On the use of multi-temporal SAR data to retrieve surface and vegetation parameters

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ESA study: “Exploiting longer wavelength SAR data for the improvement of surface process modelling” (ELASIM),
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Objective

- develop and assess a retrieval algorithm for soil moisture content underlying winter wheat using L (or C)-band SAR data
  - simple: single/double polarization (e.g. PALSAR system in default modes, i.e. HH pol., $20^\circ$-$40^\circ$ incidence; ASAR/Sentinel-1, VV/VH, $20^\circ$-$30^\circ$ incidence)
  - robust: a priori information
  - multi-temporal data: revisiting time (e.g. 1-6 weeks)

Context

- Assess the potential of integrating radar data into crop growth and hydrological models (local-regional scales)
Outline

- Experimental data: Agrisar 2006 campaign
  - in situ & ESAR multi-temporal data
- SAR data sensitivity to surface parameters
- Direct model: simplified approach
- Retrieval algorithm:
  - use of a priori information & multi-temporal data
- Discussion of results
- Conclusions & future work
AGRISAR’06 Intensive campaigns: April, June & July

Roughness measurements: April

All the characterized surfaces were vertically smooth \((ks<0.5 \text{ at } L \text{ band})\)

Grid of total TDR measurements

377 points on wheat fields

<table>
<thead>
<tr>
<th>TDR - soil moisture (%)</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>occurrence</td>
<td>3</td>
<td>8</td>
<td>13</td>
<td>18</td>
<td>23</td>
<td>28</td>
</tr>
</tbody>
</table>

Wheat fields

- April, 19-21
- June, 06-07
- July, 04-06
ESAR sensitivity to soil moisture content

- Good sensitivity to $m_v$: $\approx 2\text{dB}/5\%$
- Important scatter of both HH & VV
- $VV < HH \rightarrow VV$ attenuated by canopy
- HH almost no interaction with the canopy

Field 230 – L band
avg. inc. angle 40°

Field 221 – C band
avg. inc. angle 32°

- Previous experiments (e.g. Matera (I), 2001; Sheffield (UK), 2003) at C-band, VV & 23° inc.: good sensitivity to $m_v$ even at the peak growing stage
- At C-band & low incidence, ESAR observations over Demmin in substantial agreement with previous studies
Direct model: semi-empirical approach

\[ F(\theta, \lambda, p_{j=1..M}) = \sigma_0^S e^{-2\gamma(\bullet)h \sec(\theta)} \]

An anisotropic uniaxial lossy dielectric slab with an effective permittivity \( \varepsilon_r^{\text{veg}} = \begin{pmatrix} \varepsilon'_o + j\varepsilon'_e & 0 & 0 \\ 0 & \varepsilon'_o + j\varepsilon'_e & 0 \\ 0 & 0 & \varepsilon'_o + j\varepsilon'_e \end{pmatrix} \)

\( \gamma_{VV} = b_{VV} W \), vegetation water content / m³

mostly dependent on crop structure & \( \lambda \)

Expected Validity:
- C-band: VV & 20°-30° inc.
- L-band: 20°-50° inc.
  \( b_{HH} \approx 0 \)
Retrieval algorithm

- Ancillary data:
  - Land use, crops (e.g. broad/narrow leaves)

- A priori information:
  - $m_v$ & $s$ (& vwc)

- In situ data

### Preprocessing
(calibration, registration, filtering, masking)

### Inversion:
constrained minimization
(Mattia et al., 2006)

### Output:
N - $m_v$ (& vwc) maps

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Input:

- Trade off:
  - N-large & $\Delta t$ “short” (i.e. roughness const.)
- L-band: HH
- C-band: VV & low inc.

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Corr. length: no a priori information $\to$ fitting parameter

\[
C = \frac{1}{N} \sum_i \frac{\| (\sigma_0)_i - F_i(\theta, \lambda, P_{j=1..M}) \|^2}{(\Delta \sigma_0)_i^2} + \frac{1}{M} \sum_j \frac{\| p_j - \hat{p}_j \|^2}{(\Delta p)_j^2}
\]
L-band, 3 images & Δt ≈ 1 week

April 19

June 13

July 07

y = A + Bx
A = 1.45(%) & B = 0.99
rms error = 4.11(%) & R² = 0.84

DoY: 109, 158, 186

SAR-retrieved mₜ (%) vs Measured-TDR mₜ (%)
Perturbation: L-band, 3 images & $\Delta t \approx 1$ week

$\hat{m}_v^{\text{pert.}} = \hat{m}_v^{\text{unpert.}} + \varepsilon$

$\varepsilon$: Gaussian Noise (0% mean & 5% std)

$m_v^0 = [6.13\%, 0.37\%, -10.5\%]$
L-band, 3 images & Δt ≈ 2 weeks

$y = A + Bx$
$A = 3.93(\%) \& B = 0.77$

rms error = 4.97(\%) \& $R^2 = 0.71$

Day: 109, 158, 186
L-band, 3 images & $\Delta t \approx 5$ weeks
C-band over field 221, 3 images & $\Delta t \approx 1$ week

Field 221: low incidence angle

DoY
109 123 131 136 144 158 164 172 186 193 207

Wheat fields
April, 19-21
June, 06-07
July, 04-06

C-band SAR derived vol. sol. moisture (%) vs L-band SAR derived vol. sol. moisture (%)

$y = A + Bx$

$A = 5.72(\%) \quad & \quad B = 0.70$

rms error = 4.27(%) $\quad & \quad R^2 = 0.61$

9 dates; mean $m_v$ values estimated over field 221
C-band over field 221, 3 images & $\Delta t \approx 2$ weeks

9 dates; mean $m_v$ values estimated over field 221

$y = A + Bx$

$A = 6.14(\%)$ & $B = 0.68$

rms error = 3.94(%) & $R^2 = 0.76$
C-band simulated experiment, 3 images

Simulated ground data set

<table>
<thead>
<tr>
<th>Mean Parameters</th>
<th>1st date</th>
<th>2nd date</th>
<th>3rd date</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;s&gt; (cm)</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>&lt;lcorr&gt; (cm)</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>&lt;Reps&gt;</td>
<td>6</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>&lt;vwc&gt; (Kg/m²)</td>
<td>1.2</td>
<td>2.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Simulated a priori information

- Mean parameters + ε_p
  - ε_p Gaussian noise: zero mean, std= 20% total variability range

Simulated VV, 23°

\[ y = A + B x \]

A= 2.0 (%) & B=0.91

rms error=4.0 (%)
Conclusions

- A soil moisture retrieval algorithm for wheat crops using 3 subsequent SAR acquisitions either at L-band & HH pol. or at C-band & VV pol & low incidence angles was developed.

- Observations over the Demmin site indicate that in order to retrieve superficial soil moisture content with an accuracy of approximately 5% the following two conditions have to be met:
  - availability of a priori information on surface parameters (with an accuracy within approximately 15% of their total variability range)
  - time lag between multi-temporal acquisitions within 2-3 weeks

Future work

- Assess the feasibility of applying the same method to other crops (e.g. sugar beet, winter rape, tomato)
- Apply the algorithm to PALSAR & ASAR data at high & lower resolution