Using fully polarimetric SAR data for the retrieval of soil surface roughness: potentials and limitations

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Objective

Soil surface roughness important for numerous physical processes

Related to eco-hydrological Modelling (watershed scale)

- Infiltration
- Runoff generation
- Soil erosion (water and wind)
- Heat fluxes
- Gas exchange (soil <-> atmosphere)
- etc.

Derivation of soil moisture by means of SAR data

Large uncertainties in roughness parameterization s, l, ACF?
Objective

Well established polarimetric roughness estimators available

Anisotropy, $|\rho_{RRLL}|$, $\text{Re}[\rho_{RRLL}]$, DERD

Mostly developed in theoretical experiments and not multi-temporal adopted

For an operational use potential of estimators can only be evaluated multi temporal/ under different crops and growing stages

Data pool of AgriSAR 2006 campaign has great potential to study the retrieval of soil surface roughness
ESA funded campaign for the simulation of Sentinel I+II

Frequent field measurements were carried out on a weekly basis during the agro-phenological cycle (April to August 2006)

E-SAR flights simultaneous to field campaigns on 11 dates
  L-, C- and X-Band acquisitions
  Vegetation- and soil physical measurements by CAU and DLR/Zalf

DEMMIN Testsite
  North East Germany
  Smooth topography
  Intensive agricultural landuse
  Mean field size : approx. 200 ha
Sample Points AgriSAR 2006

Legend:
- ESU
- Feldgrenzen
- NDVI (CASI1500)

- High: 0.986010
- Low: -0.022546

- Winter Barley
- Maize
- Sugar Beet
- Winter Rape
- Winter Wheat
Photogrammetric and Laser (19-20.04.06) measurements

Photogrammetric system:

Metal Tripod/Frame
- Horizontal coverage of 0.5m²
- Image overlap: 65%
- Pixel size: 0.54mm
- Height/base ratio: 2.5
- Highly accurate GCP’s

Rollei d7 metric camera
- Metric camera
- Known interior orientation
- Remote controlled
- 5 megapixel
**In field** roughness data

**Accuracy of derived micro DSM**
- RMSE: 0.16 cm
- Mean absolute Error: 0.12 cm
- Max Error: 1.01 cm
- Positional accuracy better than a pixel (<0.5mm)

**Qualitative comparison between roughness data and ISSIA Laser profiles (different locations on Field 102)**

<table>
<thead>
<tr>
<th></th>
<th>s</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISSIA</td>
<td>0.76</td>
<td>0</td>
<td>3.8</td>
<td>-5.6</td>
</tr>
<tr>
<td>Photogram</td>
<td>0.73</td>
<td>-0.48</td>
<td>3.3</td>
<td>-3.7</td>
</tr>
</tbody>
</table>
**In field roughness characterization**

Derived micro scale DSM for calculation of RMS Height $s$

![Image of rough field surface with measurements]

<table>
<thead>
<tr>
<th>Field</th>
<th>101 (WR)</th>
<th>250 (WW)</th>
<th>440 (WB)</th>
<th>102 (SB)</th>
<th>222 (M)</th>
<th>460 (SB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s_{\text{mean}}$</td>
<td>0.8</td>
<td>0.9</td>
<td>0.91</td>
<td><strong>1.07</strong></td>
<td><strong>1.74</strong></td>
<td><strong>1.29</strong></td>
</tr>
<tr>
<td>$s_{\text{max}}$</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td><strong>1.8</strong></td>
<td><strong>2.9</strong></td>
<td><strong>2.4</strong></td>
</tr>
<tr>
<td>$s_{\text{min}}$</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td><strong>0.8</strong></td>
<td><strong>1.0</strong></td>
<td><strong>0.9</strong></td>
</tr>
</tbody>
</table>

*Due to short profile length no calculation of autocorrelation length ($l$) and ACF!*
Polarimetric estimators

**Anisotropy, \( A \) (CLAUDE 1999, 2001, HAJNIEK 2001)**
- Independent from dielectric constant
- Only applicable to surface scatter areas \((H<0.5; \alpha<42.5^\circ)\)
- Smooth areas highest anisotropy, rough areas lowest anisotropy
- \( k_s = 1 - A \) (CLAUDE 1999)

**Circular coherence, \( |\rho_{RRLL}| \) (MATTIA et. al. 1997)**
- Independent from dielectric constant
- Smooth areas highest coherence, rough areas vice versa

**Real part of the circular coherence, \( Re[\rho_{RRLL}] \) (SCHULER et. al. 2002)**
- Independent from dielectric constant
- Smooth areas lowest values of \( Re[\rho_{RRLL}] \), rough areas vice versa
- Low vegetation impact

**Double bounce eigenvalue relative difference, \( DERD \) (ALLAIN 2003)**
- DERD comparable with \( A \), wider spectrum -> Range -1 to 1
ks vs polarimetric estimators

Low correlation between ks and polarimetric estimators

Differences between and within various fields visible

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R^2$</th>
<th>$r$</th>
<th>$m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.00</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>$</td>
<td>\rho_{RLL}</td>
<td>$</td>
<td>0.02</td>
</tr>
<tr>
<td>Re[$\rho_{RLL}$]</td>
<td>0.11</td>
<td>0.32</td>
<td>0.13</td>
</tr>
<tr>
<td>DERD</td>
<td>0.13</td>
<td>-0.35</td>
<td>-0.13</td>
</tr>
</tbody>
</table>
Polarimetric α shows good correlation to wet and dry biomass

Winter vegetation fields 250, 440 -> $R^2 = 0.42$
Sommer vegetation fields 102, 222, 460 -> $R^2 = 0.5$

Mask out areas $\alpha > 40^\circ$
Improved correlation between polarimetric roughness estimators and ks

Good correlation between ks and Re[$\rho_{RLLL}$] + DERD

Stronger relationship using an exponential fit

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<th>$R^2$</th>
<th>$r$</th>
<th>$m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.04</td>
<td>-0.2</td>
<td>-0.24</td>
</tr>
<tr>
<td>$</td>
<td>\rho_{RLLL}</td>
<td>$</td>
<td>0.39</td>
</tr>
<tr>
<td>Re[$\rho_{RLLL}$]</td>
<td>0.58</td>
<td>0.76</td>
<td>0.42</td>
</tr>
<tr>
<td>DERD</td>
<td>0.54</td>
<td>-0.73</td>
<td>-0.42</td>
</tr>
</tbody>
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$n = 58$
Roughness retrieval

Based on correlation $k_s$ vs. $\text{Re}[\rho_{\text{RRLL}}]$

$\text{RMSE} = 0.078$ for $k_s$

$\text{RMSE}_s = 0.28 \text{ cm}$

$\text{RMSE} 102/460 = 0.047$

On field 222 underestimation of $k_s$

$\text{RMSE} 222 = 0.11$
Inverting Oh’s model (Oh et al. 1992) using a priori roughness information based on \( \text{Re}[\rho_{\text{RLL}}] \)

General overestimation

\( \text{RMSE} = 10.45 \text{ Vol\%} \)

Large errors at low incidence angles + high roughness (Field 222)

LIA correction improved estimations only by 1%

Best results for field 102

\( \text{RMSE} = 4.4 \text{ Vol\%} \)
Conclusions

Roughness derivation
Dependencies of polarimetric estimators from ks
Best results between ks and $Re[\rho_{RRLL}]$ (DERD) for areas $\alpha < 40^\circ$
Good derivation results for field 102 + 460 (RMSE < 0.05)
For rougher fields (or at low incidence angles) RMSE = 0.11
Operational use only on bare soils / sparse vegetated areas

In-situ measurements neccessary!

Soil moisture
Retrieved roughness as a priori information can be used in Oh's model
Large RMSE (10.45 Vol%) especially at low incidence angles
(15.66 Vol%)
Good results for field 102 (SB) -> RMSE = 4.4 Vol%

-> Further investigations neccessary!
Apply algorithms to AgriSAR C-Band data
   First results showed almost no correlation to ks (only three acquisitions available for AgriSAR users)

Using only surface and dihedral contributions for calculation of $\sigma_0$ in Oh’s model

Using IEM with a priori roughness information
   Calculation of I and ACF from DSM?

**Need for an additional AgriSAR campaign!**
   **To observe:**
   Wider roughness spectrum for improved validation
   More dynamics in geo spatial parameters (e.g. soil moisture)
   Testing sensitivity of further parameters (soil texture, bulk density)
Thank you!

Acknowledgements

ESA, DLR, Zalf, Uni Bern
Conclusions

Role of in field roughness characterization

Crusted and fresh harrowed fields can have the same RMS Heights
„Quality of roughness“ not included in $s$

-> need for better/ more complexer roughness descriptors