PolInSAR-based Retrieval of Paddy Rice Height With Large Baseline TanDEM-X Data

Juan M. Lopez-Sanchez
J. David Ballester-Berman
Fernando Vicente-Guijalba
Qinghua Xie
Esra Erten
Manuel Campos-Taberner
F. Javier Garcia-Haro
Motivation and contents

- PolInSAR has been used much more for forests than for agriculture.
- First opportunity to PolInSAR-based retrieval of agricultural crop height with satellite data: TanDEM-X science phase.
- Rice is chosen for test: primary crop in the world and well-studied.
- Ground return dominated by the double-bounce contribution: modified formulation of the direct model with bistatic acquisitions.
- In this work:
  - 3 different test sites (variety of rice types, cultivation practices, etc.)
  - Acquisitions along the whole growth season*
  - New inversion algorithm designed for rice: scene with dominant double-bounce ground contribution.

*Single-date example published in [Erten et al, Rem. Sens. Env. 2016]
Test site 1: Sevilla (SW Spain)

**TEST SITE**
- Single rice type (up to 1.05 m high)
- 4 fields monitored in 2015
- Weekly measurements of height and phenology

**TDX DATASET**
- 8 bistatic acquisitions, HHVV
- Incidence angle: 22.7º
- $\kappa_z = 2.48$ rad/m
- HoA = 2.53 m
Test site 2: Valencia (E Spain)

TEST SITE

Two rice types:
- Senia: up to 0.9 m high
- Bomba: up to 1.7 m high

16+5 fields monitored in 2015

Intensive ground campaigns every 2 weeks in alternate fields

Height measured in 2014, not in 2015

TDX DATASET

6 bistatic acquisitions, HHVV

Incidence angle: 28.8°

\[ \kappa_z = 1.83 \text{ rad/m} \]

HoA = 3.42 m
Test site 3: Ipsala (W Turkey)

**TEST SITE**

Single rice type (up to 1.25 m high)

5 fields monitored in 2015

Weekly measurements of height

**TDX DATASET**

8 bistatic acquisitions, HHVV

Incidence angle: 30°

$k_z = 1.61$ rad/m

$HoA = 3.89$ m
Data processing

Input: Data takes in CoSSC format, dual-pol HHVV

1. Range-spectral filtering (required due to large baselines)
2. Removal of flat Earth and topographic phase terms
   - Extremely flat scenes: use of SRTM or other DEM’s usually degrades the data quality
   - A constant topography is assumed for the scene (enough for analysis at parcel scale)
   - Alternatively the main phase ramp can be estimated and removed locally
   - No absolute phase reference is needed (height retrieval is relative)
3. PolInSAR coherency matrix formation and multi-looking (21 x 21 boxcar)
4. Height inversion carried out at all pixels

Analysis: ROI selection of all pixels for each rice field (with eroded borders)
   - Statistics of the estimates inside each field: average and std. deviation
Vegetation height inversion

- Main assumption: RVoG model

- General coherence expression in bistatic systems:

\[ \tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + m_D(\vec{w}) + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_D(\vec{w}) + m_{DB}(\vec{w})} \]


- With dominant double-bounce ground contribution

\[ \tilde{\gamma}(\kappa_Z, \vec{w}) = e^{i\phi_0} \frac{\tilde{\gamma}_V + \frac{\sin k_z h_v}{k_z h_v} m_{DB}(\vec{w})}{1 + m_{DB}(\vec{w})} \]

Extra decorrelation term \[ \gamma_{DB} \]

\[ k_z = \kappa_Z \sin^2 \theta_0 \]
Vegetation height inversion

- Coherences on the complex plane

Conventional RVoG (valid for repeat-pass or dominant direct ground)

RVoG for bistatic systems with dominant double-bounce ground

Effect on the topography estimation with line fit
Vegetation height inversion: algorithm

1. Line fit to the region of coherences:
   Selection of two coherences with maximum and minimum ground contributions
   \[ \gamma(k_Z, \vec{w}_{max}) \text{ and } \gamma(k_Z, \vec{w}_{min}) \]

2. Compensation of the two coherences for SNR and quantisation decorrelation
   \[ \gamma_{SNR}(\vec{w}) = \sqrt{\frac{SNR_1(\vec{w})}{1 + SNR_1(\vec{w})}} \cdot \left( \frac{SNR_2(\vec{w})}{1 + SNR_2(\vec{w})} \right) \]
   \[ \gamma_{BQ} \approx 0.965 \]  
   [Kugler et al. 2014]

3. Iterative estimation of topographic phase and rest of parameters by minimising the distance to the model
   \[ \min_{\phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}} \left| \gamma(k_Z, \vec{w}_{max}) - \tilde{\gamma}(k_Z, \phi_0, h_v, \sigma, m_{DBmax}) \right| \]
   \[ \min_{\phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}} \left| \gamma(k_Z, \vec{w}_{min}) - \tilde{\gamma}(k_Z, \phi_0, h_v, \sigma, m_{DBmin}) \right| \]
   \[ \phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax} \]
Iterative procedure

Input: Pair of (compensated) measured coherences
Initial guess for $h_v$ (e.g. 1 m)

$$\gamma_{DB} = \frac{\sin k_z h_v}{k_z h_v}$$

Line crosses the circumference of radius $\gamma_{DB}$:
Estimation of $\phi_0$

Minimisation of distance to modelled coherences:
Estimation of $h_v, \sigma, m_{DBmin}, m_{DBmax}$

Distance $< \text{TOL}$

SOLUTION: $\phi_0, h_v, \sigma, m_{DBmin}, m_{DBmax}$
Data inspection
Results: Temporal evolution of estimates

Sevilla
Results: Temporal evolution of estimates

Valencia

Valencia – Fields of Senia type

Valencia – Fields of Bomba type
Results: Map at a fixed date

Valencia
Results: Temporal evolution of estimates

Ipsala
Results: Comparison with ground data

Statistics for valid ranges

<table>
<thead>
<tr>
<th></th>
<th>Sevilla</th>
<th>Valencia</th>
<th>Ipsala</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h_v$ threshold (cm)</td>
<td>25</td>
<td>40-60</td>
<td>25</td>
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<tr>
<td>$k_v$ threshold</td>
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<td>RMSE (cm)</td>
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<td>21.1</td>
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<td>$n$</td>
<td>24</td>
<td>47</td>
<td>29</td>
</tr>
</tbody>
</table>

Sensitivity parameter

$k_v = \kappa Z h_v / 2$

Recommended range

$k_v$: [1, 1.5]

[Cloude2009]
Conclusions and perspectives

• The proposed methodology is useful to monitor the growth of rice:
  – Good results have been obtained in two test sites: Sevilla and Valencia
  – But performance in Ipsala is worse.

• Limitation: vertical sensitivity -> short heights cannot be retrieved by PolInSAR alone, even with the baselines provided during the science phase

• To be studied next:
  – More elaborated inversion approach (ranges of values)
  – Analysis and physical interpretation of the estimates of the rest of model parameters: extinction, ground-to-volume ratios
  – Influence of baseline and incidence angle
  – Limitations due to the RVoG assumption: effect of differential extinction, etc.
  – Other crops (no flooded ground)
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