Clay content and soil moisture mapping using on-ground time-domain GPR

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GPR bridges a scale gap between point scale and remote sensing scale, namely, field scale.
The approach description

Hypothesis: 2D isotropic radiation

- Electrical conductivity estimation:
  - Assuming \( \sigma = 0 \):
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{x}{x_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{A}{A_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{\Delta}{\Delta_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{\pi}{\pi_{\text{ref}}} \right)^2
    \]
  - In existence of \( \sigma \):
    \[
    E_x = E_{\text{ref}} e^{-\frac{\Delta x}{\pi_{\text{ref}}^2}} \sin(\pi_{\text{ref}} x)
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{\pi}{\pi_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{x}{x_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{A}{A_{\text{ref}}} \right)^2
    \]
    \[
    \frac{\sigma}{\sigma_{\text{ref}}} = \left( \frac{\Delta}{\Delta_{\text{ref}}} \right)^2
    \]

Clay content estimation:

- Hypothesis: Linear relationship between aggregate electrical conductivity and Clay content
  - Quadratic parallel model:
    \[
    \sigma_a = \theta \sigma_w + (1-\theta) \sigma_{\text{ag}}
    \]
  - Linear model:
    \[
    \sigma_a = \theta \sigma_w + (1-\theta) \sigma_{\text{ag}}
    \]
  - Clay content model:
    \[
    C_{\text{clay}} = a \sigma_a + b
    \]

The study area

- A ~5 ha agricultural field located in the Osling hills in North part of Grand Duchy of Luxembourg with a mean altitude of 480 m.

The ground-truths and the land conditions

- 30 locations entire the field
- 4 different depths (0-10, 10-20, 20-30, and 30-40 cm) for soil moisture validating
- 2 different depths (0-10, and 20-30 cm) for clay content validation (using Coulter counter, the cost is ~7€ per sample).

Note: because of unforeseen precipitation event, we had 2 different land conditions namely dry and wet. We applied GPR for both conditions but only 3 locations of ground-truths belonged to the dry land and the rest belonged to the wet land.

The water content maps

- Because of the slope, the water content was higher in the lower part of the field.
Results

- Local variation of water content
- Different characterization scale
- Positioning (note that because of mud the survey wheel did not work and the positioning is estimated manually)

The wet condition water content map validation

The clay content map and validation

\[ \lambda_{av} \approx 40 \text{ cm} \]

The ground-truth amounts are derived by averaging of 0-10 and 20-30 cm amounts. The small mismatch can be due to missing ground-truth values.

Conclusions

- Both water content maps derived by on-ground GPR are consistent and show the ability of common-offset method for estimating soil water content.
- The DGW penetration depth is about GPR wavelength which is a function of soil moisture and GPR center frequency.
- There is no significant benefit using linear or quadratic parallel model in order to retrieve the aggregate electrical conductivity from the apparent soil electrical conductivity.
- There is a linear relationship between clay content and aggregate electrical conductivity.
- The clay content map derived by GPR satisfies the ground-truths.

Perspectives

- Evaluating the proposed approach for other GPR antennas with different center frequencies.
- The effect-investigation of different antenna offsets on retrieving the apparent soil electrical conductivity using DGW.
- Modeling the SOC using the aggregate electrical conductivity derived by proposed approach.

Thanks for your attention

To whom it may interest:
Also we are applying the proposed approach to model the SOC. If you are interested on this job, for more details contact me via the following Email address:
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