The Compounding Effects of Sub-Surface Features in Soil Moisture Retrievals with Radar

Keith Morrison, Simon Thomas, University of Reading
Wolfgang Werner, TUW
“Desert Problem” as seen by ENVISAT ASAR
Laboratory Experiments
Stone Slabs
Laboratory Experiments
1, 3, 6cm Sand over Slabs
C-band (4-8GHz)
Experimental Set-Up

- Reference Target
- Gravel
6cm Sand over Slabs

Added 2mm of water
6cm Sand over Slabs
For $y=182\text{cm}$ (black) & $192\text{cm}$ (red)
For $y=182 \text{cm \ ns31 \ 4GHz}$
6cm Sand over Slabs
Backscatter Change

![Graph showing power (dB) vs scan number](image-url)
Gravel Layer

5mm of water added over 1.5m²

Drying over 22 days
Experimental Set-Up

Reference Targets

Reference Target

Gravel
VV Soil Movie: 0°

Image 3m x 3m

SURFACE
VV Soil Movie: 20°

Image 3m x 3m
Backscatter: Incoherent

\[ \Delta m_v = 3.3\% \]

Decreasing Moisture
Final Backscatter Curve

\[ \Delta m_v = 3.3\% \]

Decreasing Moisture
Gravel: Backscatter

![Graph showing power in dB vs scan number for Gravel and Soil Surface compared to Reference.](image)
Simulation

25dB
Unwrapped Phase

![Graph showing phase vs scan number for Surface Reference Trihedral, Gravel, and Wet Soil Surface](image)
Depth from Phase
Advanced DInSAR methods (SqueeSAR, ISBAS) are used to determine time series over low coherence areas such as agricultural areas.

According to the laboratory and modelling results, the phase of these areas could depend upon moisture state.

During drying:
- Surface soil static
- Buried targets would appear to rise.
- Combined response could result in an ‘uplift’ signal
InSAR Coherence

\[ \gamma = \gamma_B \gamma_{dopp} \gamma_{temp} \gamma_{proc} \gamma_{therm} \gamma_{vol} \]
DInSAR
InSAR

![Graph showing topographic height vs. scan number for different bandwidths. The red line represents B=10m and the blue line represents B=100m.](image)
Summary

Laboratory Measurements

- moisture-amplitude-phase relationships
- imaging geometry
- polarisation

Understand phase change as:
- return from within soil
- surface return little changed

Moisture Anomaly
- off-nadir geometry
- sub-surface gravel layer

Future
- volume-distributed
Summary

Laboratory Measurements

- moisture-amplitude-phase relationship
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- polarisation

Understand phase change as:
- return from within soil
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Future
- existing bedrock layer vs sand depths / moisture regimes
- random sub-surface layer (small pebbles)
- volume-distributed (sand-gravel mixture)
- complementary optical / IR?
The signal, $S$, of a wave passing through a soil to a buried target, $P$, is described by:

$$S(z) = S_0 \exp(-\gamma z)$$

$$S(z) = S_0 \exp(-\alpha z) \exp(-j \beta z)$$

This term relates to the phase of the signal.

Hallikainen et al. 1985
Model predicts phase change is \textit{linear for a change in moisture...}
Moisture – Phase Behaviour

0°=blue cross
10°=red square
20°=blue dot
30°=red dot
40°=green dot
50°=black dot

...and is also - independent of incidence angle


Morrison, K. Mapping Subsurface Archaeology with SAR. Archaeological Prospection, 20, 2, pp.149–160. 2013
Opportunities: VB-SAR

\[ f_V = f_R \sqrt{\varepsilon_r} \]

real frequency of the radar

\[ B_v = 13.72 \text{GHz} \]

\[ B_v = 6.40 \text{GHz} \]
First Demonstration

Drying sandy loam
C-Band, imaging geometry \( i=20^\circ \)
\( \Delta m_\gamma = 0.098 \) to 0.027
TP (SAR) Image

Real Bandwidth 0.15GHz
Virtual bandwidth 3.38GHz
Imaging Geometries

Reference Targets
Laboratory Set-Up
Backscatter Change

![Graph showing power (dB) vs. scan number for 6cm Sand, Av90:230 D=190cm ns11 1GHz]
6cm Sand: Buried Trihedral

![Graph showing the maximum power for buried trihedral 6cm. The graph plots Abs. Power (dB) against Scan Since Start. There are two lines: one for VV, one for HH, and one for VH.]
6cm Sand over Slabs
(VV, amplitude)
6cm Sand
Gravel: Phase Signal

![Phase Signal Graph]

- **Phase (degrees)**
- **Scan Number**

**Gravel**

**Reference**
Scenarios
Gravel: Backscatter vs Phase

20°, VV.
Gravel: Backscatter vs Phase

20°, VV.
Imaging Geometries