On the retrieval of soil moisture content over agricultural sites using L band SAR data

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Objective

- develop and assess a retrieval algorithm estimating soil moisture over agricultural sites from L band SAR data
  - Application context: agriculture and/or hydrology

Outline

- Experimental data: Terra SAR SIM 03 campaign
- The retrieval algorithm: direct and inverse approach
- Results
- Conclusions and future work
TerraSARSIM campaign: 2-25 April, 2003
(ESA project n. 16736/02/NL/FF)

- Barrax, La Mancha, Spain
- Mediterranean climate
- Average yearly rainfall: 400 mm
- Flat morphology
- Agricultural area
- 65% dry land, 35% irrigated land

SAR data (5 Flights)

**Sensor:** E-SAR onboard
**DLR Dornier**

**Frequency:** C-, L- and X-band

**Incidence angle:** 26° - 56°

**Doy:** 92, 92, 94, 94, 115
In situ data

N° of monitored fields: 28
Land use: 7 irr. wheat, 4 irr. barley, 5 irr. alfalfa, 12 not-irr. barley
Data:
✓ gravimetric and volumetric soil moisture at 0-5 cm (some problems!)
✓ qualitative information on surface roughness
✓ fresh and dry biomass & crop height

Selected 12 cereal fields: 8 non irr. barley; 2 irr. barely; 2 irr. wheat
Retrieval algorithm

backscattering
\[
\left\{ \begin{array}{l}
\hat{\sigma}_0 \bigg|_i = F_i \left( \theta, \lambda, p_{j=1,..M} \right) + \varepsilon_i \rightarrow \text{total model \& measurement error} \\
\hat{p}_j \quad \text{a priori estimates of surface and vegetation parameters}
\end{array} \right.
\]

Maximum likelihood solution for \( p_j \) parameters

\[
C = \frac{1}{N} \sum_i \frac{||\left( \sigma_0 \right)_i - F_i \left( \theta, \lambda, p_{j=1,..M} \right)||^2}{(\Delta \sigma_0)_i^2} + \frac{1}{M} \sum_j \frac{||p_j - \hat{p}_j||^2}{(\Delta p)_j^2}
\]

- total rms error
- error on a priori estimates

\[
(\Delta \sigma_0)_i = \sqrt{\left\langle \varepsilon_i^2 \right\rangle}
\]
Direct model

\[
\left( \hat{\sigma}_0^S \right)_i = \left( \hat{\sigma}_0^S \right)_i e^{-2\tau_i h \sec(\theta)} \quad i = HH, VV, ..
\]

\[
\overline{\varepsilon}^r = \begin{pmatrix}
\varepsilon'_e + j\varepsilon''_e & 0 & 0 \\
0 & \varepsilon'_e + j\varepsilon''_e & 0 \\
0 & 0 & \varepsilon'_o + j\varepsilon''_o
\end{pmatrix}
\]

- Integral Equation Model (IEM)
- An anisotropic uniaxial dielectric slab with an effective permittivity \( \overline{\varepsilon}^r \)

\[
\varepsilon''_o = g \left( m_w, f_v, \rho_d, str, ... \right) \approx (b_{vv} W_v) \quad W_v \ [\text{Kg/m}^3]
\]

\[
\tau_{VV} \propto \frac{2\pi}{\lambda} \varepsilon''_o
\]

\[
\tau_{VV} h \approx \frac{2\pi}{\lambda} b_{vv} W_s \propto \frac{2\pi}{\lambda} b_{vv} F_s \quad \left\{ \begin{array}{ll}
W_s \ [\text{Kg/m}^2] & \text{(Veget. Water cont.)/m}^2 \\
F_s \ [\text{Kg/m}^2] & \text{(Fresh biomass )}
\end{array} \right.
\]
Free parameters

- soil:
  - surface height rms ($s$), surface corr. length ($l$) and soil moisture ($m_v$)

- vegetation:
  - fresh biomass ($F$), structural parameters $b_{hh}$ & $b_{vv}$

Temporal updating: 2 SAR acquisitions

1st SAR date: $s$, $l$, $m_v$, $F$, $b_{hh}$, $b_{vv}$

$$\sigma_0^t = \sigma_0^s e^{-g \cdot F}$$

$$\frac{\Delta \sigma_0^t}{\sigma_0^t} = \frac{\Delta \sigma_0^s}{\sigma_0^s} - g \Delta F$$

measured

estimated on the 1st date

Multiple regression: $\Delta \sigma_0^s$ & $\Delta F$ → Updating guess values
SAR data used in the study

L band HH & VV SAR data acquired on:

- April 2, 2003 (flight n.1, in the morning)
- April 4, 2003 (flight n.3, in the morning)
- April 25, 2003 (flight n.5, in the morning)

The same guess values obtained as averages of in situ measurements

guess values obtained by temporal updating
Retrieved soil moisture: April 2 & 4

- measured: mean = 17%
- retrieved: no attenuation: mean = 9.4%, rms = 9%
- retrieved: with attenuation: mean = 18.7%, rms = 4.2%
Retrieved biomass: April 2 & 4

- Green circles represent measured biomass: mean = 0.8 Kg/m²
- Blue triangles represent retrieved biomass: mean = 1 Kg/m², rms = 0.4 Kg/m²

Fresh biomass (Kg/m²)

vol. moisture content (%)
Biomass updating: April 4 & 25

- **true increments of Fresh biomass:** mean = 0.9 Kg/m²
- **estimated increments:** mean = 1.3 Kg/m², rms = 0.64 Kg/m²
Retrieved soil moisture: April 25

- Measured: mean = 16.4%
- Retrieved (updated guess values): mean = 19.6%, rms = 4.6%
Retrieved biomass: April 25

- Measured: mean = 1.7 Kg/m²
- Retrieved (updated guess values): mean = 1.8 Kg/m², rms = 0.4 Kg/m²
Soil moisture map: April 25
Conclusions

- Soil moisture and vegetation biomass maps of cereal fields have been retrieved, with accuracies of approximately 5% and 0.5 Kg/m², respectively, by inverting L band SAR data and using a priori information;

- A technique to update a priori information on surface parameters using multi-temporal SAR data has been proposed and tested on the Barrax test site;

Future work

- Systematic assessment of the algorithm accuracy through simulation studies;

- Application of the algorithm to other data sets and extend the approach to other crops