Depolarization of GNSS Signals due to Vegetation: Application to Land Monitoring

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Outline

I. Measurement concept and antecedents

II. McGiver Instrument

III. Field Experiment

IV. Calibration of the Instrument

V. Data Analysis

VI. Conclusions
I. Measurement Concept and antecedents (i)

- Horizontally stratified vegetation layer
- Satellite moving on sky map
- Varying elevation/azimuth angle
- Attenuation due to vegetation layer
  - \( L_{\text{veg}} = e^{-\frac{\tau}{\sin \theta_{\text{elev}}}} \)
  - \( \tau \): vegetation opacity
  - \( \theta_{\text{elev}} \): GNSS satellite elevation angle
- Attenuation related to power and albedo
  - \( \frac{P_{\text{RHCP}}(\theta)}{P_{\text{RHCP}}(0)} = f(L_{\text{veg}}(\theta), w(\theta)) \)
- Albedo related to ratio of powers (TBC)
  - \( \frac{P_{\text{LHCP}}(\theta)}{P_{\text{RHCP}}(\theta)} = g(w(\theta)) \)
  - \( w(\theta) \): vegetation albedo

Original concept:
doi: 10.1109/LGRS.2011.2166242
I. Measurement Concept and antecedents (ii)

**Hypothesis:** Coherent scattering taking place over soil and forests elements (trunks, branches, leaves)

\[
P_{rl}^{coh} \approx \Gamma_{rl} \frac{P_{t} \lambda^{2} G_{t} G_{rc}}{(4\pi)^{2} (R_{t0} + R_{0rc})^{2}}
\]

\[
P_{rl}^{incoh} \approx \sigma_{rl} \frac{P_{t} \lambda^{2} G_{t} G_{rc}}{(4\pi)^{3} (R_{t0})^{2} (R_{0rc})^{2}}
\]

I. Measurement Concept and antecedents (iii)

- Coherent reflectivity decreases from ~ -15 dB to ~ -21 dB (soil), from ~ -19 dB to ~ -25 dB (canopy), from ~ -22 dB to ~ -30 dB (canopy-soil), from ~ -25 dB to ~ -33 dB (soil-trunk), when elevation angle increases from 35° to 72°
KISS = Keep It Simple and Stupid... no! It is Keep It Simple and Smart!

Go for a simpler and more practical model for global simulation purposes and retrievals

- McGiver: Monitoring of the Canopy using a GNSS-T Instrument for Vegetation Research
- Specifically designed for this application
- Dual-channel receiver:
  - Direct RHCP
  - Direct LHCP
- Receivers: COTS GPS receivers
- Antennas: 4 feed probes
  - Symmetric radiation pattern
  - Cross-polar < -15 dB
  - Isolation > 30 dB
• La Fageda d’en Jordà forest, Catalunya, Spain
• Highly populated beech forest (deciduous trees, > 10 m height)
• Experiment:
  August 2015 to May 2017
  (data analyzed 8/2015-10/2016)

• Gathering data from two different periods:
  • Autumn season (defoliation)
  • Spring season (leaf growth)
  • Assumed azimuthal homogeneity
III. Field Experiment (i)
IV. Calibration of the Instrument

Instrument calibration in open-sky conditions

Co-Pol

2015/06/02

2015/06/03

2015/06/04

X-Pol

2015/06/02

2015/06/03

2015/06/04
RHCP and LHCP in rain events

- Azimuthally averaged C/N0 at LHCP (top) and RHCP (bottom) for different satellite elevation angles as a function of time together with rain events.

- Rain attenuates the signal due to:
  - Water drops in the atmosphere
  - Water drops over the leaves surface
  - Water content increases in trees (not immediately)

- All incidence angles suffer from a power drop
Analysis of RHCP vs NDVI:

- **Strong dependence between NDVI/elevation angle and RHCP**
  - The higher the NDVI the lower the power received
  - The higher the elevation angle the higher the power received received
- **Signal attenuation due to the leaves presence**

### Table of Results

<table>
<thead>
<tr>
<th>Elevation angle</th>
<th>$R^2$</th>
<th>Slope [dB/au]</th>
<th>RMSE [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>47.5</td>
<td>0.890</td>
<td>-16.90</td>
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</tr>
<tr>
<td>52.5</td>
<td>0.917</td>
<td>-17.52</td>
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<tr>
<td>57.5</td>
<td>0.908</td>
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<tr>
<td>62.5</td>
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<tr>
<td>67.5</td>
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<td>0.481</td>
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<tr>
<td>72.5</td>
<td>0.886</td>
<td>-18.79</td>
<td>0.622</td>
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<tr>
<td>77.5</td>
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<tr>
<td>82.5</td>
<td>0.897</td>
<td>-22.61</td>
<td>0.707</td>
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</tbody>
</table>
Analysis of ratio RHCP(θ)/RHCP(82.5°) vs NDVI:

<table>
<thead>
<tr>
<th>Elevation angle</th>
<th>R²</th>
<th>Slope [dB/au]</th>
<th>RMSE [dB]</th>
</tr>
</thead>
<tbody>
<tr>
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<td>52,5</td>
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<tr>
<td>62,5</td>
<td>0,518</td>
<td>5,36</td>
<td>0,465</td>
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<tr>
<td>67,5</td>
<td>-0,078</td>
<td>1,50</td>
<td>0,433</td>
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<tr>
<td>72,5</td>
<td>0,442</td>
<td>4,35</td>
<td>0,423</td>
</tr>
<tr>
<td>77,5</td>
<td>0,307</td>
<td>4,27</td>
<td>0,498</td>
</tr>
</tbody>
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Analysis of LHCP vs NDVI:

- **Strong dependence between NDVI/elevation angle and LHCP**
  - The higher the NDVI the lower the power received (LHCP)
  - The higher the elevation angle the lower the powered received (LHCP)
- **Signal attenuation due to the leaves presence**

![LHCP vs NDVI diagram]

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<tr>
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<td>0.819</td>
<td>-18,554</td>
<td>0.796</td>
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<td>0.881</td>
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<td>0.622</td>
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<td>0.649</td>
<td>-15,670</td>
<td>1.091</td>
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<tr>
<td>62,5</td>
<td>0.633</td>
<td>-13,423</td>
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<tr>
<td>67,5</td>
<td>0.586</td>
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<tr>
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<td>0.314</td>
<td>-8,835</td>
<td>1.306</td>
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<tr>
<td>82,5</td>
<td>0.430</td>
<td>-12,767</td>
<td>1.310</td>
</tr>
</tbody>
</table>
V. Data Analysis (v)

Analysis of LHCP/RHCP vs NDVI:

• It should be independent of vegetation attenuation (!?)
  
  but actually it seems not (i.e. single scattering model not fully applicable)

• NDVI $\uparrow$, LHCP/RHCP more concentrated: larger attenuation

• Elevation angle $\uparrow$, LHCP/ RHCP $\downarrow$: lesser depolarization

\[
\frac{P_{\text{LHCP}}(\theta)}{P_{\text{RHCP}}(\theta)} = g(w(\theta))
\]
Analysis of Albedo Results

- Strong dependence with elevation angle and moderate/weak with NDVI
- Elevation angle ↑, albedo ↓
- Albedo ~ 0.1-0.2 at zenith, but as high as ~0.25-0.4 @ 47.5°
V. Data Analysis (vii)

Analysis of relationship albedo vs NDVI:

- Moderate/weak dependence with NDVI
- Elevation angle $\uparrow$, albedo $\downarrow$
- Albedo $\sim 0.1$-$0.2$ at zenith, but as high as $\sim 0.25$-$0.4$ @ 47.5°
V. Data Analysis (viii)

Analysis of relationship albedo vs LAI:

- Very weak dependence with LAI
- Elevation angle ↑, albedo ↓
- Max correlation is 0.279 at nadir (!!??).

V. Data Analysis (viii)

Analysis of relationship albedo vs LAI:

- Very weak dependence with LAI
- Elevation angle ↑, albedo ↓
- Max correlation is 0.279 at nadir (!!??).

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<tr>
<td>47.5</td>
<td>-0.124</td>
<td>-0.003</td>
<td>0.036</td>
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<tr>
<td>52.5</td>
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<tr>
<td>57.5</td>
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<td>0.042</td>
</tr>
<tr>
<td>62.5</td>
<td>-0.058</td>
<td>0.007</td>
<td>0.042</td>
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<td>0.041</td>
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<td>0.052</td>
</tr>
<tr>
<td>82.5</td>
<td>0.279</td>
<td>0.015</td>
<td>0.036</td>
</tr>
</tbody>
</table>
VI. Conclusions

- RHCP received power decreases with increasing elevation angle and NDVI (weak correlation with LAI)

- LHCP received power decreases as RHCP

- Leaves main responsible for attenuation, branches for depolarization

- Albedo derived from LHCP and RHCP is a bit higher than expected.

and...

- Attenuation does not follow a $1/\cos(\theta_{elev})$ form
- Albedo is not constant with elevation angle.
- If sort of tau-omega model is going to be used, both parameters must be a function of the elevation angle.

More on 1st presentation in the afternoon session