The dimensions of soil security,” *Geoderma*, vol. 213, pp. 203–213, Jan. 2014, doi: 10.1016/j.geoderma.2013.08.013.

[3] M. Román Dobarco, A. McBratney, B. Minasny, and B. Malone, “A modelling framework for pedogenon mapping,” *Geoderma*, vol. 393, p. 115012, Jul. 2021, doi: 10.1016/j.geoderma.2021.115012.

[4] Y. Ma and B. Minasny, “Mapping and modelling soil constraints,” CRC Press, 2023, pp. 409–418. doi: 10.1201/9781003093565-22.

[5] A. C. Richer-de-Forges *et al.*, “Remote sensing data for digital soil mapping in french research A review,” *Remote Sensing*, vol. 15, no. 12, p. 3070, Jan. 2023, doi: 10.3390/rs15123070.

[6] J. Bouma and P. Droogers, “Comparing different methods for estimating the soil moisture supply capacity of a soil series subjected to different types of

management," *Geoderma*, vol. 92, no. 3–4, pp. 185–197, 1999, doi: 10.1016/S0016-7061(99)00027-0.

[7] N. W. Chaney *et al.*, "POLARIS soil properties: 30-m probabilistic maps of soil properties over the contiguous united states," *Water Resources Research*, vol. 55, no. 4, pp. 2916–2938, 2019, doi: 10.1029/2018WR022797.